THE 13RD INTERNATIONAL CONFERENCE ON HARBOR, MARITIME & MULTIMODAL LOGISTICS MODELING AND SIMULATION

SEPTEMBER 12-14 2011

ROME, ITALY

HMS

2011

EDITED BY

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ROME, ITALY

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WELCOME TO HMS 2011

The purpose of HMS 2011 edition is to provide a unique and very sharp forum for world-wide scientists to discuss on a topic of great relevance: advances related to application of M&S to Maritime Sector, Multimodal Logistics and Supply Chain Management. HMS evolved from an International Workshop to a Conference in 2009, therefore this event it is currently at its 13rd official edition, without considering the two preliminary meetings carried out in 1996 and 1998 respectively in Genoa and Riga. The Conference format is consolidated, but it guarantees to the most innovative researches in this area to be proposed to a selected audience of experts by combining presentations and discussions; HMS is paying great attention in supporting scientific networking in this very specific activities for promoting new R&D Projects and Proposals.

The success of HMS 2011 and the high quality of published proceedings is based on the strong efforts of the International Organizing Committee, the Local Staff assisting the I_M_CS Council (International Mediterranean & Latin American Council of Simulation); the review process was based on very selective procedures and each paper was reviewed at least by three members of the International Program Committee. We greatly appreciate the opportunity provided by HMS along the last 15 years in providing a Forum to scientists, developers, users, vendors involved in break trough researches and initiatives in Maritime and Logistics M&S.

HMS this year is organised in Rome, Italy a Town from where during the Roman Age was created an impressive Road Network going from Spain to Asia, from Egypt to Morocco and from Britain to South Italy; all these Rome centred connections allowed along the centuries to support the whole Empire; these roads are still existing and represent, even today, major assets in Logistics as demonstration of the critical impact and strong benefits of such strategic decisions. In addition, during 2011, HMS Organisers supported the successful organisation of International Workshop on Applied Modelling & Simulation in connection with SCM MEMTS 2011, Simulation and Complex Modelling in Marine Engineering and Marine Transporting Systems within the International Maritime Defence Show, St.Petersburg, Russia; this success in establishing new connections with Russian Simulation Community is confirming the strong benefits and synergies generated by networking top experts from Academia, Institutions and Industries that are leading R&D in special sharp application areas.

We are confident that HMS 2011 will allows to hotly debated the current big challenges in Marine and Industrial Logistics in and out of the Conference Sessions, making this Conference a stimulating and memorable event in the wonderful framework of Rome.

Agostino G. Bruzzone
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University of Genoa

Yuri Merkuryev
MIK
Riga Technical University

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The HMS 2011 International Program Committee (IPC) has selected the papers for the Conference among many submissions; therefore, based on this effort, a very successful event is expected. The HMS 2011 IPC would like to thank all the authors as well as the reviewers for their invaluable work.

A special thank goes to all the organizations, institutions and societies that have supported and technically sponsored the event.

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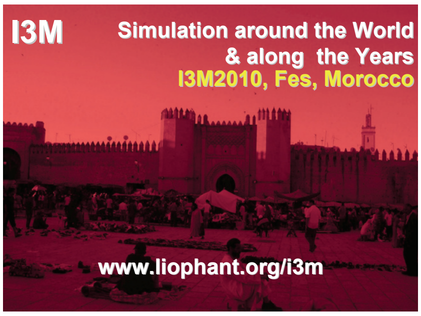

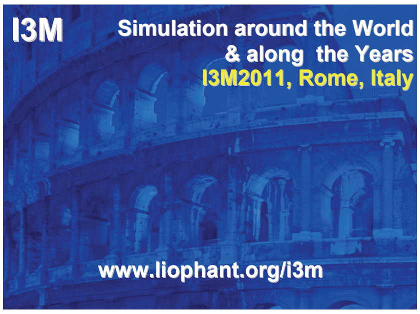

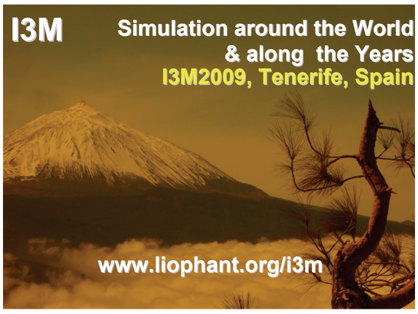

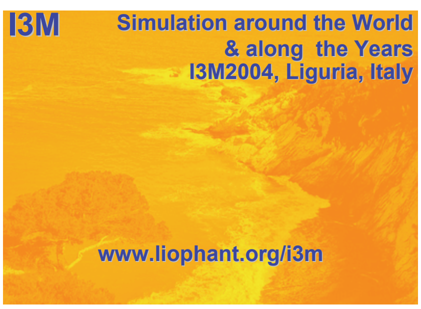

Index

INVESTIGATION OF FINANCIAL FLOWS IN LOGISTICS USING MULTIVARIATE STATISTICAL MODELLING METHODS

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ABSTRACT
Multivariate statistical modelling is used to investigate complex economic systems in cases when random values are characterized as arbitrary (nonparametric). When modelling the financial stability of the logistics firm (LF) and transport logistics system (TLS) in general, it is most essential to detect the statistical character of the interrelationships among all participants (subsystems) of TLS. In real systems these interrelationships are correlated. In this case when modelling the financial stability of TLS and the statistical character of interrelationships it would be rational to use copula as a tool of multivariate statistics.

Use of the copula and Monte-Carlo methods make it possible to approximate joint distribution of the significant factors of TLS and to estimate the behaviour of financial stability of the investigated TLS in relation to probabilities and therefore its expected values which is impossible to be achieved by classical statistical methods.

Keywords: transport logistics system, scan statistics, weak points, multivariate statistical modelling, financial stability

INTRODUCTION
Multivariate statistics is a form of statistical analysis of many statistical correlated variables. Application of methods of multidimensional statistics allows defining relations between the variables included in the model and also their impact on the problem studied. One of the multivariate statistics methods used in this article for modelling of financial flows of logistics process is the copula method. When establishing the distribution of parameters describing the behaviour of investigated TLS from empirical information most frequently it is insufficient for credible assessment of parameters offered by the function of distribution. In these cases it is necessary to use nonparametric modelling methods, given distribution of incidental values and then modelling of appropriated distribution. (Cameron and Trivedi 2006). Figure 1 presents the scheme of interrelationship of TLS subsystems in the process of cargo delivery from the consignor in the USA to the consignees in CIS countries (cargoes are delivered by sea and rail or road transport). Transaction costs are expressed in different currencies

(US dollars, EUR, LVL, RUR, and KZT).

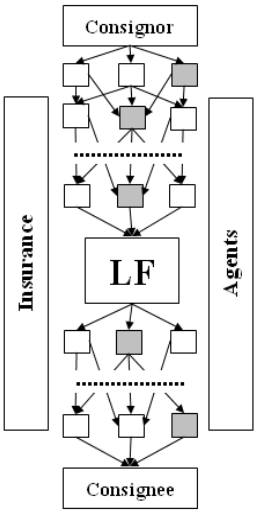

Figure 1: Scheme of Interrelationship of TLS Subsystems in the Process of Cargo Deliveries from the Consignor to the Consignee

The financial stability of TLS is the capability of all participants of TLS to implement their financial liabilities in full on the timeframe agreed upon in the contract.

Modelling of financial stability is directed towards defining the value of the "zones of risk" or “system weak points” when the TLS for satisfying financial liabilities should use financial reserves, as well as for finding the point of first time of positiveness of the financial flow. By weak points in the financial stability of TLS we understand the violation (delay) of the payment terms among the participants of TLS, changes (overrun) of the contract (agreed) costs of the works to be completed by any of the participants of TLS, as well as deviations in the technological process of cargo delivery caused by the impact of internal and external factors under uncertainty conditions (Jurenoks, Jansons, Didenko, 2009). Modelling is frequently associated with the factor of uncertainty (or risk), description of which goes outside the confines of the traditional statistical modelling, which, in its turn, complicates the modelling process (Jurenoks, Jansons, Didenko 2008).

Thus, the authors using multivariate statistical modelling investigate the impact of the factors of TLS subsystems on the financial stability of TLS in general. The main factors considered are:

- deviations of the actual timing of payments on the contract terms (payments delayed);
- deviation of actual payments from the contract amounts;
- change in the exchange rate affecting the real value of payments;
- energy price fluctuations, in particular, for diesel fuel.

The financial reserves of the TLS are used for ensuring the limited production resources in the volume required for the TLS performance. The model of using of financial reserves for maintenance the financial stability of TLS is presented in Figure 2 (Jurenoks, Jansons, Didenko 2007).

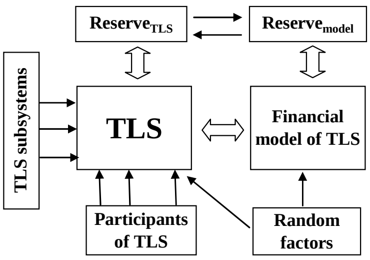

Figure 2: Model of Using Financial Reserves for Maintenance of TLS Financial Stability

Scan statistics as an instrument of research of statistical dynamics of the development of the object under investigation in space and time has been used (Jurenoks, Jansons, Didenko 2008). Research is made of statistics of weak points of the financial system in the logistics process. The methodology of research of weak points of the financial system in logistics process in space and time enables to detect the necessity of using the financial reserves (**Reserve $_{TLS}$**) for maintenance of the financial stability of TLS.

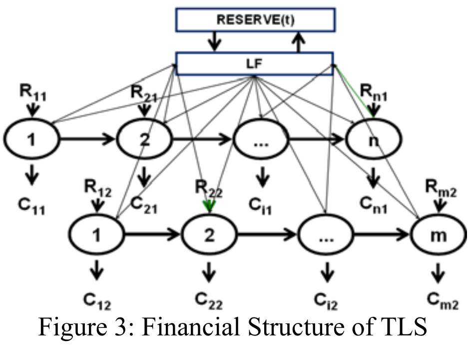

Figure 3: Financial Structure of TLS

where: R_{ij} and C_{ij} are incoming and outgoing payments. In the article (Jansons, Jurenoks, Didenko 2010) on the research subject the authors described the results of the study of the financial structure of the logistics process. The scheme of financial structure of the logistics system TLS is shown in Figure 3.

In this article the multivariate statistical modelling of the financial stability of TLS is presented. The mechanism of optimization of financial reserves of the logistics firm to compensate the negative impact of factors of the system (TLS) is studied.

The main objectives of the article are:

- to apply multivariate statistical modelling methods (copula methods, scan statistics, detection of weak points) for investigation of the financial stability of TLS;
- to model financial interrelations between TLS subsystems in dynamics;
- to investigate the financial losses of TLS and detect the weak points of TLS caused by accidental factors;
- to investigate the behaviour and statistical distribution of the level of financial losses of TLS.

Most attention is paid to the analysis of intervals of change of the required financial reserve of the logistics firm providing the stability of TLS on the whole.

1. DESCRIPTION OF THE SYSTEM

The model of technological and financial operations of the logistics process (Table 1) presents the process of cargo delivery from the consignor in the USA to the consignees in CIS countries (cargoes are delivered by sea and rail or road transport). Transaction costs are expressed in US dollars, EUR, LVL, RUR, KZT.

The information about the technological and financial operations of the logistics process to be performed is presented in Table 1. The operations of the logistics process to be performed are designated by symbols A, B, B*, D,..., F, F*, G, H. The financial flows, linked with making the financial calculations of separate stages of the logistics process according to the scheme presented in Figure 3, are divided into incoming flows (increasing the current account of LF, such flows being designated by symbols A, B*, E*, F*, H), and also outgoing flows (transferred from the current account of LF to the other participants of the logistics process). These financial flows are designated by the symbols B, C, D, E, F, G (see Table 1).

The execution of all the above mentioned financial operations is limited by time t_1, t_2, t_3, t_4.

For the incoming flow A:

- t_1 – the moment of time of signing the contract about the cargo delivery between the Latvian logistics firm and the consignor (or the consignee) of the cargo in the amount $S_{1,i}$;
- t_3 – the moment of time of advance payment transferred from the consignor (consignee) to the account of the logistics firm in the amount $S_{1,i}$ ($t_1 = t_2$);
- t_4 – the moment of time of receipt of advance payment on the account of the Latvian logistics firm in the amount $S_{2,i}$;

For the incoming financial flows (B*, E*, F*, H), increasing the current account of LF the moments of time are the following:

Table 1: Implementation of Technological and Financial Operations of the Logistics Process in Time

Directions — 1st route - USA - Kazakhstan

Type of operation	Logistics operation stage: Incoming payments	Logistics operation stage: Outgoing payments	t	S	Currency (C)	Δ_t	Δ_S
Contract execution start time	A		$t1_1$	**$S1_{A}$_contract**	USD	-	-
			$t3_1$	**$S2_{A}$_accepted**	USD	-	X
			$t4_1$	**$S2_{A}$_received**	USD	X	X
Sea transportation		B	$t1_1$	**$S3_{B}$_bill**	USD		-
			$t2_1$	**$S3_{B}$_bill received**	USD	X	-
			$t3_1$	**$S4_{B}$_accepted**	USD	X	X
			$t4_1$	**$S4_{B}$_paid**	USD	X	X
Next incoming payment	B*		$t1_1$	**$S1_{B*}$_bill**	LVL	-	-
			$t2_1$	**$S1_{B*}$_bill received**	LVL	-	-
			$t3_1$	**$S1_{B*}$_accepted**	LVL	X	
			$t4_1$	**$S2_{B*}$_received**	LVL	X	X
Port operation		C	$t1_1$	**$S3_{C}$_bill**	USD		-
			$t2_1$	**$S3_{C}$_bill received**	USD	X	-
			$t3_1$	**$S4_{C}$_accepted**	USD	X	X
			$t4_1$	**$S4_{C}$_paid**	USD	X	X
Insurance		D	$t1_1$	**$S3_{D}$_bill**	LVL	-	-
			$t2_1$	**$S3_{D}$_bill received**	LVL	X	-
			$t3_1$	**$S4_{D}$_accepted**	LVL	X	-
			$t4_1$	**$S4_{D}$_paid**	LVL	X	-
Custom operations		E	$t1_1$	**$S3_{E}$_bill**	LVL	-	-
			$t2_1$	**$S3_{E}$_bill received**	LVL	-	-
			$t3_1$	**$S4_{E}$_accepted**	LVL	X	X
			$t4_1$	**$S4_{E}$_paid**	LVL	X	X
Next incoming payment	E*		$t1_1$	**$S1_{E*}$_bill**	USD	-	-
			$t2_1$	**$S1_{E*}$_bill received**	USD	-	-
			$t3_1$	**$S1_{E*}$_accepted**	USD	X	-
			$t4_1$	**$S2_{E*}$_received**	USD	X	X
Rail or road transportation		F	$t1_1$	**$S3_{F}$_bill**	RUR	-	-
			$t2_1$	**$S3_{F}$_bill received**	RUR	-	-
			$t3_1$	**$S4_{F}$_accepted**	RUR	X	X
			$t4_1$	**$S4_{F}$_paid**	RUR	X	X
Next incoming payment	F*		$t1_1$	**$S1_{F*}$_bill**	USD	-	-
			$t2_1$	**$S1_{F*}$_bill received**	USD	-	-
			$t3_1$	**$S1_{F*}$_accepted**	USD	-	-
			$t4_1$	**$S2_{F*}$_received**	USD	-	-
Other operations		G	$t1_1$	**$S3_{G}$_bill**	KZH	-	-
			$t2_1$	**$S3_{G}$_bill received**	KZH	X	-
			$t3_1$	**$S4_{G}$_accepted**	KZH	X	X
			$t4_1$	**$S4_{G}$_paid**	KZH	X	X
Final calculations	H		$t1_1$	**$S1_{H}$_bill**	USD	-	-
			$t2_1$	**$S1_{H}$_bill received**	USD	-	-
			$t3_1$	**$S1_{H}$_accepted**	USD	X	X
			$t4_1$	**$S2_{H}$_received**	USD	X	X

N th route - USA - Kazakhstan

		t	S	C	Δ_t	Δ_S
A		$t1_N$	**$S1_{A}$_contract**	USD	-	-
		$t3_N$	**$S2_{A}$_accepted**	USD	-	-
		$t4_N$	**$S2_{A}$_received**	USD	X	X
	B	$t1_N$	**$S3_{B}$_bill**	USD		-
		$t2_N$	**$S3_{B}$_bill received**	USD		-
		$t3_N$	**$S4_{B}$_accepted**	USD	X	X
		$t4_N$	**$S4_{B}$_paid**	USD	X	X
B*		$t1_N$	**$S1_{B*}$_bill**	LVL	-	-
		$t2_N$	**$S1_{B*}$_bill received**	LVL	-	-
		$t3_N$	**$S1_{B*}$_accepted**	LVL	X	X
		$t4_N$	**$S2_{B*}$_received**	LVL	X	X
	C	$t1_N$	**$S3_{C}$_bill**	USD		-
		$t2_N$	**$S3_{C}$_bill received**	USD	-	-
		$t3_N$	**$S4_{C}$_accepted**	USD	X	X
		$t4_N$	**$S4_{C}$_paid**	USD	X	X
	D	$t1_N$	**$S3_{D}$_bill**	LVL	-	-
		$t2_N$	**$S3_{D}$_bill received**	LVL	X	-
		$t3_N$	**$S4_{D}$_accepted**	LVL	X	X
		$t4_N$	**$S4_{D}$_paid**	LVL	X	X
	E	$t1_N$	**$S3_{E}$_bill**	LVL	-	-
		$t2_N$	**$S3_{E}$_bill received**	LVL	-	-
		$t3_N$	**$S4_{E}$_accepted**	LVL	X	X
		$t4_N$	**$S4_{E}$_paid**	LVL	X	X
E*		$t1_N$	**$S1_{E*}$_bill**	USD	-	-
		$t2_N$	**$S1_{E*}$_bill received**	USD	-	-
		$t3_N$	**$S1_{E*}$_accepted**	USD	X	-
		$t4_N$	**$S2_{E*}$_received**	USD	X	X
	F	$t1_N$	**$S3_{F}$_bill**	RUR	-	-
		$t2_N$	**$S3_{F}$_bill received**	RUR	-	-
		$t3_N$	**$S4_{F}$_accepted**	RUR	X	X
		$t4_N$	**$S4_{F}$_paid**	RUR	X	X
F*		$t1_N$	**$S1_{F*}$_bill**	USD	-	-
		$t2_N$	**$S1_{F*}$_bill received**	USD	-	-
		$t3_N$	**$S1_{F*}$_accepted**	USD	X	X
		$t4_N$	**$S2_{F*}$_received**	USD	X	X
	G	$t1_N$	**$S3_{G}$_bill**	KZH	X	X
		$t2_N$	**$S3_{G}$_bill received**	KZH	X	-
		$t3_N$	**$S4_{G}$_accepted**	KZH	X	X
		$t4_N$	**$S4_{G}$_paid**	KZH	X	X
H		$t1_N$	**$S1_{H}$_bill**	USD	-	-
		$t2_N$	**$S1_{H}$_bill received**	USD	-	-
		$t3_N$	**$S1_{H}$_accepted**	USD	X	X
		$t4_N$	**$S2_{H}$_received**	USD	X	X

- t_1 – the moment of time of presenting the bill to the consignor (consignee) of the cargo on the part of the Latvian logistics firm as payment for the technological operations of the logistics process completed at a certain stage in the amount S1,i paid in advance by the Latvian logistics firm;
- t_2 – the moment of time of receipt by the consignor consignee) of the cargo requirements (bills) on the part of the Latvian logistics firm about the payments settled and transferred from the account of the logistics firm for the technological operations in the amount $S_{1,i}$;
- t_3 – the moment of time of paying the bill by the consignor (consignee) to the account of the Latvian logistics firm for completed technological operations according to the requirements received in the amount $S_{1,i}$;
- t_4 – the moment of time of receipt of financial resources (money transfer) on the account of the Latvian logistics firm for completed technological operations according to the requirements received in the amount $S_{2,i}$.

For the outgoing financial flow H:
- t_1 – the moment of time of presenting the final bill (balance/remaining amount) from the Latvian logistics firm to the consignor (consignee) in the amount $S_{1,i}$;
- t_2 – the moment of time of receipt by the consignor (consignee) of the cargo the final bill (balance/remaining amount) on the part of the Latvian logistics firm in the amount $S_{1,i}$;
- t_3 – the moment of time of payment of the final bill (balance/remaining amount) by the consignor (consignee) to the Latvian logistics firm in the amount $S_{1,i}$;
- t_4 – the moment of time of receipt of financial resources (balance) on the account of the Latvian logistics firm in the amount $S_{2,i}$.

For the outgoing financial flows (B, C, D, E, F, G) – operations paid from the account of LF to the other participants of the logistics process of LF the moments of time are the following:
- t_1 – the moment of time of completing the current technological operation of the logistics process by any participant of the logistics process and simultaneously the moment of time of presenting the bill to the Latvian logistics firm by another participant of the logistics process for payment of the works completed in the amount $S_{3,j}$;
- t_2 – the moment of time of receipt of the bill by the logistics firm from another participant of the logistics process for payment of completed works in the amount of $S_{3,j}$;
- t_3 – the moment of time of payment of the bill by the logistics firm received from another participant of the logistics process for the completed works in the amount $S_{3,j}$;
- t_4 – the moment of time of transfer of financial resources on the account of another participant of the logistics process for the completed works in the amount $S_{4,j}$.

2. DETECTION OF WEAK POINTS IN THE SYSTEM

By weak points in the financial stability of TLS we understand the violation (delay) of the payment terms among the participants of TLS, changes (overrun) of the contract (agreed) costs of the works to be completed by any of the participants of TLS, as well as deviations in the technological process of cargo delivery caused by the impact of internal and external factors under uncertainty conditions.

In the case of the Latvian logistics firm (LF) mentioned above the conditions of uncertainty are as follows:

a) time delays between scheduled (planned) and actual dates of receipt of payments on the account of logistics firm;
b) continuous changes of exchange rates (currency risks) while making currency transactions among the participants of TLS;
c) fluctuations of prices of energy resources (diesel fuel) during the cargo deliveries from the consignors to the consignees.

Figure 4 presents the moments of the possible emergence of weak points in the logistics process. In Table 1 the symbol X represents the periods of time during which the delays of technological or financial flows of the logistics process may occur that, in turn, may cause the emergence of weak points in the logistics system in general.

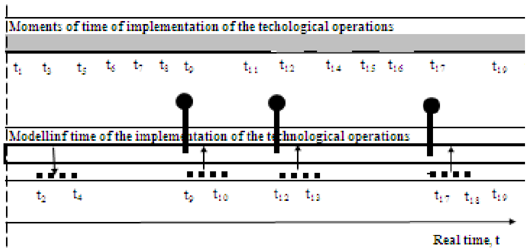

Figure 4: Scheme of Detection of Weak Points

3. INVESTIGATION OF FINANCIAL FLOWS USING THE MONTE-CARLO METHOD FOR MODELLING

When modelling the financial flows in the logistics process aimed at identifying the weak points the authors have used the Monte-Carlo method. Besides, it is necessary to model the following random values as well:
- t_{1i}, t_{2i}, t_{3i}, t_{4i}, where i=1, 2, …, N (see Table 1).

The delay time of technological and financial operations of the logistics process and, namely:
- S_{1i}, $S_{2,i}$, $S_{3,i}$, $S_{4,i}$ – planned (contract) and actual amounts of incoming and outgoing payments of the logictics firm;
- $\Delta S_i^{Incoming}$, $\Delta S_i^{Outgoing}$ – difference of amounts received to the account of LF and paid from the account of LF (formulas 1 and 2):

$$\Delta S_i^{Incoming} = S_{1i} - S_{2i}, \quad (1)$$

$$\Delta S_i^{\text{Outgoing}} = S_{3,i} - S_{4,i}, \qquad (2)$$

where:
- r_{t1} – currency exchange rate at the time moment t_1;
- r_{t3} – currency exchange rate at the time moment t_3;
- p_{t1} – price of fuel at the time moment t_1;
- p_{t3} – price of fuel at the time moment t_3.

The functional model of financial losses of TLS is presented in (3)

$$F = f(r_{t1}, r_{t3}, p_{t1}, p_{t3}, t_1, t_2, t_3, t_4, S_{1i}, S_{2i}, S_{3i}, S_{4i}, \Delta S_i^{\text{Incoming}}, \Delta S_i^{\text{Outgoing}}, N), \qquad (3)$$

where: N – number of routes.

Graphical illustration of interaction of values S_{1i}, $S_{2,i}$, $S_{3,i}$, $S_{4,i}$, r_{t1}, r_{t3}, p_{t1}, p_{t3} in the interval of time t_1 и t_3 are given in Figure 5.

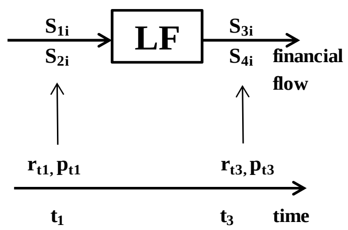

Figure 5: Interaction of Values S_{1i}, $S_{2,i}$, $S_{3,i}$, $S_{4,i}$, r_{t1}, r_{t3}, p_{t1}, p_{t3} in the Interval of Time t_1 and t_3

Let us consider the changes of the actual amount of the financial payment S_{t3} when compared to the planned amount of the financial payment S_{t1} when transferring from time t_1 and t_3 ($t_1 < t_3$).

Modelling of the actual amount of the financial payment S_{t3} in the moment of time $t_3 > t_1$ is done by applying the correction coefficient $K_{t1,t3}$

$$K_{t_1,t_3} = \frac{r_{t_1}}{r_{t_3}}. \qquad (4)$$

The value of parameters r_{t1} и r_{t3} by currency types are taken from the statistical sources of information.

According to the scheme (Figure 5) the actual amount of the financial payment S_{t3} may be greater or smaller than the planned financial payment S_{t1}. The deviation (difference) $\Delta S_{t1i,t3i}$ between $S_{t1,i}$ and $S_{t3,i}$ may be calculated using the formula

$$\Delta S_{t_1,t_3} = S_{1i} \cdot \left(\frac{r_{t_3}}{r_{t_1}} - 1 \right). \qquad (5)$$

When $\Delta S_{t1,\,t3} > 0$, the actual amount of payment, made on the account of the logistics firm for the technological operation completed, exceeds the planned amount of the payment for the same operation which leads to an additional profit for the logistics firm and increases its financial stability. On the contrary, if $\Delta S_{t1,\,t3} < 0$, the actual amount of the financial payment made on the account of the logistics firm for the technological operation completed would be less than the amount of the financial payment planned for the same operation and it will bring about losses, thus decreasing the financial stability of the logistics firm.

Changes of the value of $\Delta S_{t1,\,t3}$, leaving an impact on the financial stability of LF depend on the currency exchange rates which are applied when completing financial payments among the TLS participants. Therefore, the necessity arises to model the fluctuations of the currency exchange rates depending on the time of the logistics process. The real currency exchange rate dynamics for the time period from May 13 2010 to 29 April 2011 is presented in Figure 6.

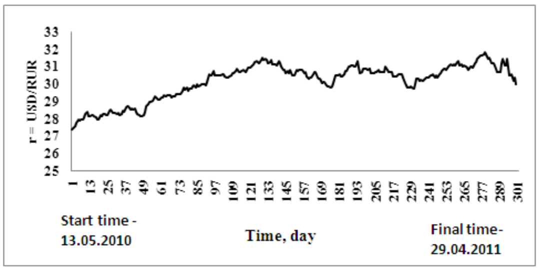

Figure 6: Currency Exchange Rate USD/RUR Dynamics from May 13 2010 to 29 April 2011

During modelling the authors alongside with the real values of parameter r (Figure 6) used the results of statistical modelling where stochastic differential equation was applied (Jansons, Jurenoks, Didenko 2010).

When modelling the delay time of completion of technological and/or financial operations of the logistics process Table 2 is used where:

A - is the minimum delay time of incoming payments to the account of the logistics firm (S_{1i}, $S_{2,i}$);

B – is the maximum delay time of incoming payments to the account of the logistics firm (S_{1i}, $S_{2,i}$);

C – is the minimum delay time of outgoing payments from the account of the logistics firm ($S_{3,i}$, $S_{4,i}$);

D – is the maximum delay time of outgoing payments from the account of the logistics firm ($S_{3,i}$, $S_{4,i}$) – see Tables 2,3 and 4.

Table 2: Intervals of Time Delays of Incoming and Outgoing Payments

	Incoming payment	Outgoing payment
delay_min =	A	C
delay_max =	B	D

For modelling the delay time of incoming and outgoing payments two basic uniform U(a, b) and normal distributions N(μ, σ) were used with parameters:

for uniform distribution a = A and b = B;

for normal distribution μ = (A+B)/2 and σ = (A – B)/6. The empiric table of values of the given values in the period of time starting from 13 May 2010 to 29 April 2011 was used for modelling values of $\Delta S_i^{\text{Incoming}}$, $\Delta S_i^{\text{Outgoing}}$.

Table 3: Extract from the Table of Frequency Distribution of Incoming Payment Values on the Account of LF and Outgoing Payment Values from the Account of LF

p	Bin	f
0.00120	800	1
0.00120	1100	1
0.00120	1500	1
……………………………….		
0.08043	3400	67
0.20168	2200	168
0.63625	1100	530

4. RESULTS OF MODELLING

Graphical illustration of the state of balance during the modelling time from 13 May 2010 to 29 April 2011 is presented in Figure 7.

Figure 7: Dynamics of Modelled Balance of LF

When modelling the routes of cargo transportation applying the currency exchange rate dynamics from May 13 2010 to 29 April 2011 and values of parameters A, B, C, D (see Tables 2, 3 and 4).

Table 4: Modelled Intervals for Time Delays of Incoming and Outgoing Payments

	Income	Payment
delay_min =	7	3
delay_max =	30	20

the following distribution of possible losses for LF was obtained due to fluctuations of the currency exchange rate (Figure 8).

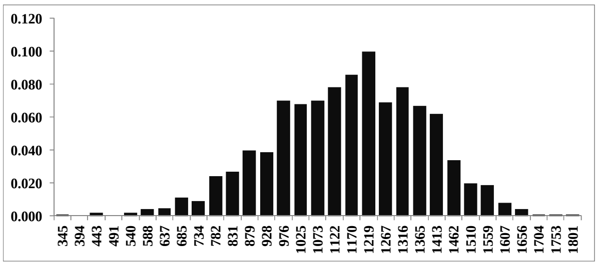

Figure 8: Histogram of Modelled Losses of LF

The distribution obtained is characteristic for describing all of the 27 routes of cargo transportations to be analysed. The results of the research may form the basis for calculation of possible risks and losses of LF and other participants of the logistics process.

CONCLUSION

The article shows the possibilities for applying the multivariate statistical modelling method for investigation of financial stability of TLS, in particular modelling the emergence of weak points in the logistics system. Impact of changes of the factors in the model is analysed, namely, impact of currency exchange rate on changes of the state of financial stability of LF and TLS in general. The research subject is the total set of routes of cargo transportation from the consignors to consignees. The authors modelled the impact of financial and organisational factors on the changes of financial and organisational stability of TLS.

The application of multivariate statistical method for modelling activity of TLS allows:

1) modelling of TLS stability using multimodal and nonparametric technique;

2) modelling of the “risk zones” in which the financial stability of TLS has been distorted;

3) optimization of the process of TLS functioning.

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FACILITATING TRADE AND ADOPTION OF THE "INTRADE" IAV IN DUBLIN PORT IN 2040

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ABSTRACT
Dublin Port is the largest and busiest port on the island of Ireland. The port's main function is to facilitate the movement of goods and people which is crucial to the Irish economy, in an efficient and cost effective manner **[*Dublin Port Company, Materplan, (p.3)*]**. Dublin Port Company launched a new Master-plan for its long-term development in March 2011.

There is a need to optimise the use of Intelligent Transport Systems (ITS) within international ports such as Dublin. Currently in Dublin Port, the movement of cargo is operated by shunter vehicles differing from Automated Guided Vehicles (AGVs) as in other international ports.

Figure 1. Shunter Vehicle

Figure 2. Automated Guided vehicle (AGV)

The IAV will use a GPS guidance system to move unmanned around port terminals, delivering containers to and from marshalling areas. Although Intelligent Autonomous Vehicles (IAV's) are not a new concept, the different is, it does not require a guidance system such as rails or transponders.

KEYWORDS: Intelligent Autonomous Vehicle (IAV). Space optimisation. Traffic management. Intermodal transport.

1. INTRODUCTION

The international seaport business has changed radically within the space of several years. Globalisation has brought about changes in the structure of the world economy and the shipping and port industries have had to respond to the challenges. Opportunities have risen as a result of the structural changes which need to be exploited.

Most ports today are competing with one another on a global scale and, with the tremendous gains in productivity in ocean transport achieved over the past decades, ports are now perceived to be the remaining controllable component in improving the efficiency of ocean transport logistics. This has generated the drive to improve port efficiency, lower cargo handling costs and integrate port services with other components of the global distribution network with regard to lowering emissions, safety and security

Ports no longer operate in an insulated or isolated environment. They face the same competitive forces that companies in other industries experience. There is rivalry among existing competitors, continuing threat of new entrants, potential for global substitutes, presence of powerful customers and powerful supplies and regulative and legislative boundaries that must be adhered to. [***World Bank Port Reform Tool Kit*/module 2. *The Evolution of Ports in a Competitive World*. (p.1)]**

There is a constant increase in the freight passing through European ports. For example, the volume of containerised freight entering and leaving seaports has doubled within the space of several years. Around 90% of the EU's trades with third countries pass through the ports of Europe, with some 3.2 billion tonnes of freight being loaded and unloaded annually.

The EU's seaports play a vital part in ensuring the competitiveness of both its internal and external trade, and they provide essential links to its islands and remote regions. Moreover, the ports generate a high level of employment both directly or indirectly, and they drive the dynamism and development of entire regions, including most of the EU's remote regions.

Europe needs a network of accessible and efficient ports. It needs greater port capacity, and existing capacity has to be streamlined. EU ports must identify all the issues they must resolve if they are to meet the ever-growing demand for transport, cope with technology change (such as containerised freight, intelligent transport systems (ITS) and new ICT technologies) and address the need to reduce emissions Europe's main transport routes need to become 'greener', taking account of environmental concerns as well as the general need for safety and security. EU ports must meet these challenges, develop their operations and become more competitive. **[*Maritime Transport without Barriers. Initiatives for Making European Ports more Efficient.* (p. 4, 5)]**

Globalisation, consumption needs and long term energy together with climate change have had dramatic effects on our environment and are at the forefront of the international maritime agenda. A feature of world trade is the increasing economic uniting of markets and as a result global cargo handling.

The operators of terminals and ports are obliged to take a more responsible stand with regard to the environment in view of the greater awareness for environmental issues and related laws and regulations. As a result, greater emphasis is being placed on the design and sustainable development of the technology that is used. These developments have brought the attention to bear on cargo-handling equipment using low-consumption, environmentally aware technologies to increase efficiencies, reduce emissions and to optimise the use of limited space. It is important that companies use equipment that is economical and environmentally compatible at the same time. The main problem in handling the increasing level of cargo in the terminals of international ports is managing the internal traffic management and space optimisation inside confined spaces.[***World Bank Port Reform Tool Kit/module*2.*The Evolution of Ports in a Competitive World*. (p.1)]**

2. DUBLIN PORT MASTERPLAN AND THE ROLE OF INTELLIGENT TRANPORT SYSTEMS

Dublin Port is the largest and busiest port on the island of Ireland. The port's main function is to facilitate the movement of goods and people which is crucial to the Irish economy, in an efficient and cost effective manner. Dublin Port Company launched a new Master-Plan; it's the long- term development, in March 2011. It handles over €35 billion worth of trade every year and supports some 4,000 jobs locally. 90 per cent of Irelands GDP is exported with 42 per cent being handled through Dublin Port. Growth in the container traffic was 1.1 per cent with an out-turn of 554,229 TEU (Twenty Foot Equivalent Unit) in 2010. 80 per cent of all exports and imports through the port are transported in containers. In 2010 the throughput was 28.711 million tonnes. Imports consisted of 6.933 million tonnes, an increase of 2.4 per cent. Exports increased to 11.184 million tonnes, an increase of 12.2 per cent. Dublin is the largest of the three base ports in Ireland, the others being Belfast and Cork. The base ports offer multi-modal services with connections to ports such as Rotterdam, Antwerp, Le Havre, Felixstowe, Hamburg, Southampton and Liverpool which are important strategic trading hubs. [***Dublin Port Company, Trade Statistics a, Facts and Figures b*]**

The aim of the Master-plan is to chart the development of Dublin Port Company out to 2040 to allow for a doubling of trade volumes. It has already seen some evidence of a return to growth with a 6% rise in throughput in 2010. Given the depressed nature of the economy at present (2011), this may not seem feasible but with Irish exports thriving in the recession Dublin Port is one of the few companies in the country operating in a growth industry.

Table 1. Historical and Forecasted Throughput

Year	***Throughput***	***AAGR****
1980	7.3m tonnes	3.2%
2010	28.9m tonnes	4.7%
2040	60.0 tonnes	2.5%

*Average Annual Growth Rate.

Table 2. Profile of Throughput to 2040

	2010 '000 tonnes	***2040 '000 tonnes***	***AAGR***
Ro/Ro	16,403	41,920	3.18%
Lo/Lo	6,317	10,480	1.70%
Bulk Liquid	4,009	4,000	-0.01%
Bulk Solid	2,054	3.500	1.79%
Break Bulk	96	100	0.12%
Total tonnes	28.879	60,000	2.47%

Table 3. Forecasted Traffic for Ro/Ro and Lo/Lo

	2010	2040
Ro/Ro ('000 units)	701	1,791
Lo/Lo ('000 units)	377	625
Total units	1,078	2,416

The Master-plan is based on the assumption that trade will grow to 60 million tonnes by 2040, this would be roughly twice the level of 2011 and imply an average annual growth rate of 2.5 per cent. If anything, this forecast might be too conservative. The volume of trade through Dublin Port in 2010 rose by 6.1 per cent to 28.9 million tonnes. Roughly three-quarters of that growth accounted for exports. While it is below the 2007 peak of 30.9 tonnes, it marked a turnaround for the port business after some difficult years affected by the recession in Ireland. [***Dublin Port Company – Masterplan Issues Paper*. (p. 7, 8)]**

In line with the ambitions and growth forecasts predicted by the Port Company, there is a need to optimise the use of Intelligent Transport Systems (ITS) within international ports such as Dublin. Currently in Dublin Port, the movement of cargo is operated by shunter vehicles differing from Automated Guided Vehicles (AGVs) as in other international ports. The INTRADE project, in which Dublin Institute of Technology (Department of Transport Engineering) are Partners with Dublin Port Company as a sub-partner, has received European Regional Development Funding through InterReg IV B. Within North West Europe (NWE), few ports are able to keep pace with the activity similar to that experienced in Dublin port. The main problem in handling the increasing level of cargo in the terminals of international ports is managing the internal traffic management and space optimisation inside confined spaces. Participation in the InTraDE project will contribute to improving the traffic management and space optimization inside confined space by developing a clean and safe ITS such as a IAV (Intelligent Autonomous Vehicle).

3. INTELLIGENT AUTONOMOUS VEHICLE (IAV)

The InTraDE project is contributing to improving the traffic management and space optimization inside confined spaces by developing a clean and safe ITS (Intelligent Transport System) such as a IAV (Intelligent Autonomous Vehicle). The technology will operate in parallel with virtual simulation software of the automated site, allowing a robust and real-time supervision of the goods handling operation using virtual simulation software.

The IAV is the logical transition from mobile robotics to that of urban vehicles. The technology will have a specific design, with multi-actuated traction and steering systems. This configuration will allow the system to be redundant in control, so that different scenarios can be defined to run the vehicle on a segment of the road or particular pre-defined trajectory. Multi-decentralized inputs help find reconfigurable solutions, when an input fault is detected and isolated. In this case, the vehicle will avoid the stop situation, without obstructing the traffic operation

IAVs will improve the traffic in international ports in terms of congestion, when the volume of vehicles is dense according to space motion. These vehicles will alter their speeds and trajectories according to the traffic status and the environmental changes such as pollution and noise. The auto-control will help significantly in decreasing the emission rate of pollution gases during the vehicles mission. In order to meet requirements of a changing industry and to service the needs of a rapidly developing economy in the long term, the IAV will reduce the time lost in moving cargo from ship to stacking areas and vice versa by 10%. In turn, this will impact on the turnaround time of vessels, a crucial factor in port and vessel efficiency, particularly in Dublin Port. In addition, the environmental benefits will include a 20% reduction in air pollution. [***INTRADE. Intelligent Transportation for Dynamic Environment*]**

The IAV will use a GPS guidance system to move unmanned around port terminals, delivering containers to and from marshaling areas. Although the IAV is not exactly new, what makes it different is that it does not require a guidance system such as rails or transponders set into the ground. Traffic management is a problem with the future development of port terminals such as in Dublin Port. The problem can be solved by having a remote 'traffic control centre' directing vehicles to marshalling areas where the containers are handled by IAV's.

In order to be efficient, cargo handling has to be situated close to the quay wall where vessels are operating, otherwise, valuable time will be lost moving the cargo from ship to storage area and vice versa. In turn, this will impact on the turn-around time of the vessels, a crucial factor in vessel and port efficiency.
[*Dublin Port Company – Masterplan Issues Paper. (p. 4)*]

3.1. Suitability and Application of IAV in Dublin Port

If Dublin port is to reach 60 million tonnes by 2040, there will be a need for some reconfiguration of the existing port with redevelopment as required. There is a limit to the volume of freight that can be handled in the ports existing estate and infrastructure. The most accurate estimate is that the port will require in the order of 30 to 40 additional hectares to cater for the 60 million tonnes by 2040. Therefore, the introduction of the IAV (Intelligent Autonomous Vehicle) and the application of the virtual port simulator will be very valuable in forecasting the impact of changing traffic flows and the foreseen increase in efficiency and cost effectiveness of good handling in the port in 2040 by designing a case study of terminal layouts using the virtual simulator.

Figure 2. DFT Terminal in Dublin Port

IAVs will improve the traffic in Dublin port in terms of congestion, when the volume of vehicles is dense according to space motion. These vehicles will alter their speeds and trajectories according to the traffic status and the environmental changes such as pollution and noise. The auto-control will help significantly in decreasing the emission rate of pollution gases during the vehicles mission. In order to meet requirements of a changing industry and to service the needs of a rapidly developing economy, the IAV will reduce the time lost in moving cargo from ship to stacks and vice versa by 10%. In turn, this will impact on the turnaround time of vessels, a crucial factor in port and vessel efficiency. In addition, the environmental benefits will include a 20% reduction in air pollution.

The novel conception approach of the IAV will identify automatic navigation routes in order to overcome any infrastructural barrier in Dublin Port. It does not require fixed tracks (and inherent costly investment) commonly required for completely automated vehicles. A major consideration in the development of the IAV is its suitability for Dublin Port in terms of its payload capabilities and its capabilities to adapt to a varied range of environmental parameters which present themselves in the redevelopment of the Port. [***INTRADE. Intelligent Transportation for Dynamic Environment.***]

This novel technology will adapt to the specific environment in Dublin port, which could then be transferred to different sizes of ports and terminals in the NWE region and beyond.

3.2. Technical Innovation of IAV

The IAV is novel in terms of its advancement of ITS designs with innovative features including:

- Autonomous platform totally operable by a remote control computing in virtual environment, semi automatic mode possible;
- Two degrees of mobility to command directly due to the 4 wheels steering with 360° mobility on all wheels;
- Totally modular design, intelligent “corners” with drive, steer and suspension;
- Electric hub motors (in-wheel), battery operated, associated with thermal generator according to the transport scenario;
- Low consumption and minimizing of CO2 and noise pollution;
- Carrying standard containers, with standard connections, stackable within weight limits;
- Position feed-back for the remote control by appropriate sensors (GPS, lasers, ultrasonic, …);
- Safety in freight transport and human-machine interaction: vehicles with low speed motion, two modes of driving ((manual and automatic)
- and using a real-time supervision of the overall system and soft system maintenance;
- Efficient traffic management inside an enclosed and in some cases, urban areas. The second innovation related to this project concerns the development of on-line virtual simulator for the port including all the traffic management and space optimisation. It can also simulate the external environment and accidental situations.

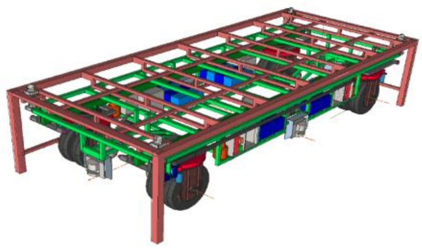

Figure 3. IAV Design

3.3. Specifications and Capabilities of the IAV

- The IAV will handle 20ft and 40ft containers;
- Two IAV’s coupled together will handle a 40ft container;
- A tow hook on the front will allow the vehicle to be towed incase of failure;
- Maximum velocity on horizontal flat floor forward and backward 25km per hour;
- Autonomy 10km for four hours continuously;
- Slope general of 3%;
- Transversal slope general of 3%;
- Noise level internal and external power supply by battery.

Table 4. Battery specifications of IAV

Working temperature	-10C, +40C
Storage temperature	-20C, +50C

Table 5. Payload volume of 20ft container

Length	6m
width	2.4m
Height	2.6m
Volume	1360 cu ft

1.

Table 6. Summary of Technical Specifications of IAV

Weight (without load)	3000 kg
Payload	7000 kg
Wheels diameter	760 mm
Dimensions	L: 7m W: 2.5 m
Height of handling try	1.2 m

Table 7. Characteristics of IAV

4 wheels	Double drive & steering
Mass of vehicle	2225 Tons
Height	1300mm
Width	2500mm
Length	7000mm
Wheel diameter	760mm
Height under the try	1197mm
Position of centre of Gravity	0mm, 809mm, 0mm

3.4. Simulation of Dublin Port using IAV SCANeR Studio Software

The simulation software used is called SCANeR Studio simulation engine. It has adapted techniques to develop a real-time simulation for the study of traffic flows within Dublin port and other international ports. Data and information regarding Dublin Port was imputed in the simulator in order to finalise a generic 3D dynamic simulator of the port. The tool employs an interactive approach between vehicles, traffic lights and roads that enables users to visualize a real port network and the vehicles that drive in it. The technique developed can be changed to different port layouts due to the flexible extensible method with which it has been implemented. The main study of the simulator is to set parameter values of the actual port system. Simulation is the perfect tool for evaluating system parameter values as it reduces the cost and time of a project by allowing the user to quickly evaluate the performance of different layouts, a process that is time consuming and is extraordinarily expensive. The robustness of the system can be tested using different scenarios, allowing you to explore these scenarios without changing the values therefore any changes can be easily made.

The simulator will help significantly in the pre-analysis before experimental tests of the vehicle. With the different developed vehicles, infrastructure and environment, validation of the developed algorithms on control, monitoring, space optimisation and traffic management can be carried out before real integration begins.

The software will identify potential obstacles and related problems and will reduce the number of obstacles in the port area by 3%. It will achieve a more effective method of moving cargo from ship to storage area and vice versa with a minimum efficiency improvement of 10%. Obtain a safe environment within the port area due to the simulators capabilities to locate the position of the goods at all times, a reduction in the loss or damage of cargo by 4% will be a target. Reduction in the level of accidents by 5% and it will also aim to increase the use of information and communication technology (ICT) within Dublin Port operations by 5%.

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NUMERICAL MODELING OF SEDIMENT TRANSPORT IN HARBORS AND STUDY OF PLANFORM EFFECTS ON SEDIMENTATION

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ABSTRACT

Sedimentation is a common problem in many harbors, which requires frequent dredging and involves considerable maintenance costs. Consequently harbor planform, which influences flow pattern, plays a crucial role in sedimentation in harbors. In this study a 2DH finite volume numerical model including sediment transport module has been developed and utilized to investigate the effects of harbor planform on sedimentation in harbors.

Keywords: Sediment transport, Harbor Planform, 2DH, sedimentation

1. INTRODUCTION

Sedimentation reduces the required navigation depth in harbors and disturbs vessels passage. In order to provide safe passage for vessels, maintenance dredging which is the most expensive item in running costs of harbors is necessary. The amount of maintenance dredging depends on the sedimentation rate in harbor basin and therefore, minimizing the depth reduction in harbors is one of the most important criteria in harbor design.

Generally, sediments transported to harbors by currents and waves are deposited in parts of the harbor where currents and waves are not strong enough to keep sediments in motion, which results in the sediment deposition and reduction of water depth.

2. HYDRODYNAMIC AND SEDIMENT TRANSPORT MODEL

A two dimensional depth-averaged numerical model including hydrodynamic and sediment transport module has been developed herein.

Hydrodynamic module predicts horizontal depth-averaged velocities and water surface elevation, solving shallow water equations. Finite volume technique has been utilized for discretization of the equations. In order to solve the resulting system of equations, the Alternating Direction Implicit (ADI) method has been employed.

Sediment transport module predicts suspended sediment concentration and bed level changes by solving well known depth-averaged advection-diffusion and sediment mass balance equations respectively. In order to estimate sediment erosion and deposition rate, Krone (1962) and Partheniades (1965) formulas are used respectively.

Hydrodynamic and sediment transport modules are coupled under the basic assumption that during hydrodynamic computations the bed elevation remains constant and similarly, hydrodynamic conditions do not change during bed level calculations. Moreover, it is assumed that suspended sediment load has no effect on hydrodynamic conditions in corresponding time step.

2.1. Hydrodynamic Module

Shallow water set of equations including effects of turbulence and bottom stress are represented as follows (Liggett 1994):

$$\frac{\partial h}{\partial t}+\frac{\partial(uh)}{\partial x}+\frac{\partial(vh)}{\partial y}=0 \tag{1}$$

$$\begin{aligned}\frac{\partial(uh)}{\partial t}+\frac{\partial(uuh)}{\partial x}+\frac{\partial(vuh)}{\partial y}&=-gh\frac{\partial(h+z_b)}{\partial x}\\&+\frac{1}{\rho}\frac{\partial(hT_{xx})}{\partial x}+\frac{1}{\rho}\frac{\partial(hT_{xy})}{\partial y}-\frac{\tau_{bx}}{\rho}\end{aligned} \tag{2}$$

$$\begin{aligned}\frac{\partial(vh)}{\partial t}+\frac{\partial(uvh)}{\partial x}+\frac{\partial(vvh)}{\partial y}&=-gh\frac{\partial(h+z_b)}{\partial y}\\&+\frac{1}{\rho}\frac{\partial(hT_{yx})}{\partial x}+\frac{1}{\rho}\frac{\partial(hT_{yy})}{\partial y}-\frac{\tau_{by}}{\rho}\end{aligned} \tag{3}$$

where u and v are depth-averaged horizontal velocities in x and y direction respectively, h is water depth, and z_b is bed elevation, T_{xx}, T_{xy}, T_{yx}, T_{yy} are depth-averaged turbulent stresses, τ_{bx}, τ_{by} are bed shear stresses in x and y direction respectively, ρ is water density and g is the gravity acceleration.

Bed shear stresses are determined using simple quadratic friction law as represented by Eq (4). Here C is chezy coefficient.

$$\begin{bmatrix} \tau_{bx} \\ \tau_{by} \end{bmatrix} = \rho \frac{g}{C^2} \sqrt{u^2+v^2} \begin{bmatrix} u \\ v \end{bmatrix} \tag{4}$$

Turbulent shear stresses are calculated using simple Boussinesq assumption, (Rodi, 1993):

$$T_{xx} = 2\rho\nu_t \left(\frac{\partial u}{\partial x}\right) \quad , \quad T_{yy} = 2\rho\nu_t \left(\frac{\partial v}{\partial y}\right)$$
$$T_{xy} = T_{yx} = \rho\nu_t \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) \tag{5}$$

Where ν_t is turbulent eddy viscosity and may be calculated using depth-averaged parabolic model, (Rodi, 1993) as represented by Eq (6). Here α is an empirical coefficient. In present study α is set to 0.2.

$$\nu_t = \alpha u_* h \qquad u_* = c_f \sqrt{u^2+v^2} \qquad c_f = \frac{\sqrt{g}}{C} \tag{6}$$

2.2. Suspended Sediment Transport Module

In the case of fine sediment transport, bed load is a negligible part of total load transport and in the present study is not taken into account.

Sediment transport module calculates the suspended sediment concentration solving depth-averaged advection-diffusion equation, (Zhou and Lin ,1998):

$$\frac{\partial(ch)}{\partial t} + \frac{\partial(uch)}{\partial x} + \frac{\partial(vch)}{\partial y} = \frac{\partial}{\partial x}\left(\varepsilon_x h \frac{\partial(c)}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y h \frac{\partial(c)}{\partial y}\right) + E_b - D_b \tag{7}$$

Where c is the depth-averaged concentration, ε_x , ε_y are sediment diffusion coefficients in x and y direction respectively, E_b is sediment erosion rate, and D_b is sediment deposition rate. Sediment erosion and deposition rates are estimated using Krone (1962) and Partheniades (1965) formulas as represented by Eq (8) and Eq (9) respectively.

.

$$D = \begin{cases} w_s c(1 - \frac{\tau_b}{\tau_{cd}}) & \text{for} \quad \tau_b < \tau_{cd} \\ 0 & \text{for} \quad \tau_b > \tau_{cd} \end{cases} \tag{8}$$

$$E = \begin{cases} M(\frac{\tau_b}{\tau_{ce}} - 1) & \text{for} \quad \tau_b > \tau_{ce} \\ 0 & \text{for} \quad \tau_b < \tau_{ce} \end{cases} \tag{9}$$

Where τ_b is bed shear stress, τ_{cd} critical stress for deposition, τ_{ce} critical stress for erosion, w_s settling velocity, and M erosion constant.

Krone (1962), proposed following formula for cohesive sediment settling velocity

$$w_s = 0.001C^{4/3} \tag{10}$$

where C is suspended sediment concentration (gr / lit)

Bed level changes are calculated using sediment mass balance equation (Eq.11):

$$(1-n)\frac{\partial z}{\partial t} = -(E_b - D_b) \tag{11}$$

where n is bed materials porosity.

2.3. Discretization of Equations

The governing equations are discretizied using finite volume method on a rectangular uniform grid with staggered variable arrangements.

Equations (1, 2, 3 and 7) are integrated over control volume shown in Fig (1). Convective terms are discretized using third order TVD, SDPUS-C1 scheme (Lima et al., 2010). Using first order backward scheme for time derivative terms and second order central difference scheme for diffusive terms, discretized equations may be written in the form of Eq (12). Resulting system of equations is solved using ADI technique.

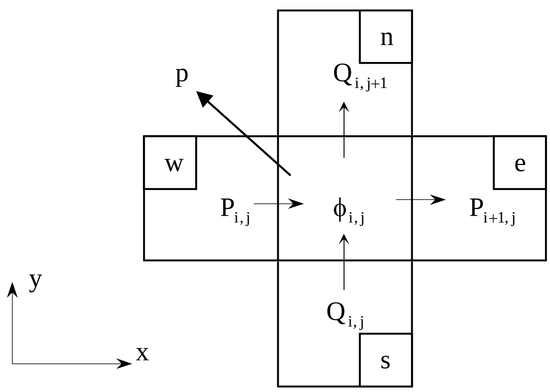

Figure (1) Two dimensional cartesian grid where ϕ stands for h,c and z. n,e,w,s are indexes for neighboring cells. p is an index for central cell.

$$\begin{aligned} &A_p H^{n+1}_{i,j} + A_e P^{n+1}_{i+1,j} + A_w P^{n+1}_{i,j} + A_n Q^{n+1}_{i,j+1} + A_s Q^{n+1}_{i,j} = 0 \\ &B_e P^{n+1}_{i+1,j} + B_e H^{n+1}_{i+1,j} + B_p H^{n+1}_{i,j} = R^n_P \\ &C_n Q^{n+1}_{i,j+1} + C_n H^{n+1}_{i,j+1} + C_p H^{n+1}_{i,j} = R^n_Q \\ &F_p C^{n+1}_{i,j} + F_e C^{n+1}_{i+1,j} + F_w C^{n+1}_{i-1,j} + F_n C^{n+1}_{i,j+1} + F_s C^{n+1}_{i,j-1} = R^n_C \end{aligned} \tag{12}$$

where P = uh, Q = vh.

3. MODEL VALIDATION

3.1. Hydrodynamic Module

In this paper experimental data of stationary free surface flow in a square cavity (Langendoen, 1992) are used for model verification. The flow into the square harbor is driven by a constant discharge of $uh = 0.042\,m^2/s$ per width in the main channel. Initial water depth was set to 0.11 m. In the physical model, channel length was 18m, but in numerical simulations the length of channel is reduced to 5m (Hakimzadeh 2004) in the favor of saving computational time. The computational domain configuration is represented in Fig (1). Numerical predictions and experimental results compared in Fig (2) show a good agreement. Another test simulates, a subcritical flow over a bump (Goutal and Maurel ,1997). In this simulation discharge per width and initial water elevation in the channel are 4.42 m^2/s and 2 m respectively. Numerical prediction and analytical solution obtained from Bernoulli's theorem show good agreement as shown in Fig (3).

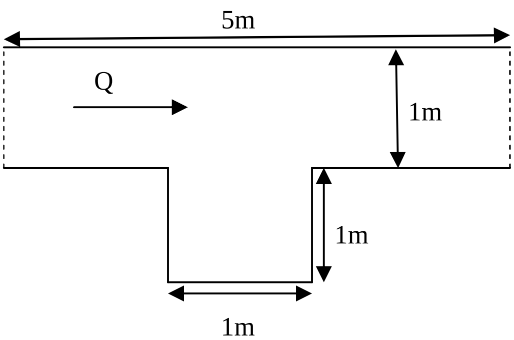

Figure (1) Numerical model configuration

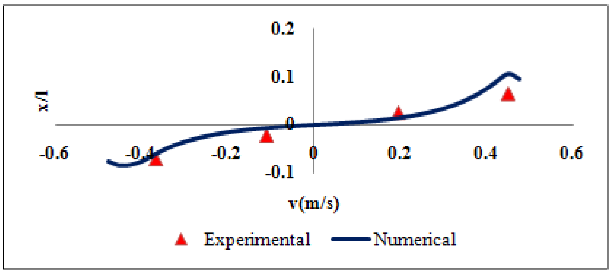

Figure (2a) Comparison of velocity of flow across x axis

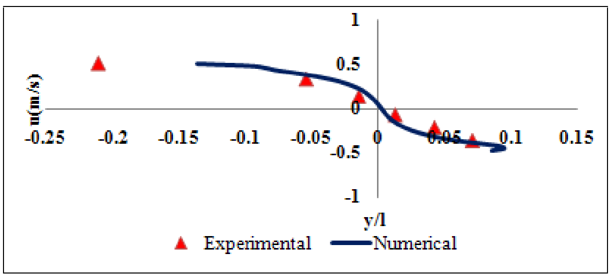

Figure (2b) Comparison of velocity of flow across y axis

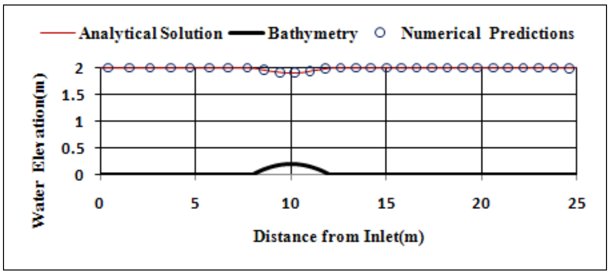

Figure (3) Water elevation (subcritical flow over a bump)

3.2. Sediment Transport Module

To evaluate sediment transport module combined advection-diffusion Transport and sediment mass conservation are examined. Results demonstrate model capabilities in solving advection-diffusion equations and maintaining sediment mass conservation accurately.

3.2.1. Combined Advection-Diffusion Test

Wexler (1992), proposed analytical solution, to the advection-diffusion equation including source-sink terms (Eq.12). Boundary and initial conditions are presented by Eq (13). Velocity profile and diffusion coefficients are assumed to be constant over computational domain. Equation (14) reads the analytical solution.

$$\frac{\partial(ch)}{\partial t}+\frac{\partial(uch)}{\partial x}+\frac{\partial(vch)}{\partial y}=\frac{\partial}{\partial x}\left(\varepsilon_x h\frac{\partial(c)}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y h\frac{\partial(c)}{\partial y}\right)-\lambda c \tag{12}$$

$$\begin{aligned}
&c = c_0 \quad \text{for} \quad x = 0 \quad \text{and} \quad y_1 < y < y_2\\
&c = 0 \quad \text{for} \quad x = 0 \quad \text{and} \quad y_1 > y \quad \text{or} \quad y > y_2\\
&\frac{\partial c}{\partial x} = 0 \quad \text{for} \quad x = L, \quad \frac{\partial c}{\partial y} = 0 \quad \text{for} \quad y = 0\\
&\frac{\partial c}{\partial y} = 0 \quad \text{for} \quad y = W\\
&c = 0 \quad \text{for} \quad 0 < x < L, \quad \text{and} \quad 0 < y < W\\
&P_n = \frac{y_1 - y_2}{W} \quad \text{for} \quad n = 0\\
&P_n = \frac{\sin(\eta y_1) - \sin(\eta y_2)}{n\pi} \quad \text{for} \quad n \neq 0
\end{aligned} \tag{13}$$

where L = length of domain and W = width of domain

Results for unit depth, $u = 1$ ft/day , $v = 0$ ft/day , $k_x =$ 200 ft/day^2, $k_y =$ 60 ft/day^2, $\lambda =$ 0.001 are shown in Fig(4), that confirm the accuracy of advection -diffusion simulation. In the figure, red lines represent analytical solution and contours show numerical prediction.

$$c(x,y,t)=$$

$$c_0 \sum_0^{\infty} L_n P_n \cos(\eta y) \times \left\{ \exp\left(\frac{x(U-\beta)}{2k_x}\right) \operatorname{erfc}\left(\frac{x-\beta t}{2\sqrt{k_x t}}\right) + \exp\left(\frac{x(U+\beta)}{2k_x}\right) \operatorname{erfc}\left(\frac{x+\beta t}{2\sqrt{k_x t}}\right) \right\} \tag{14}$$

$$\beta=\sqrt{U^2+4k_x(\eta^2 k_y+\lambda)}$$

$$\eta=\frac{n\pi}{W}, \quad n=0,1,2,.$$

$$L_n=0.5 \quad \text{for} \quad n=0, \quad L_n=1 \quad \text{for} \quad n>0$$

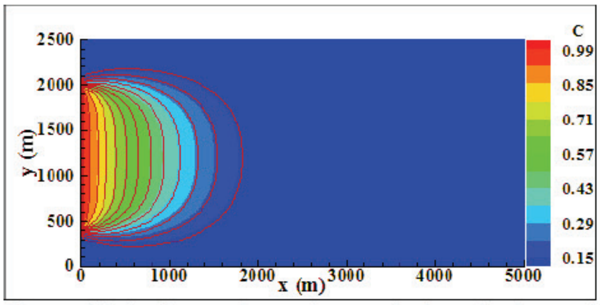

Figure (4) A Comparison of numerical prediction and analytical solution to the advection-diffusion equation.

3.2.2. Sediment Mass Conservation Test

To evaluate model capabilities in simulating sediment transport, a numerical simulation of sediment transport on a rectangular domain with a simple sloped bottom has been carried out as reported by Pandoe et al. (2004) and demonstrated in Figure (5a) and (5b). Except for critical shear stresses for erosion and deposition, other parameters are same as those used by Pandoe et al. (2004). The flow boundary condition with the discharge of $uh=2.50\ m^2/s$ per width is imposed on the left hand boundary and the water elevation is kept constant ($\eta=0$) on the right hand side. Other two boundaries are land boundaries. The computational domain is 12 km long and 4 km wide. After 24 hours the simulation is stopped. To maintain sediment mass conservation, of net erosion (erosion + deposition) should equal to the sum of suspended sediment volume in water column and sediment volume that leaves the channel from open right boundary. Fig (6a) and (6b) show suspended sediment concentration in water column and bed erosion/deposition along the centerline of the channel. Results presented in Table (1) shows an error of only 2% for sediment mass conservation simulation. The source of error is the accumulative numerical errors that come from discritization and the solution of hydrodynamic and sediment transport equations.

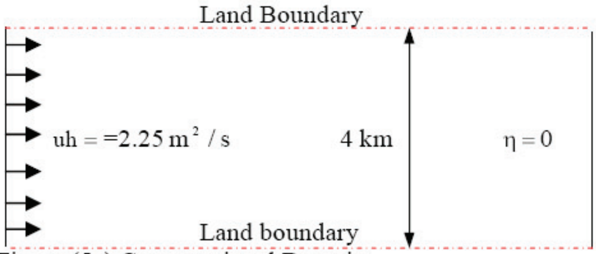

Figure (5a) Computational Domain

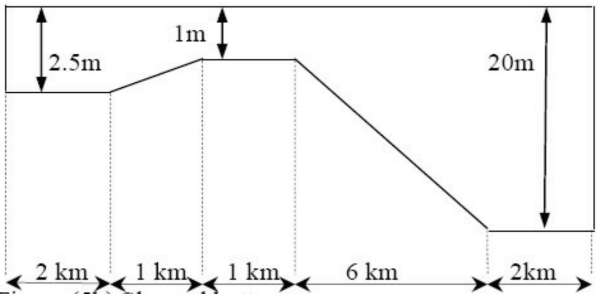

Figure (5b) Slopped bottom

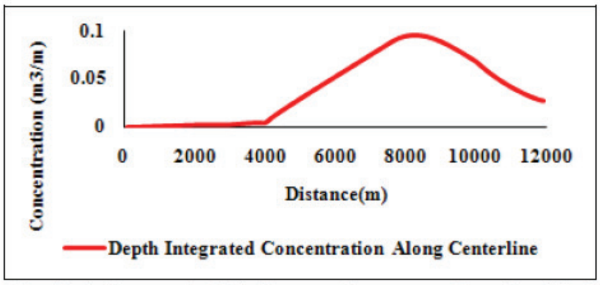

Fig (6a) Suspended Sediment Concentration Per Unit Width along Channel

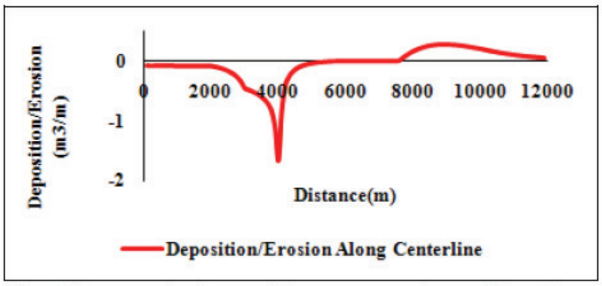

Fig (6b) Erosion/Deposition Per Unit Width along Channel

Table (1) Sediment mass conservation results

Net Erosion	Suspended sediment	Sediment inflow	Sediment outflow	Error
$2450\ m^3$	$1820\ m^3$	$0\ m^3$	$639.95\ m^3$	%2.0

4. PLANFORM INVESTIGATION

Sediments are transported into the harbor basin and deposited when the flow is no longer capable of keeping sediments in suspension. Therefore the flow characteristics play an important role in suspended sediment transport and deposition pattern in harbor basin.

Flow in the harbor basin is driven by flow in main channel and one or more eddies depending on harbor geometry form in the harbor (Kuijper et al., 2005). Flow separation occurs at upstream corner of the basin and a turbulent mixing layer forms between harbor basin and main channel flow (Winterwerp, 2005), as shown in Fig (7).

Amount of sediment exchange that occurs between harbor basin and main channel depends on strength of turbulent mixing layer between harbor and main channel which is also influenced by harbor geometry (Winterwerp, 2005 and Kuijper et al., 2005). Therefore, in addition to flow characteristics, harbor planform affects sediment exchange between harbor and main channel to a high extent.

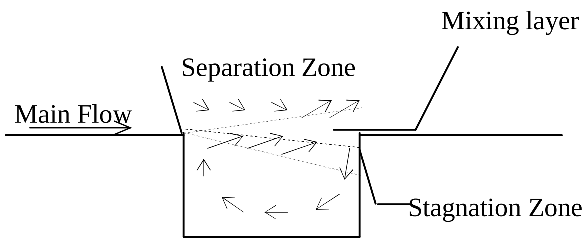

Figure (7): Schematic form of mixing zone (Kuijpe et al., 2005)

In this study, to investigate the planform effects on sedimentation in harbors a wide range of aspect ratios for rectangular harbors with constant area of 2.25 m^2 have been examined in the numerical model. In all simulations, flow discharge and the still water depth are se to 0.042 m^2/s per width and 0.11 m respectively, as has been demonstrated in Langendoen (1992). Zero water elevation imposed at the right open boundary and the suspended sediment concentration at the left boundary is set to $10\,kg/m^3$. Initial suspended sediment concentration is $0.6\,kg/m^3$.

Critical shear stress for deposition is reported between 0.05 and 0.1 N/m^2 (Self et al., 1986). Parchure and Mehta (1985) reported values for τ_{ce} between 0.04 and 0.62 N/m^2.Reported values for M coefficient lies between 0.00001 and 0.0005 $kg.m^{-2}s^{-1}$ (Van Rijn, 1993).

After 30 minutes simulation is stopped and net deposition in the harbor basin is the measure for which, comparison has been considered. Other simulation parameters and geometry of numerical model are presented in Table (2) and Fig (8) respectively.

Table 2 Numerical simulation parameters

Inflow m^2/s	τ_{ce} N/m^2	τ_{cd} N/m^2	C $m^{0.5}/s$	M $kg.m^{-2}s^{-1}$
0.042	0.2	0.05	90	0.00001

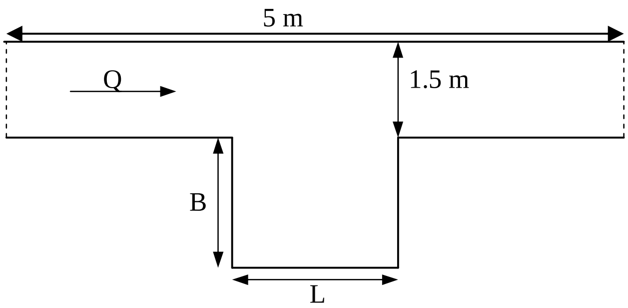

Figure (8) Numerical simulation geometry

5. RESULTS AND DISCUSSION

Simply, it may seem that reducing harbor mouth necessarily leads to sedimentation reduction in the harbor, but it is not exactly the case. Although, the wider harbor mouth may possibly lead to more suspended sediment exchange between harbor and main channel, but on the other hand, it results in stronger flow in the harbor basin, so, the hydrodynamic characteristics in the harbor have to be taken into account. Sedimentation volume against aspect ratio is plotted as seen in Fig (9).

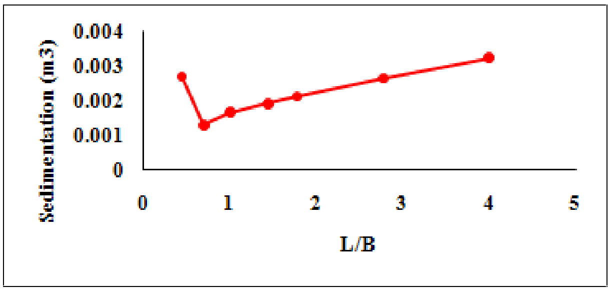

Fig (9): Aspect ratio effect on sedimentation volume

As indicated by results, for L/B<0.7, although increasing harbor mouth leads to increase in suspended sediment exchange between harbor and channel, but stronger flow reduce deposition in the harbor. So as long as L/B<0.7, the flow is dominant factor in sedimentation in harbor. Similarly for L/B>0.7, it can be observed that sediment exchange across the harbor is more important. In addition, it can be observed that for square harbors (L/B=1), the sedimentation volume per unit area is decreased with increasing harbor length, Fig (10)

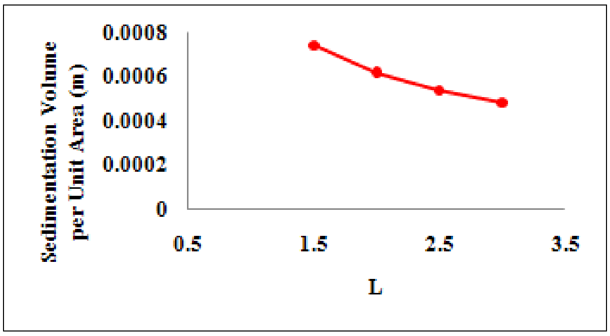

Fig (10): Dimension effect on sedimentation volume per unit area in Square harbors

6. CONCLUSION

A numerical hydrodynamic and sediment transport model has been developed herein. The model has been validated against both experimental and numerical results which confirm the accuracy of predictions.

In this study planform effects on sedimentation in the harbor basin is investigated by examination of a range of aspect ratios varying from 0.44 to 4.0. For L/B<0.7 flow characteristics play a more important role in sedimentation whereas, for L/B>0.7, sediment exchange between harbor and channel is a more dominant factor. Moreover, in order to minimize sedimentation in the square harbor, the aspect ratio should be kept as close to 0.7 as possible.

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THE COMPOSITE SUPPLY CHAIN EFFICIENCY MODEL

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ABSTRACT

In an effort to compete globally, South African supply chains must achieve and maintain a competitive advantage. One way of achieving this is by ensuring that South African supply chains are as efficient as possible. Consequently, steps must be taken to evaluate the efficiency levels of South African supply chains. This paper discusses the composite supply chain efficiency model using variables specifically identified as problem areas experienced by South African supply chains. The composite supply chain efficiency model evaluates the overall efficiency of a supply chain based on three criteria, namely, reliability efficiency, cost efficiency and speed efficiency. It identifies bottlenecks along the supply chain and in so doing identifies key focus areas for firms if they want to improve their overall efficiency and become more competitive.

Keywords: supply chains, efficiency, modelling, DEA

1. INTRODUCTION

South Africa is striving to become a major force in the global market; however, it is presently facing many obstacles. Poverty, a high level of unemployment, a lack of skills and an inefficient utilisation of infrastructure are all aspects that are hindering the country's growth. In addition, logistics was identified by the South African government in the Accelerated and Shared-Growth Initiative of South Africa (ASGISA) as being a potential hurdle that may limit future growth in the country (Ittmann 2007).

The growth and development of South Africa's economy and the resulting wellbeing of its people are closely linked to trade; with more than 95% of South Africa's trade volume taking place via sea transport (Chasomeris 2005). In order to be able to compete with global supply chains, existing maritime supply chains to and from South Africa must function efficiently and new efficient supply chains must be developed. Many export industries are dependent on imported inputs and the importance of efficient import supply chains cannot be over emphasised.

The efficiencies of the supply chains on which the trade of many of South Africa's competitors in world markets depend, have received concerted attention by industry and the governments in those countries. However, South Africa's government has only recently realized the importance of such a focus (Neill 2003).

The model presented in this paper proposes a set of guidelines that can assist South African industries in becoming internationally competitive by providing them with a tool for evaluating their levels of efficiency both as an individual firm and as a component in an overall supply chain. The model also helps them to identify the processes that need improvement to increase their overall supply chain efficiency.

2. EXISTING PRACTICES IN SOUTH AFRICA

Measuring supply chain efficiency in South Africa is hindered by a number of obstacles. Firstly, a large percentage of companies do not understand the importance of determining the levels of efficiency in their supply chains and therefore do not record any data that can be used in a model for measuring supply chain efficiency. Secondly, several supply chains in South Africa consist of both public and private sector participants. Therefore certain links and nodes are provided by the private sector, while the others are provided by the public sector. This complicates the process of measuring supply chain efficiency as the main goal of the private sector is to maximise profit, while the public sector generally takes social considerations into account, and it becomes more difficult to achieve efficiency as the overall goal. Thirdly, the models that are currently available to companies, for example, the SCOR model, are expensive and require extensive training to be able to use effectively and therefore exclude small firms with a limited budget. Finally, there is unwillingness in South Africa to share information between different companies along a supply chain, which makes accurate supply chain efficiency measurement more complex.

Further, South African supply chains cannot be viewed in isolation. For South African firms to be able to compete globally, they have to meet international standards. This can only be achieved if South African firms are aware of how they perform in comparison to international benchmarks.

3. MODEL

The model is broken into and is presented in four steps:

The first step involves the determining of factors that influence the overall level of efficiency in a South African supply chain. A detailed background study was conducted to investigate and build upon strengths, as well as to investigate any weaknesses identified by previous research on the topic. An analysis of existing practices in South African supply chains was undertaken and guidelines devised according to both local and international best practice. Qualitative research was conducted to understand and determine bottlenecks that are currently plaguing South African supply chains.

Factors that influence supply chain efficiency in South Africa, as identified through the study, are:

- The ratio of idle time to productive time
- Throughput, lead time and utilisation of the supply chain capacity
- Infrastructure availability and utilisation
- Low transport productivity
- Method of freight handling
- Interface arrangements
- Labour competency
- Communication throughout the supply chain
- Incidence of damage to goods and pilferage
- Imbalances in cargo flows
- Documentation required
- Customer co-operation

These factors can typically be categorised as either Supply Chain Efficiency Measures or Logistics Performance Measures. Parameters were chosen according to those factors that were considered as important in determining efficiency across a supply chain. The parameters are broken down into three broad categories, namely, speed, reliability and cost. This also includes determining whether these factors can be considered inputs or outputs (i.e. consumables or deliverables) of the supply chain. The list of factors from which the applicable factors that affect a specific supply chain can be selected or derived are given above. The factors selected by a specific supply chain for inclusion in the model can differ from supply chain to supply chain.

The second step involved taking a model orientated view of the supply chain by subdividing it into links and nodes. Information was collected about different performance measures that could be used to calculate the performance of each of the five links and nodes in terms of the three main parameters, and finally, measures were identified that could be used to calculate the influence that the factors identified above have on the overall efficiency of a supply chain. Generic links and nodes identified for this model are: Sources or Suppliers, Points of Production, Transportation links, Points of Storage and Transhipment and Markets or Customers.

The third step in the model involves the use of formulae to convert the factors that influence supply chain efficiency into measurements of efficiency within each link or node in the supply chain in terms of reliability efficiency, speed efficiency, and cost efficiency. These calculations will give a good indication of how the individual firms along the supply chain are performing.

The information gathered in step three is then carried forward to the final step where it is used to compare the reliability efficiency, speed efficiency and cost efficiency across the individual links or nodes in the supply chain with similar links or nodes of other supply chains using Data Envelopment Analysis (DEA) to determine the 'frontier' or most efficient supply chain (the frontier can consist of a combination of various different supply chains). Finally, each individual supply chain can be compared with the frontier in order to determine how efficient it is and where the bottlenecks occur. Figure1 shows a graphic representation of how the composite supply chain efficiency model was developed.

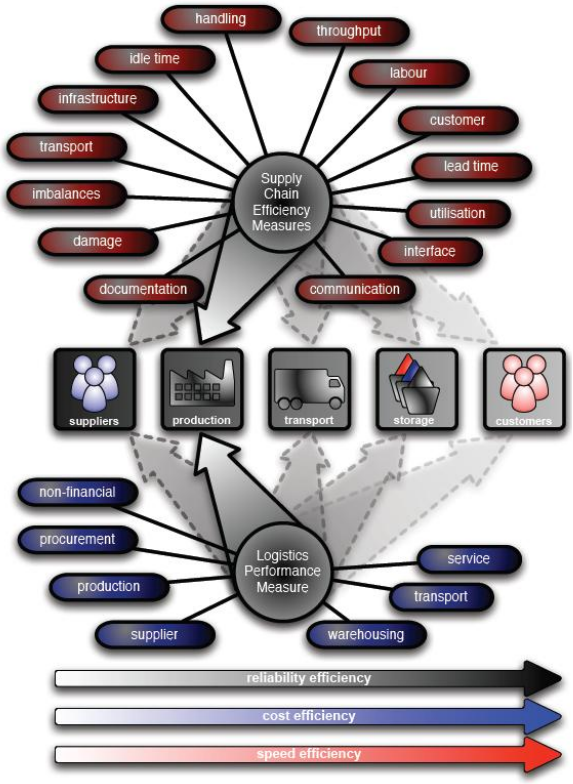

Figure 1: Graphic representation of the composite supply chain efficiency model

The generic nature of the model allows it to be used on a variety of different supply chains. If a firm finds that it wants to make changes to the input factors selected, by either including additional factors or removing some of the factors included. Depending on the focus of the supply chain under investigation, different variables can be used to calculate its efficiency. For example, for a supply chain carrying perishables products, speed is very important and therefore variables will be included to calculate the efficiency of the supply chain in terms of speed. However, for a supply chain carrying low valued bulk products speed is not important and can therefore be left out of the calculation.

It is also important to note that even though it may not be possible to compare supply chains that are exactly the same, as no two supply chains are exactly the same; benefits are still achieved by comparing supply chains with similar characteristics. For supply chains to be considered to have similar characteristics, it is important that they have three factors in common. Firstly, it is important that the supply chains have the same drivers, i.e. they must focus on the same focal points (in terms of this paper, they must arrange reliability efficiency, cost efficiency and speed efficiency in the same order of importance). Secondly, it is important that they have the same geographical context, i.e. they must all be either local supply chains or all international supply chains. Finally, the supply chains must handle goods with similar commodity characteristics, i.e. they all handle perishable products or they all handle dry bulk goods.

4. MODEL CONSTRUCTION

The mathematical technique chosen for the fourth step of the model is Data Envelopment Analysis. DEA is a mathematical programming technique that calculates the relative efficiencies of multiple DMUs based on multiple inputs and outputs (Wong and Wong 2007). DEA has been proven in various forms of academic literature as a suitable mathematical method for measuring efficiency (Seiford 1994; Bell and Morey 1995; Talluri and Sarkis 2001; Wong and Wong 2007; Wong and Wong 2008). DEA measures the relative efficiency of each DMU in comparison with all other DMUs and therefore has the ability to determine the effect that the DMU has on the overall efficiency of the supply chain under investigation. An efficiency score of a DMU is generally defined as the weighted sum of outputs divided by the weighted sum of inputs, while weights need to be assigned. The DEA model computes weights that give the highest possible relative efficiency score to a DMU while keeping the efficiency scores of all DMUs less or equal to 1 under the same set of weights (Wong and Wong 2007).

Since DEA is a form of linear programming, it follows that one of the simplest ways of solving the problem is by writing it in its canonical form.

$$Maximise\ \ z = \sum_{r=1}^{s} u_r y_{rj_0}$$

Subject to: (1)

$$\sum_{i=1}^{m} v_i x_{ij_0} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, \quad j = 1,2,...,n$$

$$u_r \ge \varepsilon,\ \ r = 1,2,...,s \quad v_i \ge \varepsilon,\ \ i = 1,2,...,m$$

In linear programming (LP) it is possible for DEA to formulate a partner linear program or LP using the same data, and the solution to either the original LP (the primal) or the partner (the dual) provides the same information about the problem being modelled. The dual model is constructed by assigning a variable (dual variable) to each constraint in the primal model and constructing a new model based on these variables (Emrouznejad 2001).

The main reason for using a dual to solve a DEA model is that the primal model has n + s + m + 1 constraints whilst the dual model has s + m constraints. As n, the number of units, is usually considerably larger than s + m, the number of inputs and outputs, it can be seen that the primal model will have many more constraints than the dual model (Emrouznejad 2001). For linear programs in general, the more constraints there are, the more difficult it is to solve the problem. The dual for equation (1) can be given as follows:

$$\theta^* = Minimise\ \theta$$

Subject to: (2)

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{ij_o} \qquad i = 1,2,...,m;$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{rj_o} \qquad r = 1,2,...,s;$$

$$\lambda_j \ge 0 \qquad j = 1,2,...,n.$$

By virtue of the dual theorem of linear programming $z^* = \theta^*$. Therefore either equation (1) or equation (2) can be used to calculate the solution. The optimal solution, θ^*, yields an efficiency score for a particular DMU. The process can be repeated for each DMU_{jo}. DMUs for which $\theta^* < 1$ are inefficient, while DMUs for which $\theta^* = 1$ are boundary points.

Some boundary points may be "weakly efficient" because they include non-zero slacks. This may result in lower confidence levels in the solutions found as alternate optima may have non-zero slacks in some solutions, but not in others. Input slacks indicate the surplus number of inputs that are being utilised by DMU_{jo} and the output slacks represent the shortfalls in the outputs of DMU_{jo}. Therefore the slacks can be used by managers to identify bottlenecks in supply chains. This problem can be avoided by rewriting equation (2) to include the slacks which are taken to their maximal values. This equation can be written as follows:

$$Maximise = \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+$$

Subject to: (3)

$$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta^* x_{ij_o} \qquad i = 1,2,...,m;$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{rj_o} \qquad r = 1,2,...,s;$$

$$\lambda_j, s_i^-, s_r^+ \geq 0 \quad \nabla i, j, r$$

where the choices of s_i^- and s_r^+ do not affect the optimal θ^* which is determined from equation (2).

According to the definition for DEA efficiency by Cooper, Seiford and Zhu (2004) the performance of DMU_{jo} is only fully (100%) efficient if and only if both (i) $\theta^*=1$ and (ii) all slacks $s_i^- = s_r^+ = 0$. The definition for weakly DEA efficient states that the performance of DMU_{jo} is weakly efficient if and only if both (i) $\theta^*=1$ and (ii) $s_i^- \neq 0$ and/or $s_r^+ \neq 0$ for some i and r in some alternate optima (Cooper, Seiford and Zhu 2004).

The variable θ gives the technical efficiency, which is what the model is trying to calculate and s_i^- and s_r^+ are the input and output slacks respectively. When DMU_{jo} is proven as either strongly or weakly DEA efficient then no further calculations are required. However, when DMU_{jo} is inefficient, appropriate adjustments (equations 4 and 5) can be applied to the inputs and outputs in order to make DMU_{jo} more efficient.

$$x'_{ij_o} = \theta^* x_{ij_o} - s_i^{-*}, \qquad i = 1,2,...,m \tag{4}$$

$$y'_{rj_o} = y_{rj_o} + s_r^{+*}, \quad r = 1,2,...,s \tag{5}$$

The dual model of the above formulation, which is also known as the envelopment model, has the ability to identify possible solutions to improve the efficiency of a DMU and in so doing highlights ways in which managers can make improvements to the supply chain. An additional convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$, can be added to equation (3) to yield a measure of the pure technical efficiency if the constant return-to-scale (Banker et al. 1984) assumption does not apply. The above model (equation (3)) is used to calculate the technical efficiency of a supply chain and can therefore be referred to as the technical efficiency model.

The next step in developing a model to measure supply chain efficiency across an entire supply chain is to minimize costs along the supply chain without reducing the level of outputs achieved. This can be calculated by the cost efficiency model shown below:

$$Minimise \sum_{i=1}^{m} c_{ij_o} x_i$$

Subject to: (6)

$$x_i \geq \sum_{j=1}^{n} x_{ij} \lambda_j \qquad i = 1,2,...,m$$

$$y_{rj_o} \leq \sum_{j=1}^{n} y_{rj} \lambda_j \qquad r = 1,2,...,s$$

where c_{ijo} is the unit cost of the input i of DMU_{jo} which may vary from one DMU to another. The total cost efficiency (CE) of the DMU_{jo} would be calculated as:

$$CE = \frac{c'_{ij_o} x'_{ij_o}}{c'_{ij_o} x_{ij_o}} \tag{7}$$

Equation 7 above can be described as the ratio of minimum cost to the observed cost. It is then possible to calculate the allocative efficiency (AE) by dividing the cost efficiency by the technical efficiency (TE) as shown in equation 8 below.

$$AE = \frac{CE}{TE} \tag{8}$$

The AE measure includes slacks which reflect an inappropriate input mix (Ferrier and Lovell 1990). This information together with the opportunity cost calculated provides important information regarding the technical and cost efficiency along a supply chain. This information can be helpful to managers as it provides them with reliable criteria on which to base their decisions for allocating resources and it helps to identify ways of ensuring that the supply chain adjusts to the changing needs of the customers.

5. MODEL VERIFICATION AND VALIDATION

The first three steps of this model are verified and validated by the fact that they can be replaced by the well-respected Balanced Scorecard method. The Balanced Scorecard method is implemented by many firms around the world. Data measured by either the first three steps of this model or the Balanced Scorecard method will give similar results.

DEA is suitable to be used as a tool for measuring supply chain efficiency because it can handle multiple inputs and outputs and it does not require unrealistic assumptions on the variables which are inherent in typical supply chain optimisation models (Wong and Wong 2007). Various sources of literature substantiate the use of DEA in measuring efficiency (Seiford 1994; Bell and Morey 1995; Talluri and Sarkis 2001).

According to the literature and experts in the field, DEA is mainly used for two different evaluation purposes. First, it can be used to compare the performance of one firm or one department with another, given the major assumptions that all firms or departments have similar strategic goals and directions (Wong and Wong 2008). Second, DEA can be used to compare the efficiency of a department or firm with historical data in order to see how it has performed over time.

DEA has the ability to compare variables with various different units and provide meaningful results. When DEA is used to compare different supply chains, i.e. competing supply chains with similar characteristics, the results obtained represent the leading supply chain as well as how the other supply chains compare (the leading supply chain is not necessarily an actual working supply chain. It can be made up of a combination of links or nodes from different supply chains). When DEA is used to compare one supply chain over time, i.e. with historical data, it indicates how the supply chain has improved or deteriorated over time.

6. ADVANTAGES OF THE MODEL

The advantages of the model include the fact that it is a generic model for measuring supply chain efficiency. It defines a framework that helps with the identification of the major links or nodes of a typical South African supply chain. The supply chain efficiency results generated by the model can be used to identify weaknesses/bottlenecks in South African supply chains. The results can also be used for the analysis of the causes of the weaknesses/bottlenecks.

An additional advantage of the method applied to this model is that it has the ability to compare individual nodes both separately and as part of an entire supply chain, i.e. a firm that wants to know how it compares to similar firms will be able to use the model as well as a firm that is looking to determine which is the most efficient supply chain.

7. EXAMPLE

The composite supply chain efficiency model was applied to the iron ore supply chain from Sishen to Saldanha to validate the robustness of the model.

The example used is an input-oriented model with variable returns to scale. It is developed as an input-oriented model, because the efficiency of the supply chain must be measured to determine whether it is achieving the current level of outputs given the minimum level of inputs. If it is possible to decrease the inputs while retaining the required level of outputs then it is operating inefficiently. Mines operate according to demand. Therefore, as the demand from customers increases, mines strive to increase their extraction. However, when demand remains unchanged, mines improve their efficiency levels by reducing the resources required to meet the output. Variable returns to scale is the best option to use, because various links and nodes in the supply chain may exhibit increasing, constant and decreasing returns to scale.

A variable in the model is classified as an input if it is a ratio used to measure resources placed into the link or node or used in its operation to achieve an output or a result. A variable in the model is classified as an output if it is a ratio used to measure the work done by the link or node. The variables used in the model were divided into categories according to the appropriate link or node. They were then further divided into subcategories to measure the efficiency of the link or node in terms of reliability efficiency, cost efficiency and speed efficiency. All variables that were classified as being either utilised in the working of the supply chain or as having an impact on the working of the supply chain were classified as inputs, while all variables that were classified as a consequence of the supply chain were classified as outputs.

7.1. Supply Chain Efficiency Measurement Software

A software tool was developed by Gerber (2009) to reduce the effort required to handle the creation and solving of the LP problem and the organising of the DEA results that are required to implement DEA. The sum of the number of variables and the number of constraints are typically the sum of the number of DMUs and the number of measurements per DMU. For this model it is more than 120, which is extremely cumbersome and error prone if done by hand.

The software makes use of standard file formats so that programs like Microsoft Excel can be used to input the data for the model analysis. Results of the analysis are also written to a standard file format so that further analysis of the results can be done in a program like Excel. The tool can also be used to determine the maximum value for the lower bound of the variable weights, giving the highest possible distinction between efficient and inefficient DMUs.

7.2. Analysis of Results

The study showed that the average efficiency of the rail leg was 97.34%, while the average efficiency of the mine and the port were 97% and 95.44% respectively. All three links or nodes performed well, which corresponds to the fact that the iron ore supply chain is one of the most efficient, if not the most efficient, supply chain in South Africa.

According to the study, the three areas on which the mine needs to focus in order to improve efficiency are system uptime (in terms of reliability efficiency), utilisation (in terms of reliability efficiency) and communication (in terms of cost efficiency). The three areas of importance for the rail operator are communication (in terms of cost efficiency), throughput efficiency (in terms of reliability efficiency) and cost per ton of iron ore transported (in terms of cost efficiency). The port needs to focus on infrastructure (in terms of cost efficiency), communication (in terms of reliability efficiency) and labour (in terms of cost efficiency). The results obtained from the composite supply chain efficiency model were compared to results obtained by an independent company who used the

Balanced Scorecard method to measure the efficiency of the Sishen-Saldanha supply chain. Similar results were obtained by both studies.

An additional factor to highlight is the fact that the supply chain was only compared with itself through the use of historical data. It would be interesting to be able to compare the Sishen-Saldanha supply chain with the Pilbara iron ore supply chain in Australia.

8. VALIDITY AND RELIABILITY

The reliability of the composite supply chain efficiency model was tested by test-retest reliability and alternative-form reliability. The test-retest realiability estimates were obtained by using the composite supply chain efficiency model to analyse the same set of data more than once and to analyse another set of generated data. Similar results were obtained from each evaluation, thus proving test-retest reliability. Alternative-form reliability was tested by comparing the results obtained by the composite supply chain efficiency model when run through the program written by Gerber (2009) with results obtained when it was run through the well-known computer program DEA-P (2003) as well as a program written for Excel by Naude (2009). Similar results were obtained in all three cases, thus proving alternative-form reliability.

The validity of the composite supply chain efficiency model was tested by content validity and concurrent validity. The content validity of the composite supply chain efficiency model was proven, because the variables included in the model were chosen based on a literature review as well as interviews that were conducted with business executives who work with supply chains on a daily basis and who are aware of the main problems that are being faced by South African supply chains. Concurrent validity of the composite supply chain efficiency model was proven when feedback was given to the firms that were involved in the case study and they agreed with the results that were obtained.

9. CONCLUSIONS

The composite supply chain efficiency model is a simple to use, systematic and inexpensive and can therefore be utilized by small firms with a limited budget. Its generic nature means that it can be used to measure supply chain efficiency across various different types of supply chains. It can either be used to compare different supply chains or it can be used to compare the same supply chain over time to determine whether any improvements have been made. It can be applied to South African supply chains handling a wide variety of products that are either local or export oriented, to determine whether they are operating efficiently or not. The results obtained from the composite supply chain efficiency model are easy to understand and can therefore help firms and entire supply chains identify areas to focus on to improve their overall levels of efficiency and in so doing make them more competitive.

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A CAR SHARING SYSTEM FOR URBAN AREAS WITH FULLY AUTOMATED PERSONAL VEHICLES

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ABSTRACT
The paper concerns a transport system for pedestrian areas, based on a fleet of fully-automated Personal Intelligent Accessible Vehicles (PICAVs). Vehicles are available in stations and are shared through the day by different users. The following specific services are provided: instant access, open ended reservation and one way trips. All these features provide users with high flexibility, but create a problem of uneven distribution of vehicles between the stations. Therefore, relocation must be performed. A management strategy based on fully automated vehicles is proposed. To check the performance of the proposed management strategy, an object-oriented simulator has been developed. The simulator gives as an output the transport system performance, in terms of Level Of Service provided to users and of efficiency from the management point of view. The proposed transport system has been simulated for the historical city centre of Genoa, Italy.

Keywords: fully automated personal vehicles, automatic relocation, micro simulation.

1. INTRODUCTION
The paper concerns a new transport system, which is meant to ensure accessibility for all people in urban pedestrian environments. The research has been carried out within the PICAV project founded by the European commission (SST-2008-RTD-1). The project involves a new Personal Intelligent City Accessible Vehicle (PICAV) and a new transport system that integrates a homogeneous fleet of PICAV units.

The PICAV unit is a one person vehicle that is meant to ensure accessibility for everybody and some of its features are specifically designed for people whose mobility is restricted for different reasons, particularly (but not only) elderly and disabled people. Ergonomics, comfort, stability, assisted driving, eco-sustainability, parking and mobility dexterity as well as vehicle/infrastructures and intelligent networking are the main drivers of the PICAV design. The single units are networked and can communicate with each other, with the city infrastructure and with public transport in the surrounding area, which allows for a high level of inter-modal integration.

The PICAV transport system is a new multimodal shared use vehicle system for urban pedestrian environments. Stations are distributed at different locations throughout an area, and vehicle trips can be made between different locations. The PICAV vehicles can be rented for short term periods (usually a couple of hours at a time, with the latest return time being the end of the day). People commute into the city, reach the pedestrian area border by public or individual transport modes, jump in a PICAV vehicle, visit attractions (shops, monuments, museums) in the pedestrian area and drop the vehicle off at any PICAV station.

The PICAV transport system will provide high flexibility for users. However, the system will be prone to becoming imbalanced with respect with the number of vehicles at the multiple stations. Due to uneven demand, some stations during the day may end up with an excess of vehicles whereas other stations may end up with none.

One way trips, open ended reservation and instant access are the main characteristics of new car-sharing systems. For these systems, according to the literature, the two main categories of relocation strategies are user-based and operator-based, with some systems using a mixture of both. Operator-based relocation strategies resolve the balance problem through a strategy where some operators manually relocate a vehicle or a platoon of vehicles from stations having too many vehicles to stations having too few vehicles. Several transport systems of this type have been realized, for example the Coachella Valley in California (Barth and Todd, 1999), near Palm Spring's airport, the two CarLink experiences, and IntelliShare, established at RiverSide University campus, the Praxitèle in Paris, the Honda ICVS in Singapore, then also CarLink I and CarLink II.

User-based relocation strategies ensure that at least part on the relocations are performed by the transport system users. The most important issue regarding the user-based strategies is the possibility of giving users some incentives, such as a reduction in prices, in order make them improve the transport system performance.

A transport system of this type has been implemented in the city of Ulm (Firnkorn and Müller, 2011). A fully user-based relocation strategy has been proposed by Cepolina et al. (2010): a system supervisor is in charge of addressing at least part of the PICAV users (flexible users) to specific stations where they have to return the PICAV units. This management strategy is suitable when users reach the intervention area by public transport and then have alternative locations from which they can get a public transport service to return home. The system supervisor makes their decision knowing real time information about the traffic conditions, i.e. the number of vehicles available, the length of queues and waiting times at each parking lot and also the choice set of destination parking lots the user is happy to return their vehicle to.

The performance of a relocation strategy is generally assessed as a function of users waiting times and number of relocations. For the operator-based strategies, an optimization procedure has been proposed by Kek et al. (2007) for assessing the staff strength and the shift hours which maximize the system performance. For the fully user-based strategies, a procedure for finding the fleet dimension and its distribution among the stations that maximize the system performance has been proposed by Cepolina and Farina (2011a). Several authors, such as Shaheen et al. (2009) focus on modal split issues: the capability of these new transport systems to attract users from private transport modes. An overview about existing shared vehicle systems, with a particular focus on vehicles relocation techniques, has been performed by Cepolina and Farina (2011b).

The level of automation of car-sharing vehicles is increasing so rapidly that a fully vehicle based relocation strategy will soon be possible. In this paper a fully vehicle based relocation strategy is proposed: instead of having people that manually relocate a vehicle or a platoon of vehicles, vehicles automatically relocate among the stations. This removes the need of operators and also eliminates any constraint on users. In the transport system proposed in this paper the users decide to which parking lot they return the PICAVs and are not restricted in this choice by a system supervisor.

The paper is organised as follows: Section 2 describes the proposed transport system. Section 3 outlines the architecture of the transport system microscopic simulator. Section 4 describes the model implemented for the historical city centre in Genoa, Italy. Major conclusions and future work follow.

2. MAIN CHARACTERISTICS OF THE PROPOSED TRANSPORT SYSTEM

2.1. The user trips

We consider only visits to the urban pedestrian area during a day, therefore the number of users that enters the area during a day equals the number of people that exits the area in the same day.

If during a trip the PICAV user makes a stop that lasts more than 1h, the PICAV unit will need to be parked in a station. If the stop duration is less than or equal to 1h short-term parking along the street is permitted and the PICAV unit does not need to be returned to a station.

In the area of study we identified stations for the PICAV units. Trips by PICAV units begin (source) and end (sink) in these stations. Generally speaking, the trip between two stations could be travel single trip on board the PICAV unit or a sequence of trips on board with activities that require short term parking along the street. We take into account only visits to the pedestrian area and we consider only the following three types of trips in the pedestrian area:

Type A is a multi-task trip, the PICAV user has a sequence of short term activities to perform in the pedestrian area. The user arrives on the pedestrian area border, they pick-up a PICAV unit, they make an activity travel pattern , which comprises of a number of short term activities (like shopping, visits to: banks, post office, etc.) within the pedestrian area, they then return the PICAV unit in a PICAV parking lot and they go back home again.

Type B is a single-task trip, the PICAV user has to perform an activity that requires a long rest in the pedestrian area. The user arrives on the pedestrian area border, they pick-up a PICAV unit, and go to the PICAV parking lot closest to their activity place where they return the PICAV unit and they reach the activity by foot.

Type C is the return part of the single-task trip, the PICAV user has finished their activity within the pedestrian area and would like to go back home. The user thus goes by foot to the PICAV parking lot closest to their activity place, they pick-up a PICAV unit, they return the PICAV unit to the pedestrian area border in a parking lot and go back home again.

If the user reached the pedestrian area by a private mode, their overall trip in the pedestrian area is a round trip. If the trip is of type A, the origin and destination will coincide. If the trip is a single task trip, the origin of a type B trip coincides with the destination of the related type C trip.

If the user reached the pedestrian area by public transport, their overall trips in the pedestrian area could be one way trips: they may exit the area from a different point from the one they entered the area.

2.2. The PICAV vehicle

A PICAV vehicle is about 0.8 m wide and 1.1 m long. A draft idea of the vehicle is shown in figure 1. Its net weight is about 250 Kg.

The PICAV vehicle will be provided with a clean efficient power module to ensure greenhouse emissions are below the targets set in the Kyoto agreement and Euro V. This will be done by regenerating braking energy and using it to supplement the batteries and by targeting the conversion efficiency of standard electric vehicles to obtain a satisfactory power system for very small vehicles in the pedestrian environment.

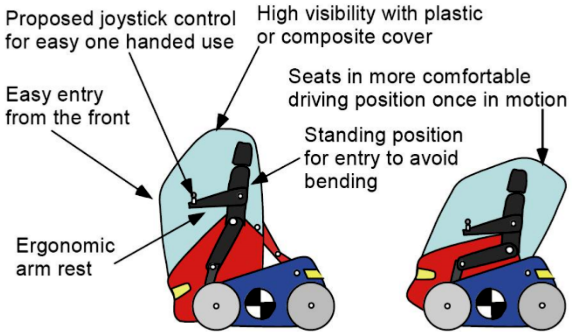

Figure 1: The PICAV vehicle characteristics

The power system is in charge of supplying the energy for traction and electric and/or electronic devices. In the configuration of energy accumulators that we take into account there are two batteries: one dedicated to traction and the other one dedicated to electric and electronic devices.

As it concerns the battery for traction, a lithium-ion battery has been selected in a first scenario by MAZEL (2011). The characteristics of the cell are: Specific Energy:132 Wh/Kg; Energy density: 345 Wh/l; Total Energy: 1000,00 Wh; Net Weight: 8,33 Kg; cell capacity: 20 Ah. A battery pack formed of 18 cells has been selected for simulation.

The PICAV units are able to recharge when they are idle at stations.

The battery discharging law depends on: the average up and down slopes of the path, the PICAV speed, the air density, the PICAV frontal area, the aerodynamic and rolling coefficients, the mechanical and electrical efficiency, the motor voltage and the overall weight of the vehicle.

A normal charging process has been considered. The battery charging law depends on: initial charging level, the final charging level and balancing time.

The PICAV unit can be fully user driven, its control system can provide driving assistance or the unit can automatically move thanks to the sensors and control techniques. Sensors and control techniques are being developed by INRIA, Ronquecourt, Versailles.

The PICAV speed is a function of pedestrian density on the street. It is envisaged that the PICAV will move more quickly when driven by the user compared with when it travels in a fully automatic way. Herewith are reported the two relationships between the PICAV speeds and pedestrian density depending on driving mode. The two equations are:

PICAV user driven:

$$v = - 1.44677 \cdot K + 1.57751 \quad (1)$$

PICAV automatically driven:

$$v = - 1.44677 \cdot K + 1.37751 \quad (2)$$

Where:

v = PICAV speed [m/s]

K = pedestrian density [ped/m^2]

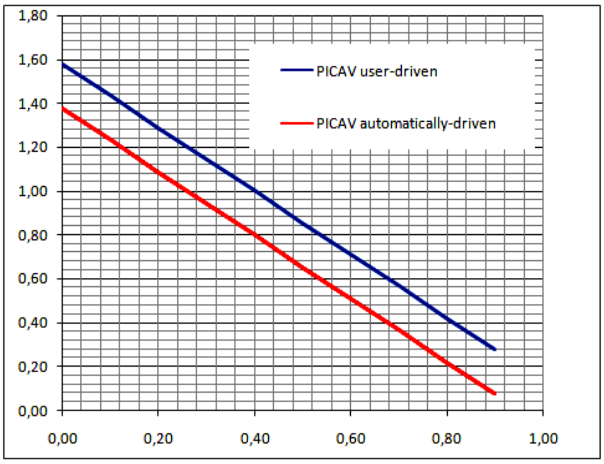

Figure 2: PICAV speeds against pedestrian density

In the case of a user driven PICAV, its speed-density relationship is the result of a linear regression performed on empirical data (Holloway et al. 2011). If PICAV travels in a fully automatic way, we will assume a lower speed. However this speed is not the one allowed by the current technologies but it is a speed close to the pedestrian one that therefore allows the PICAV motion to disturb as less as possible pedestrian flows. Therefore the proposed transport system could be implemented only in a next future when technologies will be further developed.

2.3. The management strategy

Characteristics of the PICAV transport system are: open ended reservation, instant access and one-way trips. The main problem of the proposed transport system is that it may quickly become imbalanced with respect to the number of vehicles at the multiple stations. Due to uneven demand, some stations during the day may end up with an excess of vehicles whereas other stations may end up with none.

When relocations are required, a system Supervisor has the duty to redirect unused vehicles from a station to another, according to the system needs and the actual waiting times at the stations. According with the Supervisor hints, PICAV vehicles automatically relocate themselves, thanks to their high level of automation.

A relocation is required when a critical situation occurs. A critical situation occurs when the number of vehicles in a given station at a given time instant goes below the station’s critical threshold. This situation is referred as ZVT, i.e. zero vehicle time (Kek et al. 2005). When this condition occurs, the station has a shortage of vehicles and some users may need to queue. When a queue forms a request for a vehicle is generated. The critical threshold could be assumed constant in time or a function of time.

When a ZVT situation takes place, the system Supervisor addresses the vehicle request only to stations where the number of vehicles is above the low buffer threshold. According with Kek et al. (2005) the low buffer threshold is the minimum number of vehicles that a station needs to have in order to be able to send vehicles.

Among the stations to which the vehicle request could be addressed, the providing station will be selected by the system Supervisor according to two criteria: the closest station (shortest time criterion) and the station having the highest number of vehicles (inventory balancing). The shortest time criterion relates mainly to service levels, while the inventory balancing mainly focuses on cost efficiency. Therefore, an appropriate choice of relocation technique should be made according to the current system situation.

3. THE MICRO SIMULATOR

The simulator is written in Python language and it follows an object – oriented logic. The simulator receives in input the transport demand, the characteristics of the network, the relocation strategy and the PICAV fleet.

Each run of the simulator represents a day. The simulator allows to track the second-by-second activity of each PICAV user, as well as the second-by-second activity of each vehicle.

The simulator gives in output the transport system performances, in terms of Level Of Service provided to users and in terms of efficiency from the management point of view.

3.1. Input data

3.1.1. The transport demand

The transport demand is given to the simulator in the form of OD matrices. Rows and columns in the OD matrix represent stations; each cell gives the hourly number of trips from the station the row refers to to the station the column refers to. Each OD matrix refers to a specific type of trip (A, B and C). The day has been divided in time periods. In each time period the transport demand has been assumed constant. If n is the number of time periods within one day, the transport demand is represented by $3\text{x}n$ OD matrices, one for each type of trip and for each period of the day. The time at which a user arrives on the area border is generated randomly, accordingly with the OD matrixes.

3.1.2. The road network

The road network is defined by: the position of each station and the most used path for each pair of stations. For the paths, we are interested in the overall length, the average up and down slope and average pedestrian density in the different periods of the day. The average pedestrian density on a given path in a given period of the day allows one to assess the average speed at which the PICAV vehicle is able to move on the path. The average slope and average speed allows one to accurately simulate the battery discharging process.

Paths are created in Google Maps and imported into Google Earth where the elevation profiles of the paths are viewed and inspected visually to determine upslope, flat and downslope sections. For each path the total distance of that path and the average slope needs to be assessed. Distances, average slope and densities are given as data input in the simulator in the form of matrixes.

3.1.3. The PICAV fleet

The PICAV fleet is described by: the fleet dimension, the number of PICAV units at each station at the beginning of the day, the battery capacity, the charging and discharging laws.

The battery charging technique is the *opportunity charging*. The term opportunity charging refers to the charging of the batteries wherever and whenever power is available. Simply put, rather than waiting for the battery to be completely discharged, or for the duty cycle or work shift to be over, opportunity charging is the “power as you go” opportunity to extend the capabilities of your equipment during every stop in a station. If in a station a vehicle is charging and its current battery level is above the threshold of 10% and a user arrives or a relocation is required, the vehicle stops the charging process and becomes available either to the user or to be relocated.

3.1.4. The relocation strategy

The relocation strategy is described by two vectors. Their dimension equals the number of stations in the area, the value of each vector component is the station’s critical threshold for the first vector and the station’s low buffer threshold for the second vector. The transport system performance is considerably affected by these two vectors, therefore their values should be carefully selected. The authors are working on defining a methodology for their optimisation.

In periods of low usage, the most appropriate relocation technique is by inventory balancing. In periods of high usage, then the shortest time technique performs best.

3.2. Output data

3.2.1. Level of Service (LOS)

LOS measurement are assessed based on the statistical distribution of wait times. Castangia and Guala (2011) proposed a new LOS measurement scale using as reference the average waiting time of the 50^{th}, 90^{th} and 95^{th} percentile of users at stations.

3.2.2. Efficiency

From the management point of view, the transport system efficiency is inversely proportional to the PICAV fleet dimension and the number of required relocations. Another measure of the system efficiency is the ratio between number of PICAV available or occupied by users at each time instant and the PICAV fleet dimension.

4. A STUDY CASE

The proposed transport system has been planned and simulated for the historical city centre of Genoa, Italy. The historical city centre of Genoa has an area of about 1,13 km^2 and it is a pedestrian area.

The localizations of: bus stops, underground stations and car sharing parking lots have been identified. We have identified as well the localization of hotels, museum, offices, schools and commercial activities (food shops, clothe shops, handicraft shops and other shops). We designed 9 stations: 2 internal to the area (parking lots n. 10 and 11) and 7 on the area border (parking lots n. 1,2,3,4,5,6,7).

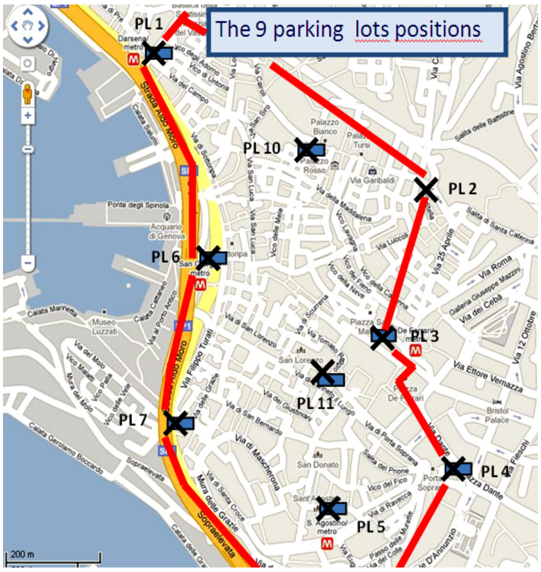

Figure 3: The intervention area and the parking lot positions

From the data collected in the field (Cepolina 2010), an off-peak period in the morning (starting at 8 a.m. until 4 p.m.) and a peak period in the afternoon (from 4 p.m. to 8 p.m.) were identified. The peak transport demand is almost 1.5 times the off-peak demand.

We assume that 1% of the people that currently enter the historical city centre by foot will use the PICAV transport system. The overall PICAV travel demand in the reference day is 1060 users. The OD matrices in the off peak period are reported in figure 4 for the different types of trips. From the data collected in the field (Cepolina 2010) it was found that 55% of the people exiting the historical city centre, perform a single trip (Type B) while 45% perform a multi task trip (Type A). The OD matrices in the off peak period are shown in figure 4.

The most used path for each pair of stations have been identified via Google Maps and imported into Google Earth where the elevation profiles of the paths were viewed and inspected visually to determine upslope, flat and downslope sections. An example of a path is reported in figure 5 and in table 1 the data from each of these paths are summarised.

OD - type A off-peak period

	1	2	3	4	5	6	7
1	0	1	2	1	1	1	0
2	1	0	0	0	1	1	0
3	1	0	0	0	2	1	0
4	1	0	0	0	1	1	0
5	1	1	2	2	0	1	0
6	1	1	2	1	1	0	0
7	0	0	1	1	0	0	0

OD - type C off-peak period

	1	2	3	4	5	6	7
1	0	0	1	1	1	0	0
2	1	0	0	0	1	1	0
3	1	0	0	0	1	1	0
4	0	0	0	0	1	0	0
5	0	0	1	1	0	0	0
6	1	1	2	2	1	0	0
7	0	0	1	1	0	0	0
10	1	1	3	3	1	1	0
11	1	1	3	2	1	1	0

OD - type B off-peak period

	1	2	3	4	5	6	7	10	11
1	0	1	1	0	0	1	0	1	1
2	0	0	0	0	0	1	0	1	1
3	1	0	0	0	1	2	1	3	2
4	1	0	0	0	0	1	1	3	2
5	0	1	1	0	0	1	0	2	1
6	0	1	1	0	0	0	0	2	1
7	0	0	0	0	0	0	0	1	0

Figure 4: OD matrices (hourly number of trips) in the off peak period

Figure 5: Test route, going from Darsena metro to Piazza de Ferrari.

For assessing average pedestrian density in the different periods of the day, we recorded by video cameras pedestrian flows in Via san Luca in different periods of a day (Holloway et al. 2011) . According with the data collected in the field, we found an average pedestrian density of 0.15 ped/m^2 in the off-peak period and 0.35 ped/m^2 in the peak period in Via San Luca. For the current simulation we assumed these densities are the same for all paths in the area.

For the PICAV fleet, we considered 100 PICAV units. This fleet dimension seems reasonable since it is in accordance with the outcomes from the Barth and Todd's research (Barth and Todd 1999). Barth and Todd found that for all the various travel demand cases they analysed, the best number of vehicles to place in the system ranges from 3 vehicles per 100 trips to 6 vehicles per 100 trips. We have 1644 trips per day. This number of trips results from the overall PICAV travel demand, which consists of 1060 users. 45% of these users (i.e. 477 users) make 477 Type A trips whilst the other 55% (i.e. 583 users) make 583 Type B trips plus the return way trips (Type C trips), i.e. other 583 trips. A fleet dimension of 100 for 1644 trips gives 6.08 vehicles per 100 trips.

Table 1: Lengths and gradients of some routes between stations

Origin	Desti-nation	Total Distance [m]	Up [m]	Down [m]	Flat [m]	Up Slope [%]	Dn Slope [%]
1	2	1060.00	805.60	247.50	0.00	3.87	-2.88
1	3	976.00	717.80	258.00	0.00	3.97	-3.67
1	4	1200.00	911.00	323.00	0.00	3.99	-2.94
1	5	1400.00	682.00	719.00	0.00	4.18	-3.51
1	6	604.00	319.90	285.80	0.00	5.27	-7.17
1	7	1100.00	589.50	492.90	0.00	3.89	-5.03
1	8	489.00	408.70	77.40	0.00	6.63	-3.90
1	9	1060.00	762.30	290.90	0.00	3.71	-2.67
2	3	316.00	28.96	287.00	0.00	9.17	-2.06
2	4	846.00	611.90	233.71	0.00	2.61	-3.89
2	5	1180.00	660.70	517.00	0.00	2.52	-3.33
2	6	732.00	264.30	465.75	0.00	2.82	-4.99
2	7	1100.00	144.80	451.00	308.00	15.07	-5.75
2	8	489.00	310.50	177.76	0.00	7.35	-9.09
2	9	747.00	341.80	405.03	0.00	4.68	-4.47
3	4	414.00	255.51	158.30	0.00	6.25	-4.44
3	5	516.00	264.50	250.10	0.00	13.67	-13.4
3	6	569.00	146.90	417.10	0.00	2.97	-4.76
3	7	829.00	437.29	386.00	0.00	4.28	-6.39
3	8	563.00	399.10	163.60	0.00	6.89	-9.68
3	9	326.00	174.01	152.30	0.00	4.79	-6.28
4	5	481.00	309.06	171.80	0.00	5.68	-11.4
4	6	848.00	219.80	476.00	149.00	2.22	-6.81
4	7	1080.00	558.76	518.00	0.00	2.87	-8.28
4	8	866.00	435.80	429.96	0.00	3.48	-4.37
4	9	379.00	248.50	130.17	0.00	3.98	-11.6
5	6	834.00	231.90	603.20	0.00	4.10	-5.30
5	7	804.00	269.20	531.94	0.00	5.22	-7.11
5	8	1050.00	440.50	606.50	0.00	4.29	-3.72
5	9	372.00	210.60	160.26	0.00	6.52	-9.55

The proportion of vehicles in each station at the beginning of the day is shown in table 2 . This initial distribution was established from the fleet optimisation procedure carried out by Cepolina and Farina (Cepolina and Farina 2011a) for the same case study, however, in that research a fully user-based relocation strategy was used.

As it concerns the relocation strategy, the critical thresholds and low buffer thresholds are reported in table 3. The relocation technique used is the shortest time technique.

Table 2: The proportion of vehicles in each station at the beginning of the day

station n°	1	2	3	4	5	6	7	10	11
n° of Picav units	11	12	13	13	14	10	9	9	9

Table 3: Critical thresholds and low buffer thresholds for the stations

Station n°	1	2	3	4	5	6	7	10	11
critical threshold	2	2	2	2	2	2	2	2	2
low buffer threshold	4	4	4	4	4	4	4	4	4

The performance of the proposed car sharing system for the case study of Genoa has been assessed by simulation.

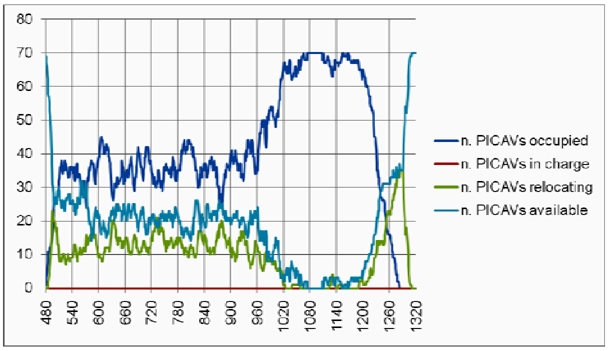

Fig. 6 number of PICAVs in each state against time

As it concerns the transport system efficiency, in figure 6 the number of PICAVs is each state (occupied by users, available, in charge and relocating) is plotted against time: the time is expressed in minutes starting from midnight, therefore a time of 480 refers to 8a.m, a time of 960 refers to 4p.m. and a time of 1200 refers to 8p.m.

At least 70% of the fleet is available to users (occupied by users or available at stations) in all the simulated period. As it concerns the power system, all the vehicles do not reach a battery level below the 10% threshold: therefore when they are at stations, they are always available to users. As it concerns the management strategy, in the peak period, the maximum number of vehicles simultaneously allocated is 9. The number of performed relocations was 531. This means that the proposed transport system works quite well from the management point of view.

According with Castangia and Guala (2011), the Level Of Service (LOS) provided is between LOS C and D. In fact, the average wait time of the 50th, 90th and 95th percentile of users result equal to 0s, 180s and 420s respectively.

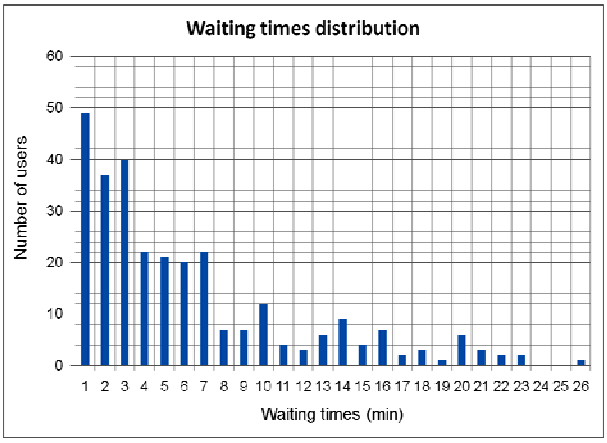

Fig. 7 waiting times distribution

According to the simulation results, a specific LOS can be attributed to each station. The following table shows the LOS assessment.

Table 4: The LOS assessment.

	Wait time (s) at stations			LOS
Station ID	50^{th} percentile	90^{th} percentile	95^{th} percentile	
1	0	60	180	B
2	0	0	0	A
3	0	60	120	A/B
4	0	120	300	B/C
5	0	300	540	D/E
6	0	420	480	D/E
7	0	1380	1560	F
10	0	120	360	C
11	0	600	1140	F

5. CONCLUSIONS AND FUTURE WORK

A new operator-based shared vehicle system is proposed in this paper. In this shared system vehicles are fully automated, they are able to travel without being driven by a user, therefore they can automatically relocate among the stations, according to the station's needs. This transport system is simulated through an object – oriented logic, and the characteristics of the roads, their degree of crowd, the transport demand are the simulator inputs. The simulator follows each user and each vehicle within the simulation period, and gives the distribution of waiting times and the number of vehicles available at each parking lot in each simulation time instant. Therefore, the transport system performance can be assessed.

As stated before, vehicles are available only at specific stations, this is despite the fact that capillarity (i.e. the possibility that vehicles are available also along the roads), is a very good way to satisfy better user demand. As stated in the work by Ciari et al. (2007), the capillarity is a key way to ensure a high level of user satisfaction. Therefore, a new transport system where vehicles are available along the roads should be investigated in future studies. In this scenario, users may book, require and check-in vehicles of the system via a cellular GPRS technique, the overall system management would then identify a user actual position and deliver them a shared vehicle, or also tells them the position of the nearest vehicle . Then, as users trips are performed, they can leave the vehicles at any position within the intervention area. This new kind of transport system may be the topic of further research.

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INTELLIGENT SUPERVISION OF AUTONOMOUS HEAVY VEHICLES: APPLICATION TO MARITIME AREA

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ABSTRACT

There is a strong need to improve the efficiency of existing transport infrastructure of seaport in North West Europe. One of the solutions would be to integrate intelligent transportation systems allowing the transportation of goods in the internal traffic of the seaport. However, the design of intelligent and autonomous vehicles integrates the definition of fault detection and localization algorithms and strategies of control reconfiguration. The ultimate objective of our work is to design a supervision system representing the management of the operating modes and giving the conditions for reconfiguration of an autonomous system, in real time. Then, a co-simulation is done on a platoon of Intelligent and Autonomous Vehicles (IAVs) inside seaport terminal in the framework of the European project InTraDE (Intelligent Transportation for Dynamic Environment).

Keywords: Intelligent transportation system, maritime logistics, supervision, Bond Graph, self-diagnosis, intelligent and autonomous vehicle.

1. INTRODUCTION

Innovation is an important factor for maintaining the development of logistics industry. There is a strong need to improve the efficiency of existing transport infrastructure in North West Europe. The construction and implementation of intelligent transportation systems (DeLaurentis 2005) will be a key factor in this development.

Because the ports are of primary importance for regional and national economies, the introduction of intelligent transportation systems (ITS) in their dynamic environment is an essential necessity to improve their economic competitiveness and efficiency.

The main problem of the development in the ports and terminals of some North West European area depends on the internal traffic management and space optimization inside a confined space. A solution was proposed for a selection of major ports such as Rotterdam, Düsseldorf and Hamburg, to automate the handling of goods using automatic guided vehicles (AGV). This solution has resolved some relative internal traffic issues, although it has highlighted several limitations.

Thus, the vehicles will adapt to the infrastructure rather than the reverse. The proposed solution consists in automating the routing of goods using automated guided vehicles (AGV). This solution was able to manage one way traffic, but it has several internal structural limitations. Thus, the European project InTraDE (http://www.intrade-nwe.eu) contributes in the improvement of internal traffic management, the optimization of space and the development of a clean and safe intelligent transportation system in order to adapt the considered environment. This ITS should be transferable on different sizes of port terminals. This transportation system operates in parallel with Virtual simulation software SCANER Studio allowing robust and online supervision.

The ultimate objective of this work is to design a supervision system representing the management of the operating modes and giving the conditions for several possible reconfigurations by using functional and behavioral models. The intelligent and autonomous vehicles (IAVs) should be able to transport goods from one specific place to another in both normal and degraded functioning by using global reconfiguration strategies which will be detailed in this paper and the simulation of the faulty scenario is done by using SCANNER Studio software which represents the supervision system.

2. SUPERVISION STRATEGY:

The main tasks considered in the supervision strategy are the fault diagnosis and the reconfiguration.

2.1. Fault Diagnosis:

The objective of a self-diagnosis system is to diagnose the states of devices mounted in the vehicle when a fault occurs. To achieve this purpose, we use fault detection and isolation procedures based on functional and behavioral models of the vehicle. After detecting and isolating of a fault, a reconfiguration strategy is applied to a vehicle operating in a platoon (Rajamani, Howell, Chieh, Hedrick, and Tomizuka 2001). A platoon is a set of independent and interconnected IAVs structured in leader-follower (Wang, Pham, Low, and Tan 2006). The IAV, called RobuTainer (Figure 1), is a 4 x 4 decentralized multi inputs multi outputs system (Merzouki, Medjaher, Djeziri, and Ould-Bouamama 2007). It contains a real time monitoring system, makes it possible to detect and isolate the actuator and sensor faults.

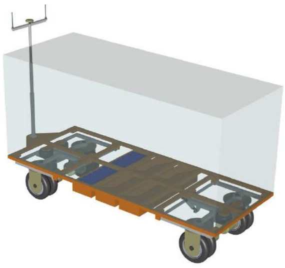

Figure 1: RobuTainer

2.1.1. Functional Model:

So, let us consider at first the case of a supervision system of low level decomposition by taking as illustration the electrical wheel motor for which the main objective is to give mechanical torque to the wheel. The realization of this objective requires many services such as the generation of an electrical power, the conversion of the electrical power to a mechanical one, the transmission of the mechanical energy to the tire and a measurement service required to control the motor in closed loop. These services can be decomposed as shown in Figure 2.

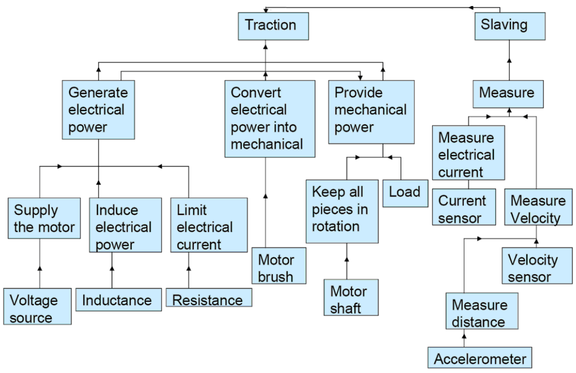

Figure 2: Hierarchical functional decomposition

The elementary components, such as the electrical resistance R, the electrical inductance L and so on, allowing the services realization are also shown by this functional decomposition. The latter is built from the interconnection of different components. The interconnections are taken into account by considering higher level components which aggregate lower level ones. Sensors, actuators, process components are at the (lowest) field-level. They are named elementary components and provide elementary services. The highest level of aggregation corresponds to the overall system and its objectives.

This figure shows that the evaluation of the potential for the system to achieve its objectives rests on the evaluation of the potential for the components of lower-level to provide their associated services. This service availability evaluation requires a physical and behavioral description (Venkatasubramanian, Rengaswamy, Yin, and Kavuri, 2003)

The Bond Graph (Merzouki, Djeziri, and Ould-Bouamama 2009) tool by associating each service with a behavioral equation is a well suited to quantify the availability of services by indicators of faults directly related to a technological component.

2.1.2. Behavioral model:

The description of the behavioral model of the system is done by The Bond Graph which is a graphical representation of the physical effects and their interactions in a physical system (Staroswiecki, and Gehin 2001). It is consistent with the first principle of energy conservation. It is a multidisciplinary approach. In addition, its structural and causal properties can be exploited to generate systematically faults indicators directly associated with the components. To each elementary service, a Bond Graph element can be associated as shown by Table 1.

Table 1: Elementary components of each service of the DC motor

N	Services	BG elements
1	Measure velocity	Df_2
2	Generate electrical power	$R:R_A; I:L_A; MS_e$
3	Provide mechanical power	$R:F_m; I:J_m; S_e:Ch$
4	Convert electrical power into mechanical	GY
5	Measure acceleration	Df_3
6	Measure current	Df_1
7	Keep all the pieces in rotation	$R:F_m; I:J_m$
8	Limit the electrical current	$R:R_A$
9	Induce an electrical current	$L:L_A$
10	Maintain	-

The Bond Graph Model is then built (Figure 3). It details the realization of the service of traction given by the motor itself. It can be split into several parts corresponding to services of lower levels. Then, we use a software graph analysis tool FDIpad to generate the residuals from the Bond Graph Model. The residuals allow to build the fault signature matrix which permits to show whose faults are detectable and isolable by analyzing the independent lines of the matrix. The three following residuals are found in our case:

$$R_1: -I\frac{dDf_2}{dt} - f_e.Df_e + Se_2 + Df_1.R = 0$$

$$R_2: Se - R.Df_1 - I\frac{dDf_1}{dt} - K_e.Df_2 = 0$$

$$R_3: Df_2 - Df_3 = 0$$

The fault signature matrix derives directly from the generated residuals. It is given in Table 2.

Table 2: Fault signature matrix of DC motor

BG Els	Components	M_b	I_b	R_2	R_2	R_3	V
Se_2	Load	1	0	0	1	0	V_1
Se	Voltage source	1	0	1	0	0	V_2
Df_1	Current sensor	1	0	1	1	0	V_3
Df_2	Velocity sensor1	1	1	1	1	1	V_4
Df_3	Velocity sensor2	1	1	0	0	1	V_5
R	Resistance	1	0	1	0	0	V_2
L	Inductance	1	0	1	0	0	V_2
GY	Gyrator	1	0	1	1	0	V_3
Fm	Friction	1	0	0	1	0	V_1
Im	Inertia	1	0	0	1	0	V_1
-		0	0	0	0	0	V_6

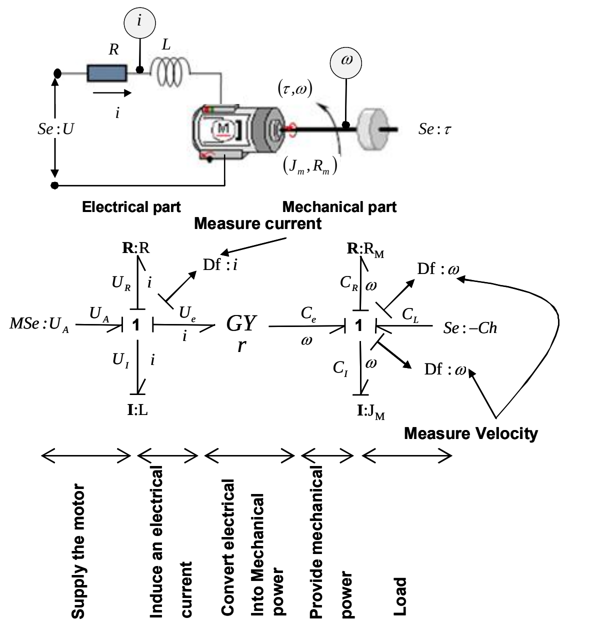

Figure 3: Association between Functional Model and Bond Graph model (Behavioral Model)

The lines V_4, V_5, which are different for the other lines, show that speed sensor failures are detectable and isolable. This fault isolation is provided by the hardware redundancy of the speed sensors. The three lines noted V_1 are identical. This means that the fault cannot be isolated between the part load and the motor shaft. But as these two parts are implied in the realization of the same service: ¢provide mechanical power¢, this allows to conclude about the unavailability of this service when the signature corresponding to the line V_1 is observed. Nevertheless, for the signature corresponding to V_3, the unavailability may refer either to the conversion service or on the current measurement service. Without additional information, the fault cannot be isolate. Probabilistic approaches related to the failure rate may help in decision-making.

2.2. Fault Diagnosis:

The management of the operating mode is represented by a finite automaton as seen in Figure 4.

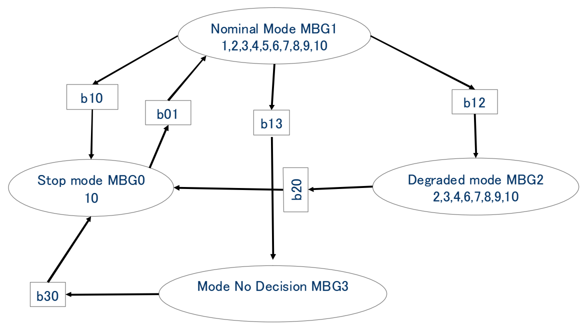

Figure 4: Finite automate describing the management of operating modes

Each operating mode, corresponding to a graph node, is associated with a set of services, and is defined by a single Bond Graph model. The service availability (associated to the Bond Graph elements) and the conditions of passage from one mode to another are analyzed by faults detection and isolation algorithms generated on the basis of the structural and causal properties of the bond graph tool. The reconfiguration is described by different operating mode as shown in the finite automate.

Initially, the system is in nominal mode and remains there while all services are available. If the velocity sensor fails (i.e. signature V_4 is observed) then the system goes into the degraded mode MBG2. If the signature V_1 is observed, the system switches to MBG0 because whatever the failure, the service ¢provide mechanical power¢ is no longer available. If the signature V_3 is observed, then the system switches to MBG3 where the operator must intervene to evaluate the criticality of the failure. The reconfiguration is activated when a fault is detected and isolated as described before. This leads to a new reconfigured mode of the Platoon. In the case of degraded mode, a reconfiguration strategy should be applied on the platoon as seen in the next section.

3. SIMULATION RESULTS

The simulation is realized on SCANeR studio (http://www.oktal.fr). This latter is a dynamic and real time simulator which will be used to supervise the platoon by bilateral teleoperation.

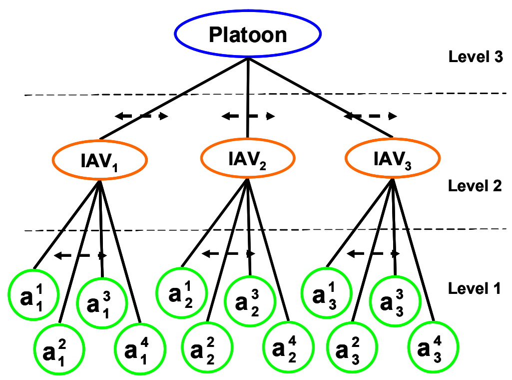

Figure 5: Platoon in normal operating mode

Let us consider that the platoon is in normal operating mode (Figure 5). The maximal detected inter-distance between IAVs is 10 m. To avoid collision, each IAV needs to respect the safety inter-distance of 2 m.

We suppose that at time 13 s, faults occur on the applied voltage efforts and on the current Inputs of the 1st and 3rd actuators for the 2nd IAV. The low monitoring level detects the faults at 15 s, and then isolates the faulty system by using the multi model approach described before at 18.5 s.

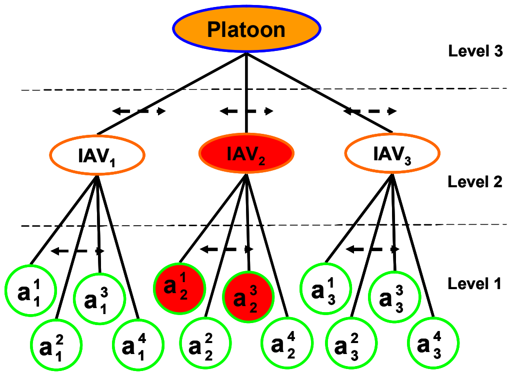

Figure 6: Platoon in degraded operating mode

So, the operating mode of the 2nd IAV becomes failed. Consequently, the platoon operates in degraded mode (Figure 6). The 3rd IAV stops at 14 s to avoid collision with the 2nd one.

We suppose that the considered scenario for the reconfiguration strategy consists of removing the faulty IAV from the main trajectory of the actual platoon. The reconfiguration (Zhang and Jiang, 2008) of the platoon can be done by generating progressive reconfigurations of the platoon of IAVs as follows:

1. Reconfiguration 1: in this case, the platoon is stopped and the 2nd IAV is put out after a progressive lateral and omnidirectional motion using the steering systems.
2. Reconfiguration 2: in this case, the 3rd IAV is accelerated until it approaches the 1st one in order to reconstruct the new platoon with respect to the inter-distance, using the front laser sensor.
3. Reconfiguration 3: in this case, the new reconfigured platoon is moved to achieve the initial planed mission.

Then, we can summarize the studied scenario by Figure 7.

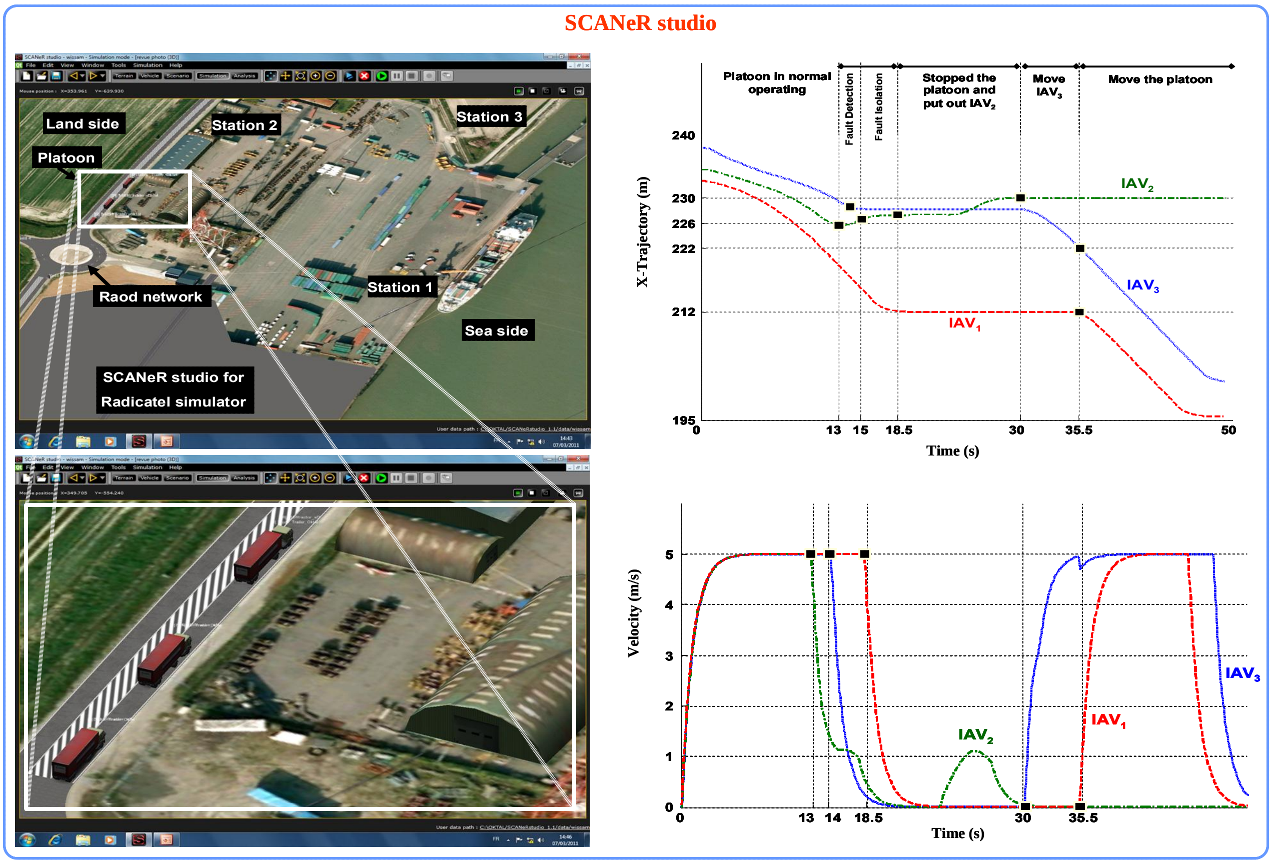

Figure 7: Operating modes and real velocities of the three involved vehicles

4. CONCLUSION

The use of intelligent and autonomous vehicles overcomes the limitation of the seaport infrastructure. The realization of this system needs a supervision system which can be able to diagnosis the different operating modes of the vehicle. However, the supervisor oversees the operating state of an autonomous vehicle through the availability of the functions and services provided by the vehicle components. Thus, the functional analysis provides a systematic tool for finding the different reconfiguration strategies of a system when faults occur by taking into account the availability of the elementary system components. Then when a fault occurs, a management reconfiguration is applied to a platoon. The first simulation on virtual port simulator shows the feasibility of the research work. The second step is going on and concerns an implementation of algorithms in real IAVs developed in this framework.

ACKNOWLEDGMENTS

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IDENTIFICATION OF CONSTITUTIVE CHARACTERISTICS FOR ADAPTABLE LOGISTICS CHAINS AS BASIS FOR AN ASSESSMENT BY SIMULATION

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ABSTRACT
Logistics chains are mostly influenced by changes in their business environment. A systems adaptability is seen as one potential to effectively counteract these environmental changes. To consider the effects of adaptability on the whole supply chain, a framework for configuring adaptable logistics chain will be developed within the research project “KoWaLo”. Therefore, the main constitutive characteristics of adaptable logistics chains and their specifications will be identified by a scenario based approach. In the following, these characteristics will be assessed in a case study based on a simulation model to evaluate the impact of specification changes within certain characteristics on the logistics chains KPIs. This paper deduces the approach to identify constitutive characteristics for establishing adaptable logistics chains and gives an outlook on how adaptable configurations will be assessed in a case study based on a discrete event simulation model.

Keywords: Logistics, Supply Chain, Adaptability

1. INTRODUCTION

Nowadays manufacturing companies are increasingly exposed to changes in their business environment. Current examples like sudden bottleneck situations in supply due to ecological disasters or political instabilities, or more general, the trend towards stronger customer orientation along with shorter delivery times, introduction of new products or product variants, new market trends or allocation in new markets, show the necessity for companies to handle these turbulences. Reasons for these impacts can be changes in technologies, internationalization or ongoing changes in supply and demand (Balve, Wiendahl, and Westkämper 2001; Westkämper, 2007). Such events can have significant effects on the logistics performance of a company. Therefore the topic “adaptability”, which can be described as the ability of a system to perform both reactive and proactive adaptations by specifically varying processes, is an important approach to deal with turbulence and retain competitiveness (Balve, Wiendahl, and Westkämper 2001; Nyhuis, Reinhard, and Abele, 2008). In comparison to flexible systems, which only can deal with changes within a certain range, adaptable systems allow to shift the range of flexibility to a higher or lower level by specific arrangements as shown in figure 1, e.g. through investments and/or organizational arrangements (Nyhuis, Reinhard, and Abele, 2008).

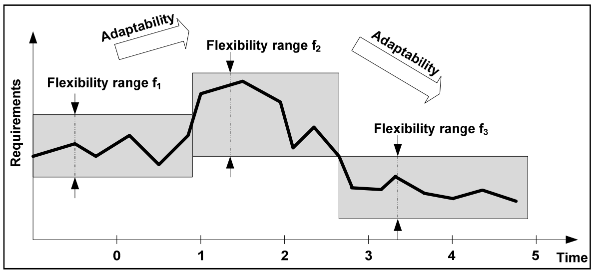

Figure 1: Adaptability as the Capability to Shift Flexibility Ranges (Wiendahl, ElMaraghy, Nyhuis, Zäh, Wiendahl, Duffie, and Brieke, 2007)

Previous research activities on adaptability have mainly focused on the factory level, the supply chain as a whole has been taken into account to a lesser extent (Nyhuis, Fronia, and Pachow Frauenhofer, 2009). First research activities in this matter were carried out by Christopher on a conceptual level without discussing defined constitutive characteristics precisely (Christopher, 2000) and Dürrschmidt by developing a concept for planning adaptable logistics systems for serial production without disclosing approaches for configuring logistics chains (Dürrschmidt, 2001). More recent research activities focusing on adaptability in logistics chains were carried out by Nyhius et al. by evaluating intra-enterprise logistics chains based on the requirement and the economic value added of an adaptable configuration (Nyhuis, Nickel, Horváth, Seiter, and Urban, 2008).
Within the research project “KoWaLo” a framework for configuring adaptable logistics chains based on concretely defined constitutive characteristics will be

developed in order to consider the effects of adaptability on the efficiency of the whole supply chain. The Austrian Research Promotion Agency funded this project with the partners Knorr-Bremse GmbH Division IFE Austria, Seisenbacher GmbH and the Vienna University of Technology. The focus of this paper is to describe the procedural method to identify the main constitutive characteristics in order to set up the configuration framework.

2. ADAPTABILITY IN LOGISTICS CHAINS

As described in the introduction adaptability offers great potential to cope with turbulences. In this respect adaptability considers structural changes in three basic principles: rapidness, flexibility and costs. Until now adaptability was primarily discussed with a focus on production systems, factory structures, organizational matters or order processing systems, thus primarily focusing on intra-enterprise issues. Within these areas of research the fundamentals of adaptability are seen in self-organizational and self-optimizing complex systems that can be (re-)configured permanently and rapidly (Westkämper, 2007). Adaptability may then in this context be empowered by modularity, compatibility, mobility, universality and scalability of equipment, space and building systems as well as on the organizational level (Klußmann, Nofen, and Löllmann, 2005).

However, in many industries 50-70% value added is contributed within a supplier network. Hence environmental dynamics do not only affect intra-enterprise matters, but also the supply-chain as a whole. Therefore the adaptable positioning of an individual company is not sufficient; in fact it is necessary to synchronize the adaptability of the whole logistics chain. To the Austrian industry, characterized by a high customer orientation, adaptability is of great importance. The research project KoWaLo addresses the problem on how adaptability can be applied to logistics chains by analyzing the logistics chain between the two Austrian companies mentioned above. To show the potential of adaptable logistics chains, company-wide case studies will be carried out.

Basically there are several reasons for the necessity of adaptable logistics chains: from the supply chain management point of view, the stability of the supply chain needs to be preserved at its best. While meeting delivery times or coping with an increased demand, companies face the problem of increased logistics costs. This leads to extra or emergency transports with for example low capacity utilization and/or the usage of expensive carriers like planes instead of trucks or trains. Along with these financial issues there are issues like increased emissions and their ecological effects. Longer-term supply shortfalls due to production breakdowns or quality problems may be considered when choosing sourcing strategies whereas changes in demand may be considered when planning distribution networks. These examples show the importance of developing a framework helping companies to empower adaptability in their logistics chains.

As major basis for configuring adaptable logistics chains, it is necessary to identify and assess the main constitutive characteristics and their respective specifications with regard to their ability to enable the logistics system to be (re-)configured continually, rapidly and in a cost effective manner. For the purpose of identifying those characteristics, an analysis of different environmental dynamics scenarios and their effects on the logistics system has to be done (Spath, 2009). By analyzing these effects together with the ability of the general constitutive characteristics of logistics systems to handle environmental dynamic, the main characteristics can be identified. The modifiable specifications of these characteristics finally allow the development of scenarios on how the logistics system can be configured aligned with the principles of adaptability.

As to secure cost effectiveness the configuration of adaptable systems has to be carried out in consideration of the systems cost effectiveness during its life cycle or a given time horizon (Zäh, Müller, and Vogl, 2005). The total costs of adaptability can be divided in system-costs (initial investments) and process-costs. Process-costs can further be divided in direct costs comprising costs for operating the system and costs for flexibility shifts, whereas the indirect costs comprise inefficiencies of the system caused by over- or under-designed systems.

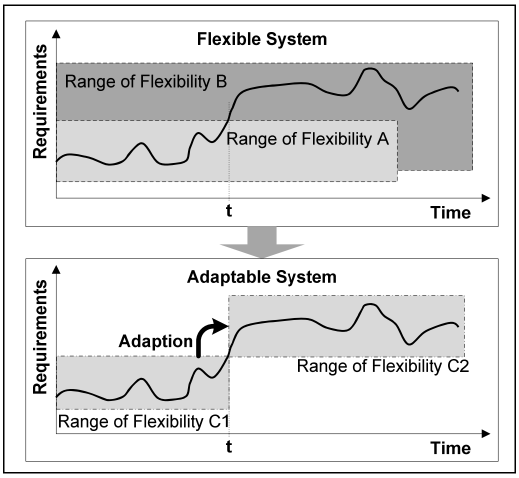

Figure 2: Demarcation between Flexibility and Adaptability.

Comparing the different systems in Figure 2 by costs generally leads to the conclusion that, due to the lower flexibility of range A, flexibility range A would induce lower system costs than range B. However, flexibility range A would induce indirect process-costs due to the inability of the system to meet the requirements over the subject time horizon. Whereas range B can meet those requirements it has inefficiencies because of the over-dimensioned flexibility considering the time spans before and after t separately. In the adaptable system the flexibility ranges C1 and C2 would induce certain system-costs that together are most likely higher than those of range A and range B, respectively. Although the shift from range C1 to C2 induces direct process costs, the indirect process cost will be minimized as each flexibility range will be synchronized with the dynamic requirements along the time span.

As there might be several scenario possibilities on how to set up an adaptable system, companies need to consider these with subject to the degree of adaptability and related total cost in order to be able to choose the most favorable configuration, i.e. the one with the lowest total cost expected. Therefore the different scenarios need to be evaluated by appraising the different types of costs for each scenario. As shown in Figure 3 the favorable scenario might not be the one with the highest degree of adaptability.

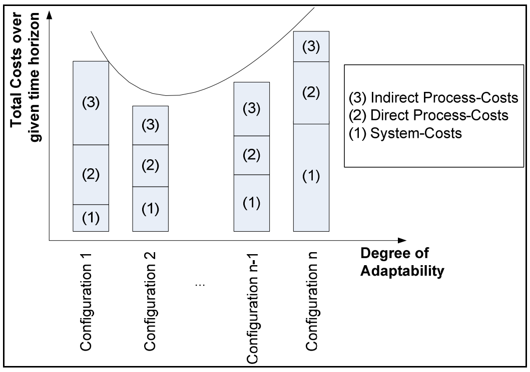

Figure 3: Total Costs Consideration of Different Scenarios (Zäh, Müller, and Vogl, 2005).

Therefore, the configuration model to be developed not only needs to consider the identification of characteristics contributing to adaptability and possible configurations of the very same, but also the assessment of the configurations degree of adaptability and the total costs over the contemplated time horizon.

Chapter 3 presents the scenario based method for the identification of major constitutive characteristics for establishing adaptable logistics chains and the assessment related to their contribution to adaptability, whereas Chapter 4 presents the simulation model for the assessment of respective configurations related to performance and cost issues.

3. APPROACH FOR IDENTIFICATION OF CONSTITUTIVE CHARACTERISTICS FOR ESTABLISHING ADAPTABLE LOGISTICS CHAINS

In order to provide adaptability in logistics chains it is essential to consider when adaptability is needed and how a configuration can be done. Therefore triggers or scenarios which induce changes in the logistics chains have to be identified. For example, such events can be customer requests to change the duration of the frozen zone or major changes in order sizes.

After defining the scenarios or rather scenario categories it is essential to identify the relevant regulating variables in logistics dealing with the impacts of the scenarios. To fulfill the requirement constitutive characteristics directly influenced by the scenario categories have to be identified.

Subsequent to the identification of possible scenario categories with impact on the logistics system and the identification of directly influenced constitutive characteristics of logistics, an assessment according to their contribution to adaptability has to be made. Therefore the intersection between these factors (scenario categories, constitutive characteristics and principles of adaptability) has to be found (Figure 4). To provide consistency a link between these factors has to be defined:

- *Scenario categories – adaptability:* Scenarios requiring adaptable structures are categorized. At this, scenarios with effects within middle termed horizons are considered. (see chapter 3.1)
- *Constitutive characteristic – adaptability:* Constitutive characteristics are rated by their flexibility and rapidness in change of specifications (e.g. changes from Just-in-Time to Just-in-Sequence within the constitutive characteristic supply concept) and the costs in associated with such changes (operation costs, investment costs, transformation costs). (see chapter 3.2)
- *Scenario categories - constitutive characteristic:* The linkage is established by key performance indicators (KPI) in logistics. At first, the direct impacts of the scenario categories on the KPIs are rated (yes/no). In the following, the KPIs directly influenced by the scenario category are used as a characterization of the scenario category. In a second step the effects of changes of constitutive characteristics specifications on the KPIs are rated (yes/no). These two assessments provide a combined analysis identifying the relevant constitutive characteristics in regards to evaluated scenario categories. (see chapter 3.3)

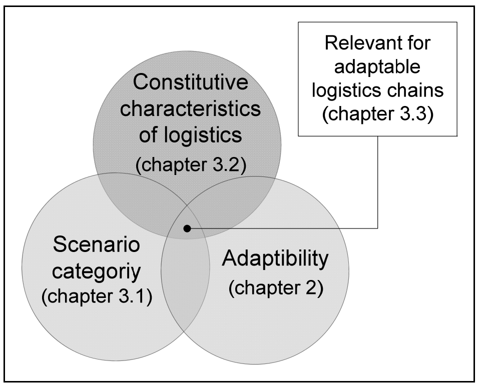

Figure 4: Identification of Relevant Regulating Variables for Adaptable Logistics Chains.

3.1. Identification of generic scenario categories

Due to the numerous different influencing factors a logistics chain can be affected by, it is important to classify them and focus on factors which require adaptable structures. The classification is based on a differentiation between short, middle and long term horizons (Figure 5).

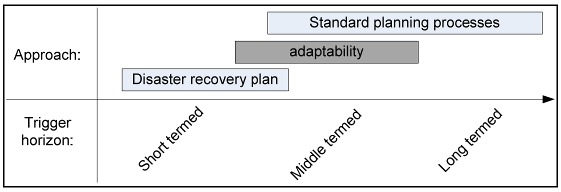

Figure 5: Classification of Triggers.

In case of short termed influencing factors, disaster recovery plans are used to provide continuous logistics processes respectively material supply (Arnold, Isermann, Kuhn, Tempelmeier, and Furmans 2008; Tang, 2006). For middle term and long term triggers standard planning processes are used. These planning processes focus on logistics changes which are not subject to shifts of the market, e.g. location planning (Tang, 2006). Whereas in case of middle term triggers which are caused by changing requirements of the market, e.g. change of frozen zones, the concept of adaptability is a promising concept to handle these recurrent changes.

To provide a generality of the concept a clustering of all middle term triggers which can be handled by adaptable systems is necessary. Within KoWaLo the generic groups “demand/customer risks”, “supply/supplier risks” and “environmental risks” were defined. More precising sub-groups were defined which focus on the changed parameters in the logistics (time, place, quantity, quality).

Changes in...	**Time**	**Place**	**Quantity**	**Quality**
Demand/ Customer	...delivery time	...point of delivery	...quantity demanded	...customer requirements
Supply/Supplier	...replenish-ment time	...point of procurement	...available capacities	...quality of supply
Environmental	...processing time			

Figure 7: Extract of Identified Scenario Categories.

3.2. Identification of constitutive characteristics in logistics

A multitude of overviews concerning constitutive characteristics of logistics can be found in literature (Arnold et al., 2008; Pfohl, 2004; Gudehus, and Kotzab, 2009; Gleißner, and Femerling, 2006). Because every overview has a different focus and provides no completeness, a unique appropriate overview has to be developed. To provide a preferably holistic overview a structured model has to be considered. In literature, different approaches exist to structure logistics system. Pfohl (2004) describes a function oriented and a performance oriented model. The functional boundary of the logistics system by phases describes the material flow beginning from the procurement market to the sales market and back. Another approach depicts the performing oriented view with focus on value added benefits for the logistics system (Figure 8). This performance oriented view allows a structured and non-redundant classification of constitutive characteristics within the logistics system. Therefore, this structure is used as the basis for the identification and classification of constitutive characteristics.

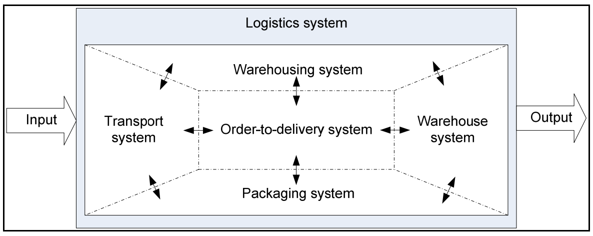

Figure 8: Performance Based Structure of Logistics Systems (Pfohl, 2004).

The literature research resulted in the identification of 90 different constitutive characteristics which can be classified within Pfohls performance oriented categories. Upon closer inspection different influences on the constitutive characteristics can be identified. Some constitutive characteristics are mainly influenced by product or strategy (e.g. design and function of products and adherent sourcing strategies: unit sourcing, modular sourcing etc.) or laws (general framework and regulations like hours-of-service regulations). Others focus on processes which have no influence on the logistics chain, e.g. processes within the warehouse system. Because these constitutive characteristics do not represent specific configuration levers for adaptable logistics chains they will be disregarded. After all 16 relevant constitutive characteristics have been identified.

	Relevant constitutive characteristics for the concept	**example**
Transport system	1	Transport concept
Packaging system	0	
Warehouse system	0	
Warehousing system	4	Order size, stock
Order-to-delivery system	11	Sourcing and supplier strategy
total	**16**	

Figure 9: Relevance of Constitutive Characteristics for Adaptability

3.3. Identification of adaptable constitutive characteristics

To identify adaptable constitutive characteristics, the analysis described in chapter 3.1 und 3.2 have to be merged. Herein KPIs are used as linkage between scenario categories (analysis 1) and constitutive characteristics (analysis 2). To provide a holistic collection of KPIs, the logistics KPI system of Schulte (1999), describing 146 KPIs sorted into different phases and groups, was applied. The system considers the logistics phases procurement, material flow and transport, warehouse and consignment, production planning and controlling as well as distribution. Each phase has their KPIs further grouped in the categories structure, productivity, economy and quality (Figure 10).

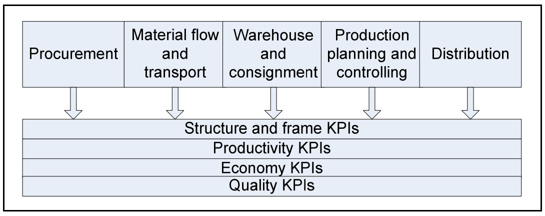

Figure 10: Logistics KPI System of Schulte (1999).

In order to merge the scenario categories and constitutive characteristics the first step is the identification of KPIs directly affected by the impact of respective scenarios. Secondly characteristics with direct influence on the respective KPIs have to be identified. Hence, the linkage between constitutive characteristics and scenarios can be established: characteristics with direct influence on a specific KPI are most likely to be taken into account to counteract a respective scenario influencing this specific KPI. Therefore, a set of characteristics can be identified for each of the scenario categories, as pictured in figure 11.

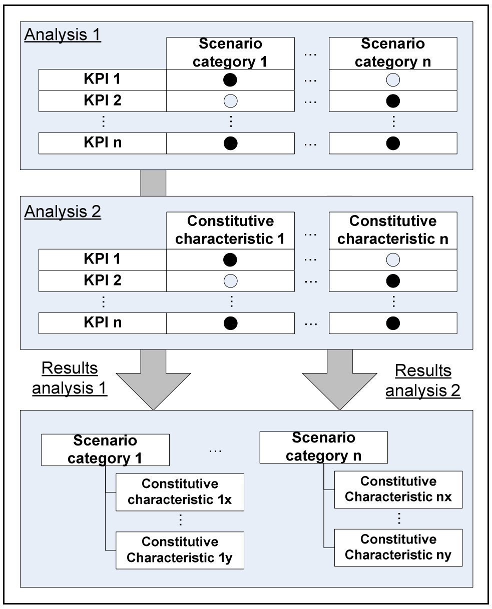

Figure 11: Combined Analysis for Identification of Adaptable Constitutive Characteristics.

3.4. Example for the identification of constitutive characteristics for establishing adaptable logistics chains

To demonstrate the concept one scenario will be treated exemplary. The selected scenario is based on a claim of customers to reduce the frozen zones in the order fulfillment process of a manufacturing company. This allows the customers to place orders within a shorter time frame. Companies with adaptable logistics are able to prepare for these triggers by considering low costs and a high logistics performance. The concept identifies constitutive characteristics which should be configured in terms of adaptability to establish economical and logistical advantages.

The first step is to assign the identified scenario to a scenario group. Using the example of frozen zone reduction, the category “Demand/Customer Risks” and “Time” was chosen (figure 7). Within analysis 1 (figure 11) the scenario has to be rated by KPIs. Therefore 13 relevant KPIs describing the scenario were defined. Among these the KPIs adherence to delivery dates, intensity of inventory or degree of information transparency are some of the relevant KPIs. The next step focuses on the impact of changes within the constitutive characteristics on the relevant KPIs (analysis 2, figure 11). When consolidating these analyses the crucial constitutive characteristics for the scenario can be identified. The characteristics below were identified for the exemplary scenario:

- *Order size:* By finding the optimal order size, frozen zones can be shortened. A balanced size has to be provided to acceptable transport and inventory costs.
- *Transport concept:* By applying the optimal transport concept changes can be performed faster. Flexible concepts like less-truck-load transports can interact better with volatility than train concepts.
- *Carrier:* Because of different start-up times between carrier concepts, the right choice is important to provide a fast change in the logistics configuration.
- *Communication strategy:* An adequate setting of communication strategy is relevant for the performance of the logistics chain. Through this, rapid changes in processes can be achieved.

4. ASSESSMENT OF ADAPTABLE CONFIGURATIONS BY SIMULATION MODEL

In order to assess the effectiveness of one or a set of constitutive criteria and their respective configurations, a discrete event simulation model was created to represent the exemplary order fulfillment process described in chapter 3.4. The simulation and evaluation model developed is depicted in Figure 12 (for higher resolution see appendix A).

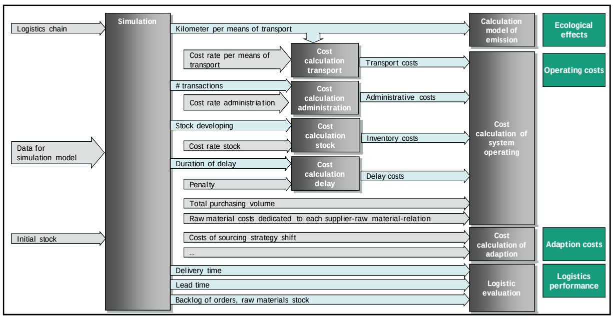

Figure 12: Structure of the Simulation and Evaluation Model.

The simulation model is based on the logistic chain of the companies named above, including inbound and outbound logistics as well as aggregated main production processes and their associated behavioural pattern concerning lead-times and deviation of lead-times. The data sets are real data sets from past production projects representing the high variant diversity in the contemplated logistic chain. By simulating dynamic effects of certain scenarios on this system, bottlenecks can be identified. By changing the specification of adaptable constitutive criteria and their theoretical effect on the systems behaviour, a statement can be made concerning the probability of an adaptable logistics chains aptitude to counteract these dynamic effects. Underlying cost rates for transport, stock, delay penalties, raw materials and adaption costs allow the evaluation of the systems total cost alongside with time effects like delivery capacity and reliability.

Hence, the simulation allows a comparison of the effects of different configurations by costs and logistics performance (as depicted in figure 3). Furthermore ecological effects in respect of transport system changes and effects, respectively, can be displayed.

The simulation application will be realized in the simulation software SLX. SLX excels in fast calculation and flexible model requirements illustration.

5. SUMMARY

Adaptable systems constitute high relevance for systems facing volatilities or continuously changing markets. According to the factors flexibility and reactivity as well as economical factors, structures can be (re-)configured to reach a high performance and low total cost. Adaptable concepts within production systems approve this statement. Nevertheless production systems only constitute one part of the value added chain and therefore adaptable concepts regarding the whole logistics chain have to be developed.

The presented approach shows a concept for the identification of relevant constitutive characteristics for adaptable logistics chains. Key elements of the concept are the scenario groups describing the impact of a change in the logistics chain. The approach to identify the relevant constitutive characteristics with KPIs out of the logistics KPI system provides a holistic view on all logistics levers. The simulation model will allow the evaluation of multiple configurations in respect of adaptability, logistics performance an underlying costs as well ecological issues like emission impacts of changes in the transport system.

Currently, the identification of characteristics and the simulation model development is completed. Further steps will be the definition of scenarios in order to deflect the impact on the system, and the evaluation of dynamic effects with the help of the simulation model.

Ongoing research will aim at the deflection of a universally valid and holistic configuration model for adaptable logistics chains that can be used as a decision support tool for companies of all sizes in order to evaluate their options to adjust their logistic system under consideration of adaptability.

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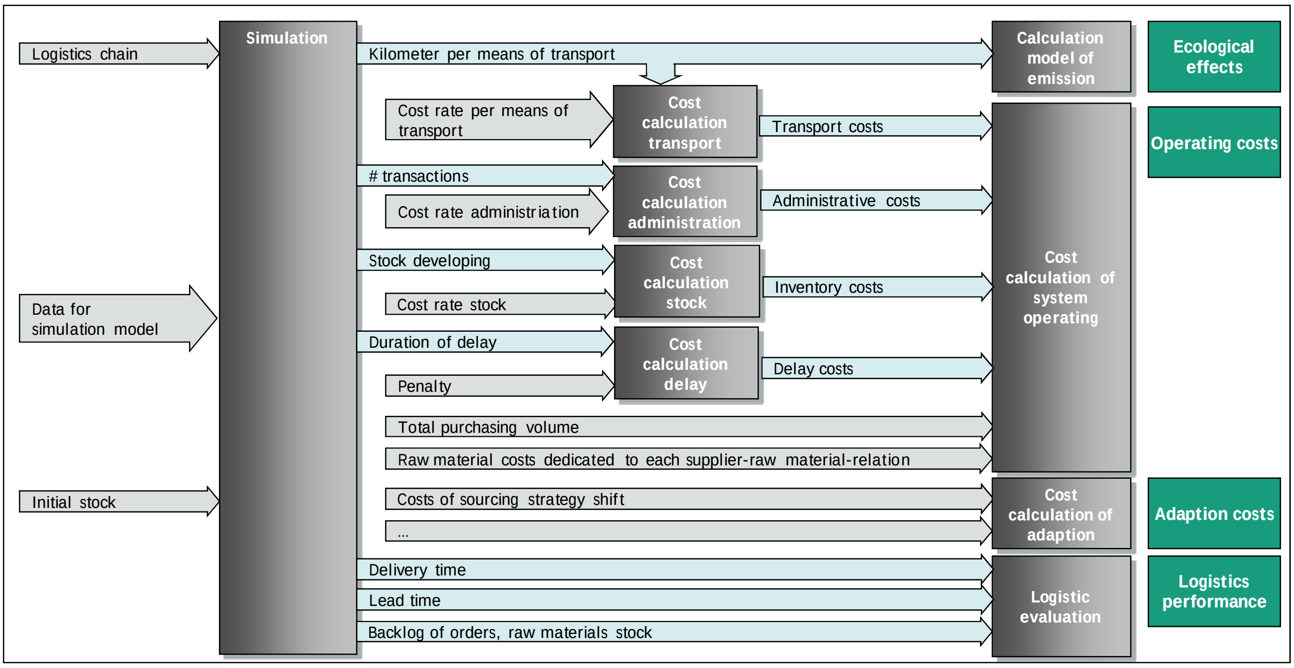
APPENDIX A: STRUCTURE OF THE SIMULATION AND EVALUATION MODEL



MODELLING OF MULTIMODAL FREIGHT TRANSPORTATION SYSTEM USING PROCESS APPROACH

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ABSTRACT
In the present paper the following main tasks are considered: choice of a set of indices characterizing efficiency of multimodal transportations, formation of optimization criteria of the system of multimodal transportation, construction of models of the multimodal transportation system, the usage of methodology IDEF0 in BPWin package to describe business processes of freight transportation.

Keywords: multimodal transportation, logistic system, criteria of optimization, business-process, modelling

1. INTRODUCTION

Current trends of development of the international system of freight transportation are characterized by essential increase of multimodal transportation in total amount of cargo transportation. Usage of several types of transport in multimodal transportation makes the management of transportation, loading and warehousing processes, in which various executors and various facilities are involved, significantly more complicated. Thus, considering great transportation volumes, miscalculations in the organization and management of these processes lead to considerable material and financial losses.

Search for optimal solutions in realization of multimodal freight transportation should be based on a set of the initial data, considering logistic rinciples, and be done using modern mathematical methods and computer engineering (Ghiani, Laporte and Musmanno 2004; Lukinsky 2008). Taking into consideration a complicated structure of multimodal transportation, high dynamics and rapidity of transport processes, the random factors influencing these processes and geographical dispersion of participants of the transportation, the task of the present research is development of the mathematical description of the multimodal transportation system. First of all, such formalization is required for managing multimodal transportation processes and searching for optimal decisions in freight transportation.

In the presented research, the following main tasks, which require solutions, are highlighted:

- choice of a set of indices, characterizing efficiency of multimodal transportation, and formation of an optimization criteria of the system of multimodal transportation on their basis;
- construction of mathematical model of the multimodal transportation system;
- usage of methodology IDEF0 in BPWin to describe business processes of freight transportation.

2. FORMATION OF OPTIMIZATION CRITERIA OF THE TRANSPORTATION SYSTEM

In the presented paper multimodal transportation is considered as a set of *logistic systems* $\mathbf{LS} = \{LS_1, LS_2, ..., LS_n\}$. Each logistics system is considered to be a route of transportation, which is characterized by a set of indices. To estimate the efficiency of multimodal transportation, the system of indices including cost, duration, reliability of transportation of cargo and its safety is used. It is easy to notice that the offered indices have the various physical natures and are measured by different physical magnitudes. The part of indices is deterministic, the part is stochastic. Additional difficulties for estimating the system's indices are related to the fact that part of indices has quantitative nature and part has qualitative nature. For example, cost and durations of transportation are quantities, but reliability and safety, estimated by experts, are qualitative parameters. For conversion of quality indices into quantitative it is offered to use Harrington's desirability function (Lukinsky 2008).

In general case set of chosen indices is used for search of optimal decision in the freight transportation task, and two approaches of optimization criteria formation can be used: monocriterion and multicriterion approaches.

The *first (monocriterion) approach* assumes usage of one generalized optimization criterion and recognizes that various indices (delivery time, reliability of delivery, safety of cargo, etc.) can be estimated in expression in terms of value. It allows constructing a generalized criterion of total costs E_Σ for realization of multimodal transportation, which unites a set of local criteria, among them:

- direct cost for freight transportation, i.e. expenses for cargo transportation, reloading and warehousing, customs operations, documentation, etc.;
- losses appearing as a result of delay in delivery schedule (including penalties for non-fulfillment of the delivery terms and the lost and-or half-received profit);

- losses from cargo loss, and deterioration of its consumer properties (partial or full damage of cargo which reduces its cost);

- expenses for capital freezing (they are defined taking into account cost of transported cargoes and time of delivery);

- losses related to currencies' exchange rates fluctuations;

- expenses for additional insurance of cargo;

- expenses for stock holding in case of irregular deliveries.

At the same time, the given criterion can be supplemented with new components, considering concrete transportation system.

In general case total costs $E_\Sigma(LS_j)$ for realization of multimodal transportation of logistic system LS_j will be calculated by the following formula

$$E_\Sigma(LS_j) = \sum_{i=1}^{n} E_i , \qquad (1)$$

where n is quantity of components (items), which form total costs for realization of multimodal transportation; E_i is a value of i-th component of expenses for realization of multimodal transportation (for example, direct cost for freight transportation; losses appearing as a result of delay in delivery schedule etc).

In this case the problem of search of optimal multimodal freight transportation system LS_{opt} on the basis of set of possible logistic systems $\mathbf{LS}$ has the following view:

$$E_\Sigma(LS_{opt}) = \min_{LS_j \in \mathbf{LS}} [E_\Sigma(LS_j)] . \qquad (2)$$

In number of cases constrains on used resources (time, technique, means etc.) are additionally introduced:

$$p_k(LS_j) \le p_k^{\max}, \quad k = 1,2,...,m; \ \forall LS_j \in \mathbf{LS}, \qquad (3)$$

where $p_k(LS_j)$ is the value of k-th index of the logistic system LS_j; $p_k^{\max}$ is the maximum possible value for k-th index for the given multimodal transportations; m is quantity of indices on whose constrains are imposed.

For the fixed number of variants of the systems, determined by set $\mathbf{LS}$, the choice of an optimum variant LS_{opt} by criterion (2) consists of checking conditions (3) and calculations of total costs for realization of multimodal transportation for $\forall LS_j \in \mathbf{LS}$.

The *second approach* considers a *multicriterion* problem of multimodal transportation, when the system of q various criteria $C_1(LS_j), C_2(LS_j),...,C_q(LS_j)$ is used. This criteria have the various physical natures and are measured by different physical magnitudes.

The part of criteria is minimised (for example, cost and time), and part is maximised (for example, safety of transportation, safety of cargo). In this case we have a *vector optimisation* problem of a kind:

$$C_l(LS_{opt}) \to extremum, \ l = 1,2,...,q; \ LS_{opt} \in \mathbf{LS} ,$$

where *extemum* for separate criteria corresponds to a minimum, for others – to a maximum.

In the present research the system of four criteria (cost, duration, reliability of transportation of cargo and its safety) is considered by authors. Respectively, we have the following problem formulation:

$$\begin{aligned} &E_{TR}(LS_{opt}) \to \min; \\ &T_{TR}(LS_{opt}) \to \min; \\ &P_{SC}(LS_{opt}) \to \max; \\ &P_{CTR}(LS_{opt}) \to \max, \end{aligned} \qquad (4)$$

where $LS_{opt} \in \mathbf{LS}$;

$E_{TR}(LS_{opt})$ is direct cost (expenses) for freight transportation;

$T_{TR}(LS_{opt})$ is time of cargo delivery;

$P_{SC}(LS_{opt})$ and $P_{CTR}(LS_{opt})$ are safety of cargo and reliability of transportation, respectively.

The multicriterion problem can be solved using method of "*consecutive concessions*» (Lukinsky 2008). This method considers a priority of criteria $C_l(LS_j), l = \overline{1,q}$. It is based on estimation and comparison of an increase and decrease in local criteria $C_l(LS_j)$, which are unavoidable in the field of compromises. In the judgment of the authors, *Analytic Hierarchy Process (AHP) method* (Saaty 2001) is the most efficient for choice of optimal logistic system. The AHP method allows arranging the systems of trasportation in the order of efficiency and showing their difference in the given set of criteria.

3. MODELLING OF MULTIMODAL TRANSPORTATION SYSTEM

The model of logistic system (LS) is constructed for the purpose of the description of cargo transportation and calculation of LS indices. Thus for the description of multimodal transportation system it is possible to use two approaches: functional and process.

1. *Functional approach* was the first for describing business-systems. It considers usage decomposition of the system, which includes 3 basic steps. On the first step, logistic system is divided into set of subsystems. On the next step subsystems are presented as a set of logistic functions (LF). On the final step, each logistic function is presented as a set of logistic operations (LO), which is characterized by its own set of indices.

The main disadvantage of the functional approach is dissociation of separate logistic functions and insufficient interaction among them. However, an ultimate goal of formalization of the description of transportation process is not only calculation of efficiency indices, but also development of the approach to efficient control system of multimodal transportation. The last is difficult for implementing using the functional approach.

2. The *process approach* has found wide application recently only. Thus the model of logistic system, realised at the functional approach, joins additional process level. This level in hierarchy of the system precedes level of functions. Logistic process is considered as a set of logistic functions, however in certain cases LP can consist of one LF. The main task of this approach is elimination of lack of the functional approach, which is noted above, and consists in absence of interaction between various LF within the limits of one system.

In the present paper the process approach is used for the description of multimodal freight transportation system. For presentation of the multimodal freight transportation system, decomposition of possible options of logistic system, including four basic steps is done (see example in Fig.1)

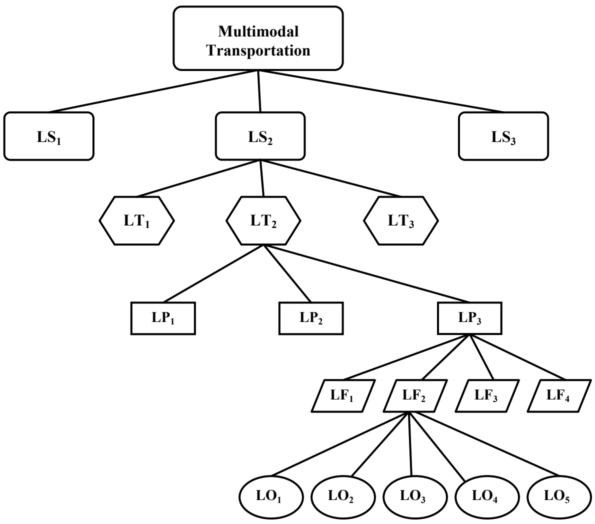

Figure 1: Decomposition of logistic system

On the first step, the logistic system LS_j is divided into a set of *subsystems* $\mathbf{LT} = \{LT_1, LT_2, ..., LT_g\}$. On the second step subsystems are presented as a set of *logistic processes* $\mathbf{LP} = \{LP_1, LP_2, ..., LP_z\}$, which are divided into a set of *logistic functions* $\mathbf{LF} = \{LF_1, LF_2, ..., LF_r\}$. On a final step each function is presented as a set of *logistic operations* $\mathbf{LO} = \{LO_1, LO_2, ..., LO_h\}$, which are characterized by own set of indices.

The constructed system of sets allows making calculations of LS efficiency, taking in account different indices. Besides, these calculations are made "bottom-up", starting from the bottom level (level of LO) and finishing by the top level (level of LS). So, the calculation process can be presented by the chain $\mathbf{LO} \to \mathbf{LF} \to \mathbf{LP} \to \mathbf{LT} \to \mathbf{LS}$.

It is necessary to underline that cost indices at the next level of hierarchical bottom-up system are calculated by simple summation of corresponding indices of the previous level. Then cost index *E* for logistic system LS_j is calculated under the formula:

$$E(LS_j) = \sum_{LT_i \in LS_j} E(LT_i) = \sum_{LT_i \in LS_j} \sum_{LP_m \in LT_i} E(LP_m) =$$
$$= \sum_{LT_i \in LS_j} \sum_{LP_m \in LT_i} \sum_{LF_h \in LP_m} E(LF_h) = \qquad (5)$$
$$= \sum_{LT_i \in LS_j} \sum_{LP_m \in LT_i} \sum_{LF_h \in LP_m} \sum_{LO_p \in LF_h} E(LO_p).$$

However, calculation of time indices in the transportation system involves severe difficulties. It is necessary to take into account factors like shifts of separate operations, functions and processes for fixed moments of time, parallel and consecutive performance of separate elements of logistic system and so forth. With this aim, methods of network planning are used (Novitsky 2004). In considered task **LO**, **LF**, **LP** and **LT** are presented by the weighed graphs in which edges are corresponding elements of appropriate hierarchy level (i.e. **LO**, **LF**, **LP** and **LT** accordingly), when time indices of functions, processes and subsystems are calculating.

4. EXAMPLE OF CALCULATION OF LOGISTIC SYSTEM'S INDICES

The created model is tested against real-world conditions. To illustrate the offered approaches, the example of multimodal freight transportation from Shanghai to Almaty by three alternative routes is considered. The suggested routes are the following:

- Shanghai – Hamburg – Riga – Almaty;
- Shanghai – Hamburg – Riga Port – Riga Terminal – Almaty;
- Shanghai – Alashankou – Dostyk – Almaty.

Let us consider features of each route.

1. Shanghai – Hamburg – Riga - Almaty. This route considers transportation of cargo in container during the whole transportation process without reloading (intermodal transportation). Container is delivered from Shanghai to Hamburg by mother vessel. Thereafter container is being reloaded onto feeder vessel for delivery to the port of Riga. In Riga container is reloaded onto truck and delivered to the terminal in Almaty.

2. Shanghai – *Hamburg – port of Riga – railway terminal in Riga – Almaty.* This route considers reloading of cargo from container into railway wagon. Cargo in container is delivered from Shanghai to Hamburg by mother vessel. Then container is reloaded and delivered by feeder vessel to the port of Riga. At terminal container is reloaded onto truck and further delivered to railway terminal. Here cargo is reloaded from container into railway wagon. Thereafter cargo is delivered to the terminal in Almaty by rail.

3. *Shanghai – Alashankou – Dosty – Almaty.* This route considers transportation of cargo in container

during the whole transportation process without reloading (intermodal transportation). Cargo in container is delivered from Shanghai to Alashankou by short see vessel. In Alashankou container is reloaded onto railway platform and further delivered to Dostyk, Chinese/Kazakhstan border point. In Dostyk the container is reloaded onto railway platform of Kazakhstan railways (changing the gauge) with further delivery to terminal in Almaty.

Actually we are considering three logistic systems presented by the graph in Fig.2. The edge of the graph corresponds to a logistic subsystem (or to a route stage).

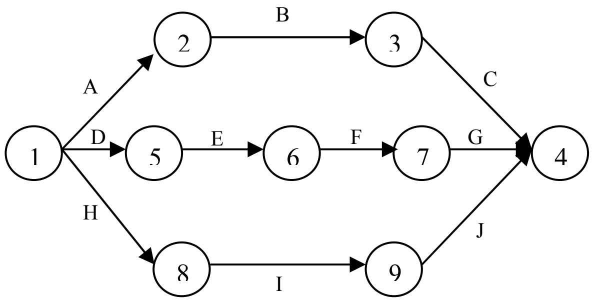

Figure 2: Logistic Systems

Description of routes LS_j is presented in Table 1.

Further the first route LS_1, (Shanghai – Hamburg – Riga – Almaty) will be considered in more details. It is presented by vertexes 1-2-3-4 (or by edges A-B-C) on the graph in Fig.2. As it can be seen, logistic system LS_1 includes three subsystems (stages of routes):

stage A - cargo transportation in container from Shanghai to Hamburg, unloading of container at port of Hamburg;

stage B - loading of container onto feeder vessel, delivery from Hamburg to Riga, unloading of container at port of Riga;

stage C - loading of container on truck at port of Riga, delivery from Riga to Almaty terminal.

Each subsystem (stage) consist of one or several logistic processes. Let us in details consider stage C which consists of three logistic processes: transshipment of container, customs clearance and transportation, shown in Fig.3.

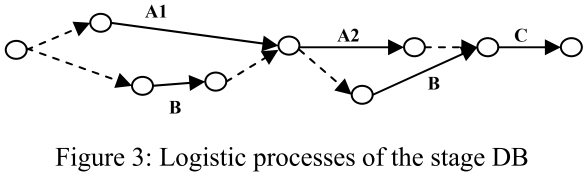

Figure 3: Logistic processes of the stage DB

Each edge in Fig.3 corresponds to one process of the stage: A1 – customs clearance of incoming container; B – transshipment of container, A2 – customs clearance of outgoing container, C – transportation. By dashed lines the edges, used for marking "fictitious processes» (shift in time, parallel performance of processes, etc.), are shown.

Table 1: Subsystems (stages) of routes

LS_j	LT_k Stage	Description of stage
LS_1	A	Cargo transportation in container from Shanghai to Hamburg. Unloading of container at port of Hamburg.
	B	Loading of container onto feeder vessel, delivery from Hamburg to Riga, unloading of container at port of Riga.
	C	Loading of container on truck at port of Riga, delivery from Riga to Almaty terminal.
LS_2	D	Cargo transportation in container from Shanghai to Hamburg. Unloading of container at port of Hamburg.
	E	Loading of container onto feeder vessel, delivery from Hamburg to Riga, unloading of container at port of Riga
	F	Loading of container onto truck, delivery from port to railway terminal in Riga.
	G	Reloading of cargo from container to wagon. Rail delivery from Riga to Almaty terminal
LS_3	H	Cargo transportation in container from Shanghai to Alashankou. Unloading of container at port of Alashankou.
	I	Loading of container onto rail platform in Alashankou. Rail transportation Alashankou – Dostyk, unloading of container at Dostyk border terminal.
	J	Loading of container onto Kazakhstan rail platform to Dostyk terminal, rail delivery to Almaty terminal.

Further we will make decomposition of processes onto logistic functions. We will show it on an example of process of container transshipment at port of Riga. In the offered statement of a problem, at the level of detailed elaboration accepted by us, we will allocate following logistic functions for transshipment process:

- handling of incoming container;
- storage;
- handling outgoing container;
- processing of documents.

Schematically this process is presented on Fig.4.

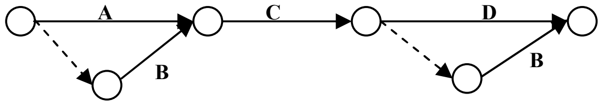

Figure 4: Process of container transshipment at port of Riga

Each stage in Fig.4 corresponds to a concrete function: B1 – processing of documents for incoming container, B2 – processing of documents for outgoing container, C – storage, D – handling of outgoing container.

Decomposition of functions is shown on example of LF „Handling of outgoing container". This function consists of set of following logistic operations:

- receiving truck number and sending the truck for loading
- registration of loading in IT system of terminal
- generating PIN code for loading;
- loading of container.

Schematically function "Handling of outgoing container" is presented on Fig.5.

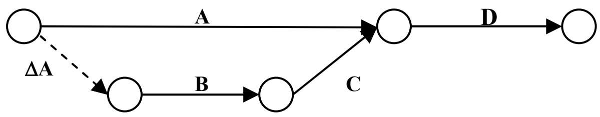

Figure 5: Logistic Function "Handling of outgoing container"

Each edge in Fig.5 corresponds to the concrete logistic operation: A – receiving truck number and sending the truck for loading, B – registration of loading in IT system of terminal, C – generating PIN code for loading, D – loading of container.

Decomposition of all elements of logistic system (route) has been similarly executed, which has allowed to define cost of transportation of cargo, using the formula (6), and to calculate time of cargo transportation from 1 in 4 (see Fig.2), having defined a critical way of the obtained graph of logistic operations.

As an example, results of calculation of duration of performance of separate logistic function «Handling of outgoing container», considered above are given. Durations of performance of separate operations of function are presented in Tab. 2.

Table 2: Operation inside the function "Handling of outgoing container"

Logistic Operations	**Duration, minutes**
A – receiving truck number and sending the truck for loading	60
ΔA – waiting time	10
B – registration of loading in IT system of terminal	15
C – generating PIN code for loading	10
D – loading of container	80

As can be seen in Fig.5, critical way AD for the presented graph is equal 140 minutes. In a similar way, a critical ways for all functions, processes, subsystems and logistic system as a whole are calculated. Results of calculations of two basic indices of efficiency of the chosen routes of freight transportation: transportation costs and transportation time – are presented in Tab. 3.

Table 3: Efficiency indices of logistic systems

Route, LS_j	**Transportation cost, USD**	**Delivery time, days**
1	8400	40
2	5800	25
3	7300	57

It is easy to notice that 2nd route has the best efficiency indices, both on delivery time, and delivery cost. Rather frequently it is not possible to receive such unanimity of criteria (see for example, indicators of efficiency of 1st and 3rd routes). In this case higher priority between price and delivery time should be chosen.

5. MODELLING OF BUSSINESS PROCESSES IN MULTIMODAL TRANSPORTATION SYSTEMS USING BPWIN PACKAGE

For carrying out a business analysis of multimodal freight transportation system, a modelling methodology IDEF0 is proposed by authors. It considers elements of the system (processes, functions and operations), required resources and gained results (Repin 2004). IDEF0 notation is one of the most popular for today and has a number of advantages: simplicity of documenting of processes; completeness of description of business process (management, information and material streams, feedback); integrated approach to decomposition (migration and tunneling of arrows); possibility of aggregation and detailed elaboration of data flows and the information (division and merge of arrows); presence of firm requirements of the methodology, providing reception of process models of a standard kind.

Realization of suggested approach is performed using BPWin software package, where modelling tools of three basic business aspects: processes/functions (IDEF0 notation), data flows (DFD notation) and workflows (IDEF3 notation) are realized (Hunt 1996.).

The usage of modelling methodology IDEF0 in BPWin is illustrated on an *example of transshipment process at Riga Port*. The diagrams, characterizing interrelation of separate elements of business processes at various levels of detailed elaboration, are constructed using BPWing tool.

In Fig.6 the contextual diagram of process of transshipment, where the basic inputs and outputs are shown, is presented. The container on a vessel arrives to the terminal where instructions and requirements from clients come. On an output of the process – the container loaded onto truck. Container handling at the terminal is performed using special equipment basing on internal instructions.

In Fig.7 container transshipment process is presented by a set of functions. In the offered statement of a problem, with accepted level of detailed elaboration, the following logistic functions for transshipment problem are stand out: handling of incoming container, storage, handling of outgoing container and processing of documents.

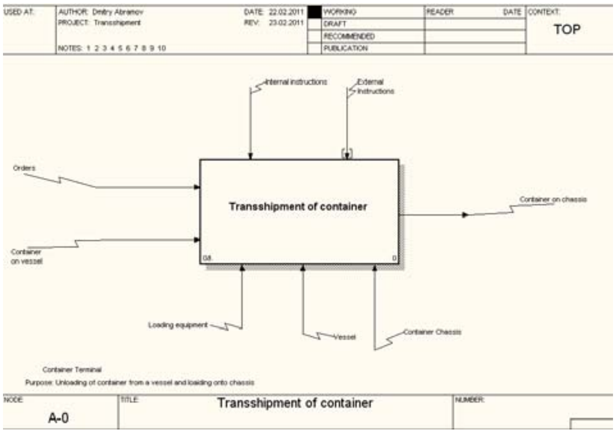

Figure 6. Context diagram of transshipment process

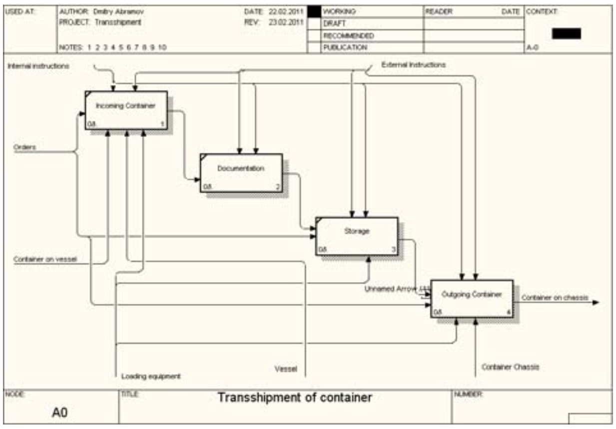

Figure 7: Functions of transshipment process

Further decomposition of function onto separate operations is performed too. In Fig.8 LF "Handling of outgoing container" is presented as a set of operations.

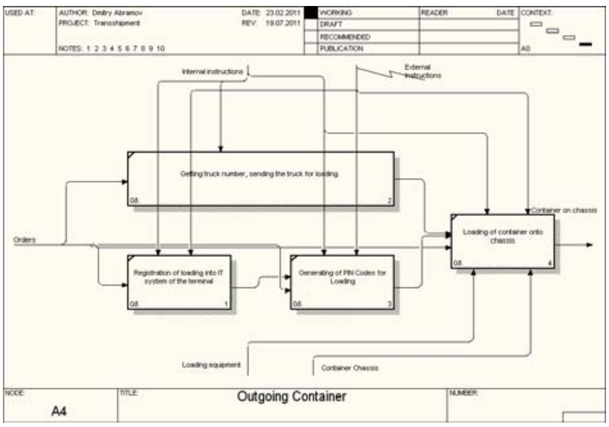

Figure 8: Function "Handling of outgoing container"

CONCLUSIONS

The constructed model of multimodal transportation system allows calculating total costs for freight transportation and total delivery time over considered routs. The received results allow choosing the most favorable route for which the indicator of system's efficiency has the optimal value.

The usage of the methodology IDEF0 in BPWin allows to describe business processes of the transportation chain as whole and to work out corrective actions to improve the transportation system.

Further guidelines of the current research are the following: to find an optimal solution of the transportation problem using the simulation approach; to consider the cases with different optimization criteria.

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MODELLING OF URBAN PEDESTRIAN ENVIRONMENTS FOR SIMULATION OF THE MOTION OF SMALL VEHICLES

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ABSTRACT
This paper has two aims. The first is to describe the results of initial experiments to understand the relationship between the speed of an electric scooter and the density of pedestrians. The second is to explain how subsequent experiments will be used to create a pedestrian model to better understand pedestrian-vehicle avoidance behaviour. The first aim has been achieved in Genoa by calculating the scooter velocity and associated pedestrian density. Then the design of future experiments, which will be carried out at the PAMELA Laboratory at UCL are described. The results of these additional experiments will be used as inputs to the SiVic simulator – this is able to simulate real-time driving of a PICAV. The SiVic simulator allows changes to the control system of the PICAV vehicle to be tested. The details of these additional experiments and the process of integrating these results into the SiVic simulator are described herewith.

Keywords: Pedestrian modelling; vehicle-pedestrian behaviour; Simulation

1. INTRODUCTION

A new form of public transport system is being considered as part a European project called PICAV (Personal Intelligent City Accessible Vehicle). This system will consist of a number of individual intelligent vehicles which can be hired on-demand by pedestrians, including those who are elderly and disabled, and used to access areas of the built environment which are otherwise inaccessible. These vehicles – PICAVs – will share the same space as pedestrians. Therefore it is important that the interactions between the pedestrians and the vehicles be understood so that a safe and efficient transport system can be developed. Also, the speed at which a PICAV can travel will be dependent on the density of the pedestrian flow in a particular street, which will subsequently affect the journey times of users and therefore the availability of PICAVs.

The first aim of this paper is to describe the results of initial experiments to understand the relationship between the speed of an electric scooter and the density of pedestrians. The results of this relationship will be used to inform minimum journey times for the fleet simulator. The fleet simulator is described in a separate paper at HMS Conference (Cepolina et al 2011).

The second aim is to explain how subsequent experiments will help to address the safety issues surrounding the use of PICAVs in the pedestrian space. The paper is divided in the following way; section 2 reports the details and results of the Genoa experiments, section 3 describes the additional experiment which will be carried out at the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA) facility and section 4 describes the SiVic simulator and the process of integrating the empirical data into this simulation environment.

2. A MODEL FOR THE PICAV SPEED-PEDESTRIAN DENSITY RELATIONSHIP

A series of video clips of an electric scooter travelling in a straight line were taken on the following two streets in Genoa, Italy: Via San Luca and Via di Canneto. These streets are pedestrian-only areas. The electric scooter was a standard electric scooter designed for disabled people, and not a PICAV unit as this is yet to be constructed.

The focus of this paper is on the analysis of the videos from via San Luca, which is typical of streets in the historical city centre of Genoa, with a number of shops on either side of the street and a street width of just over 2.5m. The surface of the street is also typical: cobbled stone. These videos were taken from a birds-eye point of view and took in an area of 18.75m2, which was divided in to 12 squares (6 squares long and 2 squares wide). The area was videoed in the morning, between 10:30 and 11:30 (i.e. during low pedestrian density), and in the evening, between 15:30 – 17:00 (i.e. during high density population). The maximum velocity of the scooter was set by limiting the power dial to mid-range. The analysis from these videos has led to a model which summarizes the relationship between the electric scooter velocity and the pedestrian density along the measured sections of the street. It is assumed for the purposes of this initial study that there is no difference in performance between the PICAV vehicle and the electric scooter used in the experiment. It is also assumed that pedestrians respond to the scooter in the same way they would to a PICAV vehicle.

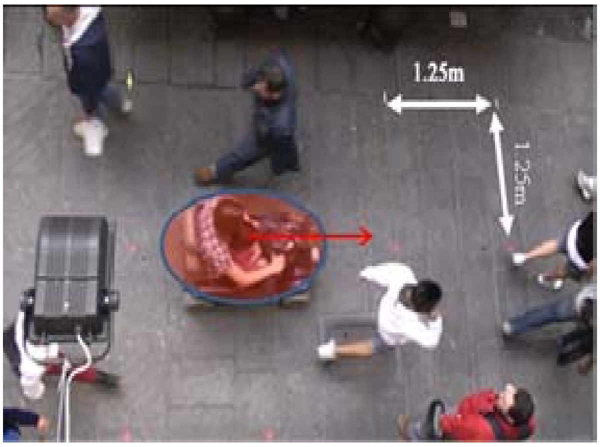

Figure 1: The electric scooter in the pedestrian area of Via San Luca

The analysis was performed by watching the video clips (Film No) and each run (Ride No) as timed from the moment the scooter entered the 18.75 m^2 area of interest until the moment it left. During this time the average pedestrian density was also recorded. Values of density are expressed as the number of pedestrians per square metre. Rides were completed in both upslope and downslope directions. Eight rides were filmed in the morning, and 36 in the afternoon. Usually, morning rides refer to low values of pedestrian density, while afternoon rides were characterised by high values of pedestrian density. The rides are the following. The entrance film time and the exit film time refer to the time reported in the video tape for when the scooter entered and exited the area of interest. It is expressed in this way: mm:ss:d. where mm = minutes ; ss = seconds ; d = decimal, i.e. 01:10:9 means: 01 minutes, 10.9 seconds.

2.1. The density-velocity model

The empirical data has been filtered to exclude three runs in the morning and three in the afternoon. These rides were different from all others as they required the scooter to avoid specific obstacles and so it did not travel in a straight line. The remaining rides have been used to create the relationship shown in figure 2, which shows the average pedestrian density on the x-axis and scooter velocity on the y-axis.

Several relationships between speed and density were explored using the statistical package R. The models explored were:

1. Linear model between scooter speed and pedestrians density.
2. Linear model between: scooter speed on one side; and on the other side pedestrians density plus an index being 1 if the scooter is going upslope and 0 if it is going downslope.
3. Polynomial models between scooter speed and pedestrians density, where s = speed, k = density. One such model could be e.g.:

   $$s = a k^4 + b k^3 + c k^2 + d k + e \qquad (1)$$

   where a, b, c, d, e are some coefficients.
4. Logarithmic and exponential model: e.g.

   $$s = a \exp(k) + \mathrm{b} \quad \text{or} \quad s = a \ln(k) + b \qquad (2)$$

5. Discontinuous linear model: e.g. $s = a\,k + b$ where a and b have two values, e.g. there is a threshold in the density, called k_0; therefore: $a = a_0$ if $k < k_0$ and $a = a_1$ if $k \geq k_0$. Several values of k_0 have been explored.

The linear model $s = a\,k + b$ performed quite well, with an adjusted R-squared value of more than 0.55 and high level of significance for both the constant and the variable (the density). When the further models were investigated it was found that the increase in complexity of the model did not result in large improvements of the adjusted R-square value. Increased values were found (0.58 – 0.59), but as the increase in the R-squared value was so small when compared to the increase in complexity it was decided to use the linear model. This is defined by the following equation:

$$v = 1.57751 - 1.44677\,\rho \qquad (3)$$

where v is the velocity of the scooter (m/s) and ρ is the density of pedestrians (number of pedestrians /m^2).

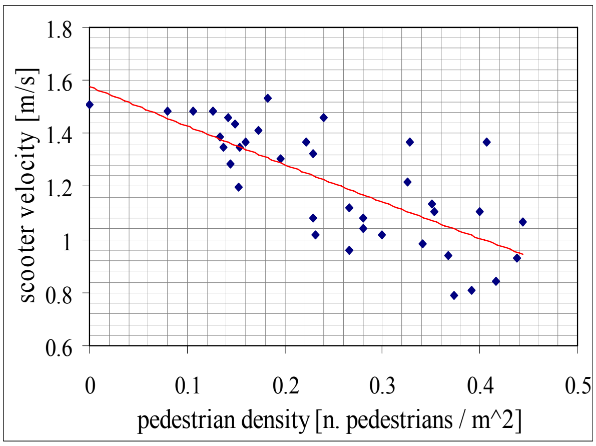

Figure 2: Pedestrian density – scooter velocity model

One drawback to the empirical work undertaken is that it was difficult to get a full range of densities and thus it was not possible to test varying velocities or driving strategies. For this reason a series of experiments will be run at PAMELA to test these various variables so that a fuller model can be developed. The next section will describe the details of these experiments and how they fit into the larger scope of the PICAV project, both in terms of vehicle design and also fleet dimension and management.

3. MODELLING OF URBAN PEDESTRIAN ENVIRONMENTS

A series of experiments are currently underway at the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA). The experiments will add to the range of data for the vehicle velocity-pedestrian density model. They will also enable a *pedestrian model* to be developed, which will be used to understand pedestrian-vehicle avoidance behaviour (see Figure 3). A large part of the analysis will involve the use of automatic pedestrian tracking; the algorithms for this will be developed as part of this project, but are not described in this paper. The results of the pedestrian model will be fed into the SiVic simulator (described in section 4.1) and used to generate people within the simulator that can react in a *real* way to a scooter. This will then enable human-machine driving interfaces to be tested for various types of people e.g. elderly and disabled people.

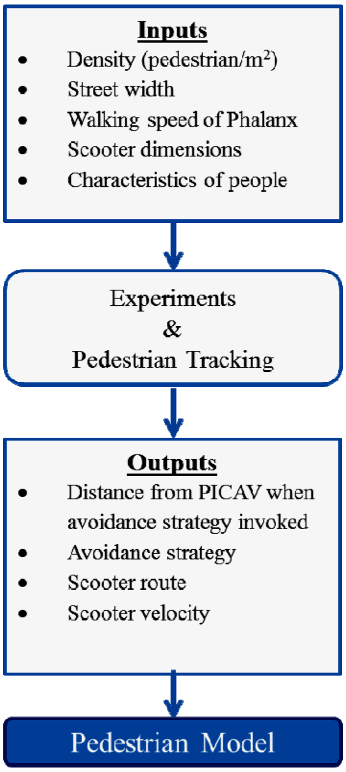

Figure 3: Flowchart of pedestrian modelling process

The PAMELA facility will now be described in section, followed by experimental methodology and a description the SiVic simulator.

PAMELA is part of the Accessibility Research Group (ARG) at University College London (UCL). It is a purpose-built unique space in which the pedestrian environment can be reproduced in detail. It consists of 82m2 of moveable platform, which can be raised/lowered/tilted to create the desired topography. The laboratory is explained in greater detail in Childs et al. (2007).

For these experiments, PAMELA is configured with 3 lanes: 1.2m, 1.4m and 3.6m wide. The interactions will be explored by asking a phalanx of people to advance towards a scooter along on of the lanes. The phalanx will consist of 9 people placed in three rows of three, in order to represent the widest controllable set of interactions between the crowd and the vehicle and between the members of the crowd (see Figure 4).

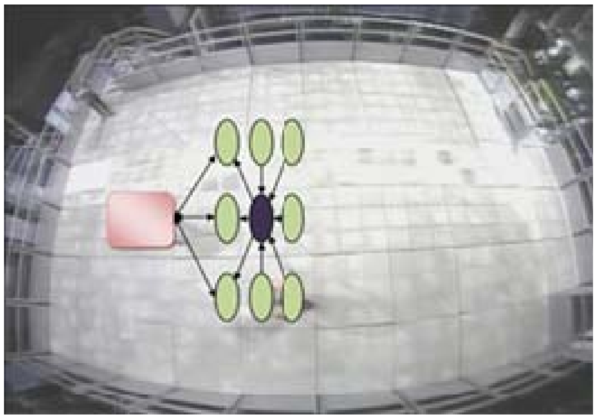

Figure 4: PAMELA laboratory configuration

The experiments will present the pedestrians under different density conditions in terms of the space within which they are set (to represent different street widths). The spacing between each pedestrian at the outset of each experiment is maintained constant (0.7m longitudinal, 0.3m transverse) in order to retain the same inter-pedestrian interactivity as far as possible. The phalanx will be instructed to proceed at different speeds towards the scooter and recordings made of the various routes taken by the pedestrians to avoid the vehicle. The spacing between each pedestrian is expected to change as a result of the interactions with the vehicle and these differences will be measured. In the first experiment the vehicle will be stationary, but in subsequent experiments the vehicle will proceed towards the phalanx at different speeds. There will be a total of six experiments (directions refer to the orientations inferred in Figure 4):

Table 1: PAMELA experiments: movement conditions

Experiment	Scooter movement	Phalanx movement
1	Stationary	Left
2	Right	Right
3	Right	Left
4	Right	Down
5	Right	Down, Up
6	Right	Left, Right

At present it is anticipated that the input parameters for the PAMELA experiments will be: Density (pedestrians/m^2), available space for dispersal (street width), walking speed of the phalanx, size of scooter, initial intended speed of scooter, characteristics of people. The outputs would be: dispersal profile of phalanx, dispersal profile of the central pedestrian (show in black in Figure 4), route of the scooter, and speed changes of pedestrians and scooter. Each pedestrian will be instructed to act individually i.e. they will not be travelling in groups. Therefore any platooning which does occur will occur due to the experimental conditions as opposed to social circumstances.

These outputs will form the basis for the calculation for pedestrian *viscosity*, something which will be used to calculate trip times in a later section of the project. They will also be used to develop general rules (heuristics) of pedestrian avoidance mechanisms. These heuristics will be used to program pedestrians in Sivic.

Furthermore, the level of service (LOS) of the footway for the pedestrians will be calculated. This will be done by measuring the space available to pedestrians (m2/person), the flow rate of the pedestrians (person/minute/m).

3.1. Process for pedestrian model

The pedestrian model will be constructed by creating a database of trajectories and velocities for each pedestrian and the scooter. This will be done using a combination of OpenCV and Python. The database will then be analysed to create a number of heuristics for modelling vehicle-pedestrian interactions in the built environment.

3.1.1. Automatic pedestrian tracking

The interactions will be recorded and evaluated using a combination of OpenCV and Python. OpenCV is a *library of programming functions for real time computer vision* and Python is *an interpreted, interactive, object-oriented, extensible programming language*. In the PAMELA experiments each of the pedestrians will wear a different colour hat to aid with automatic video detection and tracking. This will aid the automatic detection of people's routes. This should make creating the algorithms easier.

3.1.2. Pedestrian model

The pedestrian model contains all of the velocities and trajectories of the pedestrians and the scooter from the PAMELA experiments. These paths are used as an input to the simulation described in section 4. From these velocities and trajectories a set of heuristics will be created. They will include the minimum, mean and maximum distances from the scooter at which pedestrians begin to change their trajectory when approaching a vehicle given the following inputs: pedestrian density, speed of the vehicle and pedestrian characteristics. Finally a plot of average scooter speed against pedestrian density will be created so that accurate trip times can be measured.

4. SIMULATION OF THE MOTION OF SMALL VEHICLES

4.1. SiVIC (Gruyer 2005)

This simulator is a virtual sensors prototyping platform developed by the laboratory LIVIC (IFFSTAR). Its objective is to reproduce faithfully a real road scene, the dynamics of a vehicle and the operation of the onboard sensors.

Its main feature is to enable the same interactions as the ones onboard a real vehicle: steering wheel, acceleration, braking, etc. This can allow us to prototype some driving assistance solutions, to test this application in dangerous situations without any material risk to users, vehicle or other people and to reproduce scenarios.

To deal with complex scenarios, the simulator has a set of functionalities, such as onboard proprioceptive sensor model (odometer, accelerometer, gyrometers, ...) and exterior sensors (cameras, laser scanner, ...) and a management module of dynamic events. Pedestrians have been added to the SiVic environment and given velocities and trajectories of real pedestrians. These have been taken from the Genoa experiments.

4.2. Couplage of SiVIC and RTMaps (Gruyer 2006)

RTMaps is a fast prototyping software for real time multi sensor applications. It can easily retrieve and merge data from different sensors. Moreover, we can write and create easily computer programs using these data. Gruyer et al. (2006) have realized a coupling between SiVIC and RTMaps. This allows us to retrieve with RTMaps the data from a simulated sensor and test this on different scenario applications created with RTMaps. One of the RTMaps features is to test applications with data recorded during experiments. Then we can directly install these applications in the vehicle. The coupling between RTMaps and SiVIC allows us to test these applications with more and more complex scenarios as soon as we can create them in SiVIC. Once the application is validated on the simulator, we can directly test them in the vehicle. For this, we can use exactly the same computer programs written for RTMaps.

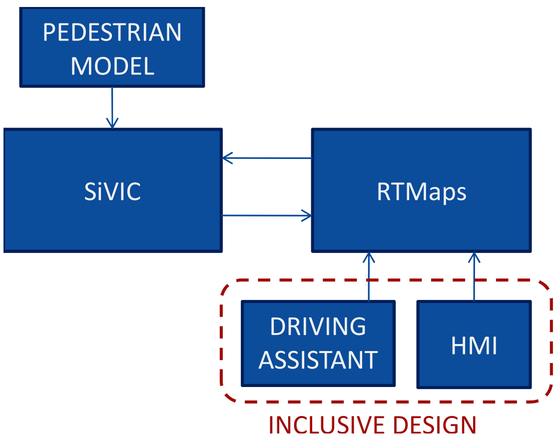

Figure 2: Inclusive Design process

This allows us to investigate different approaches to assistance for the driver of the vehicle, including the HMI, before taking the step of placing a person in the vehicle.

ACKNOWLEDGMENTS

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Catherine Holloway graduated from the National University of Ireland, Galway in 2004 with a B.E. Industrial Engineering & information Systems (Design stream). She worked as a research & development engineer for Medtronic for 2 years before beginning her PhD with the Accessibility Research Group (ARG) at UCL. She completed her PhD on the effect of crossfall gradients on wheelchair accessibility in 2011 and is currently working as a post-doctoral researcher in ARG on the PICAV project.

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Nick works with clinical, engineering, social science, arts and humanities researchers in order to explore exactly how a person interacts with their immediate environment. Nick's research portfolio amounts to some £20 million in funding from Research Councils, industry and government and he has established research projects in Latin America, Japan, China and the EU as well as in the UK. Nick invented the Pedestrian Accessibility and Movement Environment Laboratory at UCL and as developed a line of research which is leading the world in terms of evaluation of built environments in terms of actual measurable impacts on humans. Nick was the Director of the MRC Symposium on Healthy Ageing and the Physical Environment in Beijing in 2010.

Nick is the Director of the UCL CRUCIBLE Centre, which is an interdisciplinary Research Centre for Lifelong Health and Wellbeing, funded by four Research Councils. He is a member of the UCL Council, the Joint Board of Moderators of the Engineering Institutions of the UK, the EPSRC Transformational Research Advisory Group and Member of the HM Treasury Infrastructure UK Engineering and Interdependency Expert Group. He currently has 7 PhD students (4 FT, 3 PT). Completions in the last 5 years are: Cognitive approach to accessible information systems (2002 – 2010), Microscopic simulation of pedestrians in 3D environments (2002 – 2009), Bus rapid transit systems and feeder routes – a micronetwork approach (2003 – 2009), Biomechanics of wheelchair propulsion.

Nick is a Fellow of the Institution of Civil Engineers and a Fellow of the Royal Society of Arts.

REFERENCE MODEL FOR THE DEVELOPMENT OF STOCK MANAGEMENT IN SUPPLY CHAINS

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ABSTRACT
This research is performed in several enterprises which develop their activities in connection with the services, commercial, and production fields. These enterprises have in common their relation with the stock management. Cuban enterprises are facing problems such as lack of availability, supply unstableness, poor studies of demand, and obsolete productions. This research proposes to make an assessment of these problems from the point of view of the enterprises in connection with their supply chains. Such a comprehensive analysis is poorly developed in Cuban enterprises so far. Stocks represent immobilized money thus the main objective is to keep them at the lowest possible level that guarantees a high service level to the customer and the achievement of an economical and fluid management of resources. The introduction of a reference model to assess the status of the stock management in both the enterprises and the supply chains is also proposed.

Keywords: Reference model for stock management, stock indicators, logistic cycle, assortment policy.

1. INTRODUCTION

Stock management is a complex activity, thus it is impossible to evaluate it through specific isolated indicators and parameters. Only a comprehensive assessment of results makes possible to determinate the correct level of development of the enterprise in this field. For instance, any enterprise which has a high stock rotation level but at the same time cannot guarantee a high availability of products would be evaluated as "efficient", thus disregarding the fact that its services to customers, a key factor in logistic management, are affected. Parameters depend on each other to work at a suitable level and if an enterprise focuses on optimizing only one of them, thus paying no attention to a system of interrelations, this could impair its global objective of achieving a high competitiveness level. It should be taken into account that the stock represents immobilized money which directly affects the enterprise's incomes (MULLER 2003), and that its improper management can directly affects a whole organization.

An inadequate stock growth, at the enterprise level, cannot be solved through the application of reductive actions that work only punctually, but through a global review of the form of organization that brings about such mistakes, and then to take the necessary corrective steps. The stock is the result of the enterprise management behavior and a consequence of the management of relationships within the enterprise. It cannot be viewed only as a responsibility of a specific area, but as a process in which different factors are working together such as procurement and sales or commercial activity, logistics, finance, production and even the legal area, all of them affecting the occurrence of surpluses, shortages and the desired rationalization level. (De Vries 2007; Gómez and Acevedo 2007)

Some authors said that the inventory management will not be completely effectively only with the utilization of the operation research theory, because it needs to include organizational and qualitative aspects. In other hand, the utilization of complex inventory techniques is not a guarantee for the minimization of stock level; the key is the inventory process management. (Zomerdijk and De Vries 2003)

The stock management needs an integral attention, not only at the enterprise level, it is also necessary to establish and evaluate the relationships between stocks and the supply chains (Acevedo 2008), taking into account the relationships among the supply chain links (Ballou 2004), aiming at the integration of its members to achieve the objectives that meet the final customer's requirements. Best in class companies manage the inventory at network level, and this is a differentiation factor with the laggard ones (Viswanathan 2009). A proper stock management is fulfilled through a proper functioning of the relationships within the enterprise structure which is supported by the supply chain's framework. The main objective is that inventory management techniques achieve low stocks and improved customer service. (Wild 2002)

2. THE SITUATION OF STOCK MANAGEMENT IN CUBA

In Cuba several researches connected to the stock management issue, as a part of trainings and postgraduate courses, were conducted in more than 15 enterprises between the 2004 to 2011 period. During these studies problems have been found that affect enterprises belonging to different sectors of the market.

The results show that production, service, and commerce enterprises as well as hospitals, universities, factories, car repairing centers, and stores have similar management problems such as **lack of product availability at the market, supply unstableness, low stock rotation, an insufficient study of the demand, and a high level of obsolete products** all of which are directly connected with the stock situation. Therefore it is necessary that Cuban enterprises make the analysis of these problems from the enterprise's point of view in connection with the supply chain behavior. Also, it has been noticed the inexistence of methods at the enterprises which comprehensively support the stock management activity.

As a rule each area or department gives priority to its own objectives, disregarding those of the organization and this provokes an improper stock management function. Besides, those workers directly connected with de stock management lack the necessary knowledge and training to perform their jobs with an integral vision of the issue, and even in the case that the enterprise has advanced informatics systems, which in many cases include programs for the stock management handling, these tools are not properly employed either for ignorance or because the enterprise doesn't have the necessary structure. Hence, it is very important to point out the fact that at present the stock management issue is a must for an enterprise due to the world, as well as national, financial crisis. To face this situation it is necessary that each enterprise keeps its socks at the lowest possible level that guarantees the highest level of services to customers as a result of a fluid and affordable supply chain management, with the lowest immobilized resource level, and achieving a high availability and variety of products.

In practice the product's availability issue has been analyzed in several researches in all of which different problems have been pointed out. The followings are examples of this statement,

- In one university 68% of the products marketed in the professors'' virtual store has less than 95% of availability from May 2007 to May 2008.
- In an automobile repairing & maintenance service enterprise 73% of the products of a car line under consignation regime showed less than 80% of availability over the last year.
- In one transportation base 80% of the spare parts showed less than 60% of availability during the 2007 year.
- In a nationwide commercializing enterprise a survey was made for 4 different products: natural juices, meat products, soft drinks, and oils. Results showed that the overall availability was 27, 53%.

There is a contrast between the availability problems and the high levels of nationwide immobilized products in stock. One of the main reasons for this lies on the inefficiencies of the demand prediction activity due to: an improper study of patterns and tendencies related to a product; both the qualitative and the quantitative methods to define the product's demand are insufficiently employed. Is a common practice to define the demand through empirical methods and further more codification systems cannot guarantee the reliability of data processing due to, among other factors, to its bad quality.

Another problem is that enterprises do not apply a proper assortment policy and the main example of this is a nationwide commercializing enterprise which during 2010 sold more than 650 millions USD employing different kinds of marketing sites which ranged from large malls to little stands. At the stands which represent 12% of the total sales, due to a bad assortment policy problems arise such as: lack of shelve space to display the products, and poor merchandizing techniques. As a consequence 14000 codes of different products were sold because there was no guidelines for the supplies which failed to support the stability of commodities on offer, this is a risk in a retail management because they work with a high number of stockkeeping units. (Bowersox, Closs and Cooper 2002)

Codification is a common problem among all the studied enterprises. There are different problems with the code standardization, as well as with the standardization of the descriptions of goods. So, it is possible to find that the same product exhibits different codes in the database. Another problem is that more than 50% of the studied enterprises cannot guarantee that the same product exhibits the same code throughout its internal chain of market places. In several databases products were identified which have different codes at different places of the chain, this affect the product's traceability as well as any other demand analysis that might be necessary to perform. The core of this problem is the lack of a definition which establishes, with no exceptions, that each code for each product is centrally created.

Another problem is the low stock rotation of goods, which results in higher warehouses maintenance costs, and higher losses and wastages of products. It also results in a low rate of the investment return, all of which adversely affects both the enterprise's net incomes, and its ability of payment to suppliers.

Since the Cuban economy largely depends on imports, many Cuban enterprises have commercial relationships with international suppliers. As a general rule, order cycles are quite extended and unstable (3 to 6 months with less than 50% of shipments stability). Besides, due to an inefficient stock management, an improper assortment policy, and the lack of studies concerning the composition of the order cycles the generalized common practice is to order large amounts of goods which occasionally results either in idle stocks or slow moving stocks. In other cases, for the same reasons, when there is a need for an urgent consignment normally suppliers send it to Cuba as airfreight which largely increases the costs of the operation. Another problem is that the suppliers-customers relationships are weakly established, and the supply chains in which the Cuban enterprise participates, mainly as a link within the national supply chain, have a deficient organization, and wants for integration between chains links. This, along with: a) the absence of a systematic evaluation of suppliers in reference with the accomplishment of contracts and its effects on logistics, and b) the inefficient internal management of supply orders has created an unnecessary stock surplus in Cuban enterprises. This situation, in turn, has resulted in a disproportionate chain of unpaid debts which an improper use of the enterprise's active capital makes heavier.

The main reason which brings about the above mentioned situations is the poor skills of enterprises' executives and specialists on the advanced concepts and techniques of stock management. Even though the methods for planning and carrying out good stock management practices are widely exposed in the scientific literature, and that this issue is usually taught in both technical and higher education (embracing both pre graduate and post graduate teaching), enterprises' executives and specialists do not clearly master the use of this concepts in the institutional practice, and therefore their decisions are mainly based on their operational experience rather than on any analytical method. Besides, their knowledge is based on those aspects related to operational researches, rather than on the organizational management science related to the stocks.

This problem gets worse with the application in Cuban enterprises at present of the ERP (Enterprise Resource Planning) systems such as SAP, EXACT, ASSETS NS, and others. All the potential advantages of these systems are not fully exploited because, at the Cuban enterprise level, the determination function of the organizational working parameters is too weak. It has been observed that even though these systems are at present available which are capable to gather all the data related to the stocks status, and to store this information in large databases, the personnel in charge makes no use of it. Instead, they use these systems only as a data storeroom, and no further processing of such information is made. It can be said that the presence of this issue in both pre graduate and post graduate teaching programs at the universities is insufficient. (Manual de ASSETS 2004)

3. A PROPOSED SOLUTION

First, it´s important to said that the performance of inventory systems is influenced by its organizational architecture, not only for the planning and controlling process. (De Vries 2005)

Since a suitable level of the stock status results from enterprises organization within the supply chain frame, it is necessary the development of the fundamental bases to accomplish the improvement of this situation. These bases are supported on 5 basic components of the institutional organization which are the followings:

- Demand management
- Assortment policy
- Product codification and classification system
- Organization of the logistic cycle
- Purchase planning and organization

The results of previous researches have showed that the centralization of stock management planning activities is not a guaranty of the achievement of higher service levels with lower stock levels (Zomerdijk and De Vries 2003; De Vries 2005). It is also necessary to make efforts toward the fulfillment of the 5 basic components above mentioned. Furthermore, efforts should be based on both the intra-enterprise relationships, and the supply chain (Ayers and Odegaard 2007). This is the condition that guarantees a sustainable stock management at the enterprise level; it is not a partial solution to any punctual problem.

The organization of the **demand management** process guarantees a more reliable determination of the needed amounts of raw material which should be obtained through the supply chain to satisfy the requirements of the final customer (Fleury, Wanke, and Figueiredo 2000), while, in turn, the definition of **the assortment policy** allows the enterprise to decide which products should be placed at the market, with all the process based on the real market demand, and on strategic decisions.

The organization of the **product codification and classification system** guarantees the feasibility of the information system, and it also facilitates the control and decision taking activities due to the reliability of the obtained data. It would be difficult to analyze the information gathered for each individual product, thus the organization of products into groups facilitates the analysis of the information and save time. (Barry 1991; GS1-Cuba 2005; ONE 2008)

The organization of the **logistic cycle** makes possible a continuous flow of operations to cut it short, and then focus efforts on increasing its stability (Gómez and Acevedo 2007). Besides this, it is necessary to work with the information about cycle time duration or lead time in order to take decisions concerning the **purchases management,** a process supported by the 5 basic components to start on the flowing of raw material at the supply chain. (Ballou 2004)

Fig. 1 shows the diagram representing the stock management model which guarantees that the planning and control activities meet the objective of rationalize the stock.

Figure 1: Organization components defining the stock.

The correct organization of the 5 basic components enables the enterprise to properly perform the stock planning and its control to meet the final customer requirements with a minimal cost. The problem to accomplish this in Cuba is the lack of a tool which allows enterprisers to evaluate the stock management functioning level from the analysis of the different aspects of the organization since many solutions focus on those aspects connected with operational researches without taking into account the organizational aspect.

Usually it is possible to calculate some indicators that bring about results which can be analyzed to take decisions, but it is impossible to determinate, with an acceptable degree of accuracy, which are the critical points of the management that should be improved, and even its strengths are difficult to determinate due to the lack of a suitable tool to evaluate whether the management work is performed, as it should be done, to meet problems and to find the proper solutions according to the present development of knowledge, as it is defined by the good stock management practices which are included in the proposed model.

The proposed model is based on the enterprise evaluation according to those aspects related to good management practices, which are organized in several groups (De Vries 2007). These are connected to integration issues such as: demand management; the assortment policy; stock codification and control systems; stock management and parameters methods; stock classification systems; studies on logistic cycles and their variability; warehouse management; informatics systems; in force legislation; integration within the supply chain; centralization level; evaluation of costs; distribution management; and the management of indicators. All these aspects should be evaluated according to well defined criteria which establish its relevancy in each case.

One of the objectives of this tool is to obtain the integration between both the demand and the supply activities to increase the stock management in our system, having into account the real demand of consumer, and so speeding up the raw material flow to avoid either the occurrence of product accumulations due to a low demand, or the occurrence of losses due to a bad management of resources with a better use of the invested capital.

3.1. The results.

On applying this tool in a commercializing chain a number of problems in the stock management activity were detected which directly affected chain performance, such as:

- 2,5 inventory turns in a year
- More than 80% of products had less than 50% of availability in 2010, while only 10% of products had more than 90% of availability

It was defined that 42% of the model aspects represent weaknesses and for these strategies were defined which contain the following tasks:

- To define and to apply a primary registration system to perform the calculation of both the indicators, and logistic costs.
- To increase enterprise's wholesale and retail distribution (routing; allocation; costs; and service level measurement.)
- To improve purchasing methods (contract management and cycle management)
- To improve commercial activity (assortment policy design and its control; ordering system; and consumption and demand analysis.)
- To achieve internal integration at the commercial chain.
- To achieve integration at the supply chain (development of integration projects at the national supply chains and management of

contracts with the external suppliers of logistic services.)

- To perform availability studies adjusted to both the international standards. (Commodity shortages at salesrooms), and the internal country policies (reports from the Cuban Internal Trade Ministry (MINCIN).
- To perform the calculation of the stock parameters at each link of the chain and its practical application in Havana City sales stands.
- To devise a solution to the product ownership transference issue at the supply chain in order to increase the reliability during the commercialization activity.
- To design a container traceability system
- To create educative courses on stock management for the enterprise workers.
- To design distribution centers.

Model application brings about the following improvements:

- The application of the assortment policy at small sales stands and definition of the 300 basic commercial products.
- The availability increasing of the selected products (40% of products showed more than a 90% availability)
- Rotation increases (50% of the selected products showed more than 12 turns in a year.
- Higher efficiency in the supplying and storing process.
- Adjustment of the production plans of 2 regular suppliers to the actual requirements of the supply chain.

4. ACKNOWLEDGMENTS

- The stock inventory results from the relationship and process managements in the enterprises which occur within the supply chain framework.
- At present, stock management is supported by an integral management that should be performed having into account the relationships among processes, activities of all the enterprises participating within the supply chain. It is necessary the organization and integration of processes intervening in the stock management to achieve a reliable and economic performance.
- The basic condition to achieve a sustainable planning of the stock inventory is the fulfillment of the 5 basic organization components already described based on both the relationships established among enterprises, and the supply chain.
- Product and service supplies should be adjusted to the actual demand at each sales point prioritizing the visibility and the actualization of stock levels and movements.
- All the enterprises participating in the supply chain work together and make their plans to satisfy specific requirements of the final customers, rather than to fulfill their particular production plans, in order to increase their efficiency and.
- Each participating enterprise and organization makes its plan of activities based on a unique demand prediction standard: the final customer requirement.
- Management at the enterprises focuses its efforts on producing, importing, and supplying on time according to the market demand. To meet these objectives the necessary planning and control methods are already established which allow for the accomplishment of these goals, along with both a high availability of products, and a high ability to supply products and services to final customers.
- The stock management is backed up by: the informatics system; the staff training; the legal framework; and the influencing factors.
- Information systems and technologies should be integrated in order to facilitate a systematic information exchange among the supply chain participants that includes the use of the electronic trade and Web systems.
- The integrality of the indicators is a must so as to obtain full information from them on taking accurate decisions. Partial analysis should be avoided.
- Supply chains should pay a permanent attention to the increase of staff training and professionalism, including managers, technicians and other workers, through the cooperation among its members

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INTERCOMPRAS® CONTAINERS: AN INTEGRATIVE TOOL OF THE LOGISTIC INFRASTRUCTURE AND MANAGEMENT OF SUPPLY CHAINS.

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ABSTRACT

Freight transportation is, for any country's economy, the backbone of the production and service activity logistic organization. At present, the trend of the international cargo movement is characterized by the increasing use of containers in the commercial trade of goods. This process is accompanied by two facts: in one hand production of containers worldwide is insufficient to meet the demand, and on the other hand the increases of containers' customs duties concepts such as taxes, delayed return cycles, etc., all of which results in the need for speeding up the rotation cycle of all containers at present available in the international trade. The InterCompras® Containers System provides a new concept for the logistic chain of containers' movement, with the support of Internet/Intranet software, as the backbone of the supply chains within the country, as well as of the traceability of these freights unitizing means.

Keywords: traceability, containers, supplies chain management.

1. INTRODUCTION

Freight transportation represents, for any country's economy, the backbone of the production and service activity logistic organization. At present it is recognized that businesses do not compete as isolated enterprises but as Supply Chains, and at present their transformation into Security Networks is envisaged.

Supply Chains working within the national economy framework share the country's general service infrastructure such as containerized cargo management, sea transportation means, harbor terminals, railroad & road transportations of goods, road transportation, the cabotage activity, containers storing at different warehouse lots (Load & Unload Centers, hired warehouses) while at the same time chains make use of their own infrastructures.

In Cuba, due to its insular condition, harbor facilities are the main connection points to perform the exchange of merchandises. Also, its open economy accounts for the fact that all the supply chains within the country start at harbors, being these the places where raw materials, components and parts of every kind, equipments, as well as other commodities are received.

The worldwide containerized freight movement increases every day, and Cuba is not an exception (Vila, 2009). It is known that more and more shipping companies concede shorter expiry dates for containers returns, and that, at the same time, tax rates imposed on unreturned or delayed containers continuously increase. If each member of the supply chain has only partial information about the containers' situation, this is a risky condition for the economy. Therefore, it is necessary to devise an integral container cycle management which allows keeping a record of it traceability from its arrival in any harbor to its final return through the application of a new systematic model which by integrating this concepts, provides for a system of analysis and control as an accurate tool to take timely, effective, and efficient actions, in order to guarantee a high level of services to clients. A solid integration of these concepts is only possible by using advanced informatics and communication technologies and through its consolidation in an informatics system.

2. INTERCOMPRAS® CONTAINERS: A MANAGEMENT AND TRACEABILITY SYSTEM.

The development of the InterCompras® Containers Informatics System has focused on both the design, and the application of an integral control of container's cycle, which includes the main actors of containerized cargo movement chain throughout the country (Fig 1).

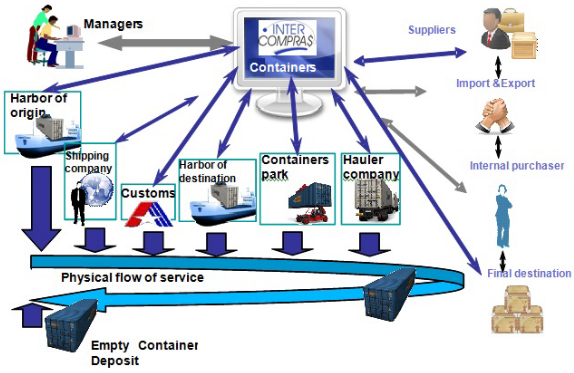

Fig 1. General design of the container management and traceability system.

The container management and traceability system is supported by the following 4 components:

1. The container cycle management model.
2. An informatics system to process information.
3. An infrastructure that guarantees connectivity among the framework links.
4. The education and training of the personnel in charge.

The basic principles on which the system should be based are meant for ensuring the following actions:

1. To trace out any container either at the export & import activities, or at the internal circulation of the national economy.
2. To keep up-to-date information record about each container registered into the system. Delays in gathering the necessary information should be kept at a minimum.
3. To trace out the whole container life cycle. For this, it is also necessary to keep focus on the global process.
4. To make an integral planning of the container's activities throughout its life cycle.
5. To keep control of the activities in which the container is involved.
6. To keep control of all the expenses resulting from each one of the container's activities.
7. To keep control on the accumulated expenses for each container.

2.1. Container Cycle Management Model.

The Container Cycle Management Model has been developed from the definition of the following elements:

- The container's cycle and its requirement.
- The container identification parameters.
- The container management parameters.

2.1.1. Container's Cycle.

The container's cycle definition has been conceived in a general way, from the primary actions to establish a contract and other details in coordination with the merchandise supplier, down to the final container returning operation to its owner (Fig 2.), so as to ensure an integral picture of the container's cycle. It also allows an accurate identification of the institutions responsible for each steep of the container's cycle, as well as the duration of each cycle's steep.

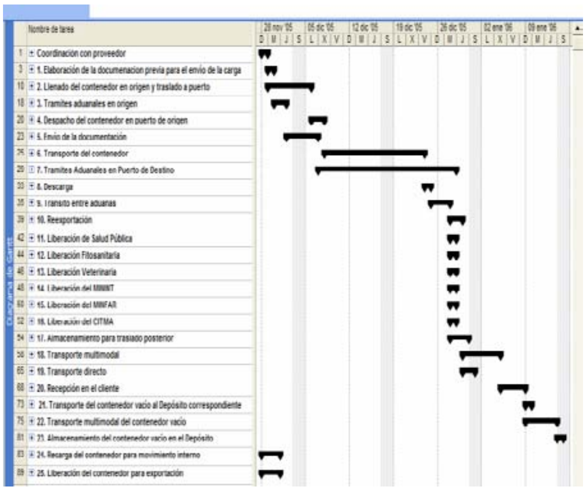

Fig 2. Imported container cycle.

The main requirements of the Imported Container Cycle are associated to the duration of some processes which are subjected to time regulations that should be met. If any importation container exceeds the fixed time duration values for a given process, it generally should pay a penalty in cash for that reason.

2.1.2. Definition of the container identification parameters.

In order to perform correct traceability actions of any resource, one of the essential requirements is to relay on an accurate definition of its identification parameters, since these allow resource localization at any moment of its life cycle. It has been already established 30 identification parameters for cargo containers, which are described in the InterCompras® Containers System Organization Manual. Among the main parameters are the followings: Identification Code; Type; and Length. Besides, the system allows users to add new parameters according to their needs. Fig 3. shows the Informatics System Interface which picks up the identification parameters of containers.

Fig 3. Identification Parameters of Containers.

2.1.3. Definition of the management parameters of containers.

The management parameters of containers should enable the planning and control of the container cycle, thus ensuring a reliable traceability of resources. The main management parameters of containers are the followings: process duration; process costs; container's state; and state of the activities. Gomez (2009) in his paper defined activities as “the total amount of tasks performed by one doer in a time period equal or longer than 1 day, within a process framework”.

3. CONTAINER MANAGEMENT MODEL AUTOMATION.

The automation of the container management model has been made through the InterCompras® Containers System based on the concept of using informatics as a key factor to modify the general notions about management that should be introduced into the movement chain of the containers. Besides, the automation of the container management model should be evaluated from both the organization, and the informatics points of view.

From the organization point of view the InterCompras® Containers System has been conceived on the grounds of 2 basic functions:

1. **To exert control:**
   a) On container behavior throughout its life cycle
   b) On the behavior of all participants at the container movement chain within the country
2. **To conduct the planning of:**
   a) The container movement throughout its life cycle performing a service.
   b) The activity level that each participant of the container movement chain should be performing in a given moment.

From the informatics point of view the InterCompras® Containers is an automated system which is structured to respond for the 5 basic processes of the organizational concept showed in Fig 4.

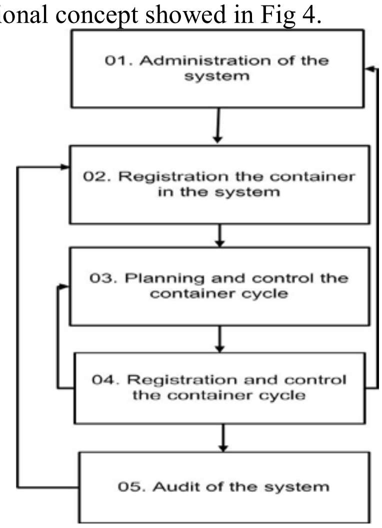

Fig 4. Container Management and Traceability System Processes.

The container management and traceability activity as supported by the InterCompras® Containers System, which in turn is backed up by either Internet or Intranet, maintains a constant communication among all the container movement chain participants 24 hours a day, 7 days a week. The status of each container is actualized at each defined control point at the chain. Also, it is possible to use different alternatives such as manual work, filing, web service, etc. to recover as well as to transfer data into the System.

4. SUPPLY CHAINS AND CONTAINER MANAGEMENT AND TRACEABILITY.

Nowadays the enterprise management in Cuba should be adjusted in accordance to new paradigms such as the followings:

1. To accomplish the integration of the whole chain (or network) from suppliers to final customers.
2. To perform a temporary synchronization of the results of all chain processes.
3. To produce and to supply at any moment according to the demand.
4. The final costumer keeps pulling the movement of the entire chain.
5. Enterprises become competitive as a participant in a chain, not individually.

In order to fulfill these paradigms it is necessary the use of sound logistics concepts, and an integral management of the supply chain. (GICS) (Acevedo, 2008).

The InterCompras® Containers System provides a modern concept as to the logistic chain management of containers movement as the backbone of supply chains within the country.

The application of this System in any company has a significant impact since it allows identifying and to conduct the planning concerning the localization and activities of each container moving through the logistic chain, supported by software based on the Internet/Intranet service, with a more proactive planning and control of container's cycle. At the same time, the system allows the planning and control of the activities level of each participant within the supply chain, as it is showed in Fig 5.

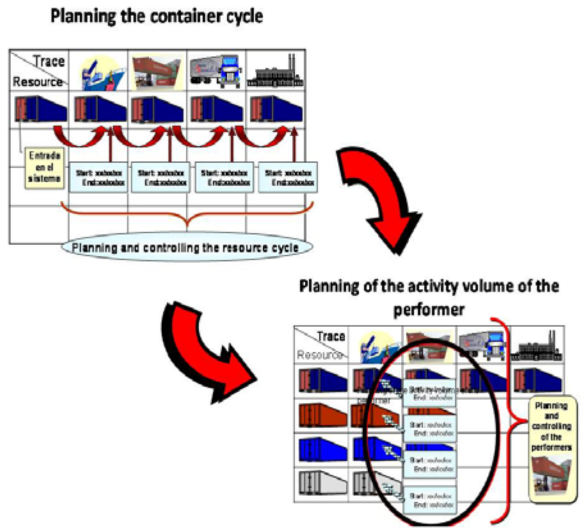

Fig 5. InterCompras® Containers System control and planning functions.

In this sense the informatics system becomes an essential tool for the logistical management of container movement within the supply chain, since it guarantees the planning and control activities of containers from the original supplier to the owner of this unitizing resource. That is why it can be said that, more than merely create an informatics system, a whole management model of containerized freights has been conceived.

At present there are systems that perform traceability of containers at only parts of its life cycle, basically in the case of traceability systems at shipping companies. However, this only allows a partial visibility of containers' life cycle.

The application of the InterCompras® Containers System in any entity is performed in a personalized way which implies a careful process of adjustment and design according to the peculiarities of each enterprise. The application project embraces the following elements:

- An organization project for container management and traceability.
- Software installing and personalization.
- Training of the personnel in charge.

The application of the InterCompras® Containers System has the following significant effects on container management and traceability within the supply chains:

- To improve clients' satisfaction.
- To increase responsive ability in the presence of unexpected troubles during the process.
- To decrease chain cycle.
- To reduce stocks.
- To reduce costs within the supply chain.
- To reduce the obsolescence of both resources: the merchandises, and the containers.

5. CONTAINER TRACEABILITY IN DRUG SUPPLY CHAINS.

Supply chains for the production and commercialization activities of medical drugs in Cuba are performed by the Drug Distributing & Commercializing Enterprise (EMCOMED) belonging to the Chemical & Pharmaceutical Enterprising Group (QUIMEFA) of the Ministry of Basic Industries. EMCOMED is a logistic operator that provides different services linked with the storing, distribution, transportation, and commercialization of raw materials and medical drugs for QUIMEFA entities as well as for health institutions throughout the country. As a logistic operator EMCOMED is responsible for the movement of containerized cargos which arrive in the country.

The EMCOMED logistic chain of imported containers extends from the international suppliers to the final customers in Cuba. It also takes care of the returning cycle of containers which ends up in the empty container deposit, as previously agreed.

Before the application of the InterCompras® Containers System, containers traceability at EMCOMED was made based upon a reactive way of gathering information, which prevented taking timely decisions in response to troubles, due to the slowness of the information processing and transmission to each one of the chain participants.

At present the Cuban enterprise EMCOMED has already established the InterCompras® Containers System according to the method shown in Fig 6. (Rodriguez, 2010).

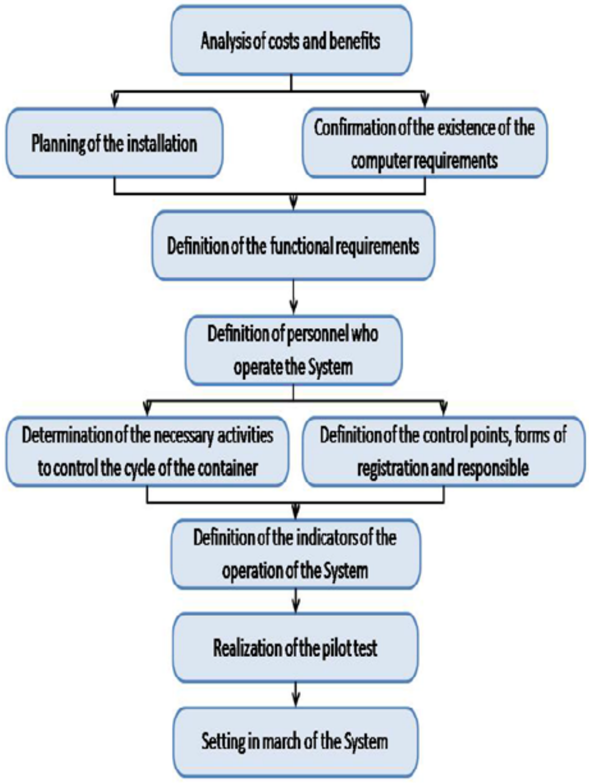

Fig 6. Application Method of the InterCompras® Containers System at EMCOMED.

InterCompras® Containers works as a connective tool among the supply chain participants, since each one of them should be keeping a record of every action they perform upon the container at any moment, whether it deals with a physical or mechanical operation or an informatics operation as well. Container's importer is the responsible agent for checking in each container into the System's registry. Also, the importer is responsible for keeping track of the first traces of each container until it is extracted out of the harbor facility limits.
The transportation of containers from the country's harbors to their different destinations is performed either by automotive means, or by multimodal means of transportation. The use of different transportation means is showed in Fig 7.

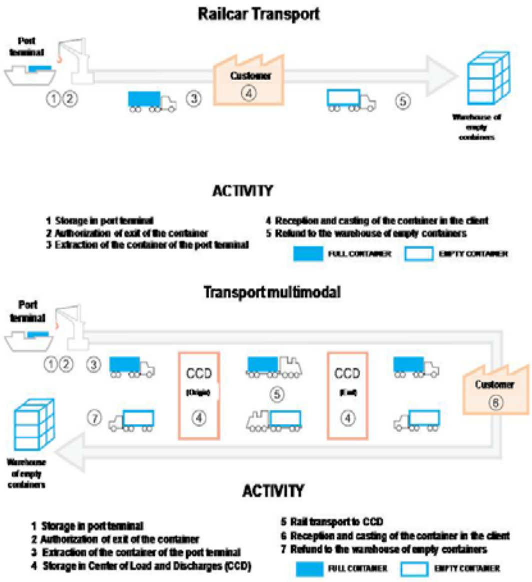

Fig 7. Transportation means of containers within the country.

EMCOMED holds responsible for containers' traceability in either way of transportation as reflected in Fig 7. However, it should be pointed out that the final customer or receptor is responsible for confirming the proper moment of container's reception in his own facilities. At present, the application of InterCompras® Containers System at EMCOMED has made possible to perform a better management of containers based on the followings advantages:

a) There is a more accurate and on real time control about container's situation.
b) There is a better definition of the responsibility of each participant in container's life cycle.
c) Penalty payments due to delays in container's return have been reduced.

6. CONCLUSIONS.

1. The InterCompras® Containers System is a tool that guarantees the management of container's movements within the supply chain frame work, through its permanent traceability 24 hours daily, every day of the year.
2. The InterCompras® Containers System can be applied in either a specific supply chain, or in a group of supply chains or organizations, as to ensure planning and control activities of containers' movement throughout its life cycle.
3. The InterCompras® Containers System application at EMCOMED allows the following advantages: there is a better definition of the responsibility of each participant in container's life cycle; it is possible to keep an “on line” control of each container in progress within the supply chain framework; it reduces penalty payments due to delays in container's return to the shipping company owner of this resource.

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EVALUATION METHODOLOGY OF THE IMPACTS OF BUS RAPID TRANSIT CORRIDORS (BRT) IN LIVORNO NETWORK

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ABSTRACT
The objective of the European project TIPS&Info4BRT was to study, analyze and evaluate the impacts and benefits of BRT corridor realization (Bus with High Level of service-BHLS in Europe). The BHLS can be seen as flexible concept able to be introduced in different contexts (urban, sub-urban area, etc.) with different service schemes and realization levels. This document faces different aspects which have to be studied and evaluated in order to realize a BHLS corridor. The first part focuses on both the characteristics and the interventions on the neighbouring areas supporting the implementation of the Corridor. Whereas, in the second part, each step of the proposed methodology is described in order to evaluate the impacts on the private traffic and the benefits for the Public Transport. The proposed methodology is suitable to be adapted in any kind of city.

Keywords: BRT/BHLS, traffic light priority, assessment of traffic impacts

1. INTRODUCTION
TiPS&Info4BRT -"Traffic lights Priority System and Information work-flow for Bus Rapid Transit Corridors" project is a European project financed by fifth EraSME program of 7FP involving Italian and German partners promoting the cooperation within SME and Research Institutes at transnational level. The project will involve 5 partners (3 SME and 2 Research Organizations) geographically distributed in Tuscany (Italy) and North Rhein Westphalia (Germany). Study cities involved into the project are Livorno and Aachen, in particular Italian consortium worked for the design, testing and validation of prioritization measures for the corridor in Livorno (1) and the German consortium worked for the design, testing and evaluation of road work event management modules (2).
The project started on December 2009 and lasts 18 months.
TiPS&Info4BRT project focuses on the evaluation of the impacts of the introduction of BHLS corridors in medium size cities by using simulation tool. In order to reach this objective, the overall assessment process deals with two different phases and supporting measures involved in BHLS implementation:

1. evaluation of impacts and validation for priority management measures at traffic lights to be activated on a BHLS corridor proposed for Livorno network. In this pilot site the study of the performances that public transport can reach adopting a good mix of physical and technological priority measures has been demonstrated;
2. evaluation and validation of the benefits of the use of a sw tool for the management and the distribution of road work event information. This tool will be integrated with simulation environment in order to assess the impacts of traffic flow redirecting measures.

To reach the above objectives, the activities carried out by the project are the following:

- Analysis of the state of art of current trend for the implementation and operation of BHLS corridor (adopted technologies, priority measures, etc.);
- Contribution to increase the awareness of the methodological steps required for the planning of BHLS corridor, evaluation of benefits and impacts, etc. through the local dissemination activities and the organization of workshop/seminars at regional level;
- Elaborate guidelines for the planning study of BHLS and the feasibility design of the whole transport system as a package (supporting measures, ITS systems, etc.);
- Evaluation of both the impacts on the private traffic flow and benefits for PT service through the use of simulation tools and results assessments;
- Synergies with running initiatives at EU level (COST).

2. BHLS CONCEPTS
The BHLS name was firstly launched in France and then largely adopted due to the relevant role carried out

by French organizations (i.e. CERTU) and experiences in pushing up the promotion of such public transport systems and in consolidating the awareness of its role, benefits and potentials.

The above mentioned increasing interest fostered:

- the discussion on the role and the potentials of such kind of transport scheme in different scale of EU cities/urban/metropolitan area;
- the benchmarking and cross-related evaluation of the various experiences grew up in EU, sometimes born without a strong coordination action of National Authority (except France and few others countries);
- the funding of EU level initiatives able to analyze the trend under progress in the different EU countries and to enhance the national initiatives by promoting the identification of best practices, recommendations and supporting measures for the adoption of BHLS (i.e. COST action TU603: "Buses with a High Level of Service (BHLS) - Fundamental characteristics and recommendations for decision-making and research", involving 14 EU countries);
- the involvement and contribution of EU stakeholders and representatives to the think-thanks which are taking place at world level (i.e.: ITDP Institute for Transportation and Development Policy BRT World Congress, Guangzhou, 27 September – 1st October 2010, 90th TRB Transportation Research Board Annual Meeting, 23-27 January 2011, Washington, etc.). These events highlight that an EU approach to BHLS is emerging: it takes the fundamental from the consolidated experiences operated in North America even if it quite far from these and from the large mass transport system adopted in Asia and other emerging countries where BHLS role in wide conurbation is comparable to the role of train transport offer in our countries.

Some differences are possible to be identified between the European experiences and world context will. However this paper focuses on the European level.

BHLS can be seen as a flexible concept able to be introduced in different context (size of the urban area, operated transport services, service scheme, infrastructure implementation, etc.). The differences in the reference context to lead the identification of different objectives for BHLS implementations: this involve various options for the realization of the corridors and the operation of service.

Generally speaking, some common issues can be identified for BHLS:

- higher reliability compared to bus transport services;
- high performances in terms of quality and comfort (bus stops, platform, vehicles, etc.);
- strong appeal of the service and increase of its marketing potential (name, logo, colour of vehicles and stops, etc.).

Analyzing the European experience it is possible to point out the difference service scheme and dimensions, investment costs, etc, on the basis of the reference context,. The difference of BHLS approach between metropolitan areas and medium size cities will be detailed including the different role BHLS can act: feeder of tramway services in large metropolitan areas, main urban axis for mass transit in large/medium size cities integrated with other public and mobility public transport services: bus feeder services, bike sharing, etc.);

In order to reach the above mentioned objectives, it is required to act at three different level:

- Infrastructures: dedicated right of way, bus lanes and other traffic engineering measures that protect the bus services from delays in traffic;
- Priority for buses at traffic signals (at crossing points, etc.) which can be divided into two typologies (also mixed system can be adopted);
  - Physical ones: lay-byes and passing lanes at bus-stops, so that buses do not delay each other, etc.;
  - Prioritizations at cross points;
- ITS systems to assist operations management and problem-solving (fleet monitoring, electronic payment system, etc).

The presentation will give an outlook of EU running implementation: the classification will be carried out in terms of performances, adopted ITS solutions, measures for priority, etc.

3. BHLS CORRIDOR COMPONENTS

The objective of a BHLS corridor realization is to provide a service with an high level of service, preserving the right balance between interventions on the road infrastructures and available resources.

Concerning each one of the possible selection for the different elements interested by the BHLS corridor have been pointed out both the vantages and the disadvantages.

The main characteristic of the BHLS service is the dedicated corridor in order to guarantee the high system performances.

The corridor level protection is to evaluate on the basis of the existing road infrastructures and on the basis of the users behaviour. A consequence of the BHLS corridor realization is a new organization of the public areas; i.e. the realization of new cycle lanes, pedestrian areas, etc.

So, on the basis of the previous considerations, it is important to increase the PT services use, in order to obtain the traffic flow reduction in line with the capacity road decrease, as consequence of the required private traffic number lanes reduction .

Furthermore it is important to evaluate the exclusivity level of the corridor, the location of the corridor in respect of the axis road, etc.

3.1. Road Infrastructure characteristics

The road infrastructures could present different conformation on the basis of several characteristics: i.e. the exclusivity level of the corridor, the level of protection in relation of the other vehicular class traffic flow, etc.

The BHLS corridor could be realize on a new or existing road infrastructure and this is one more aspect to take in consideration.

Furthermore it is possible to use different level protection in the same corridor, on the basis of the road (and others) characteristics.

3.2. BHLS Corridor Location

The BHLS corridor realization entails several interventions which have to be carried out on the adjacent areas. The interventions could be present different characteristics on the basis of BHLS corridor location (in the road centre or at the road sides).

3.3. Bus Stop

One more element which affects the level of service and safety for the users is the location of the bus-stops along the BHLS corridor. The main characteristics to be consider are:

- Distance between two next bus-stops;
- Placement;
- Platform and bus-stop structure characteristics;

3.4. ITS System

The ITS systems help and are indispensable to achieve an high performance level of the BHLS service. The main and important system which have to be used in order to guarantee a reliable public transport service for the users and a manageable system by the operators point of view have been included in the following list:

- SAE/AVM System;
- UTC system;
- Traffic Light Priority system;
- Automatic Fare system;
- Security – Video surveillance system,

3.5. Bus Line Logo (brand the service)

Usually a BHLS service is developed on the earth surface, so it required to be easily detected by the users with an exclusive brand of the bus line.

It is very important to associate a good and exclusive image to the service, in order to give the idea of reliability of the services and in order to permit to the users to detect the BHLS line on the urban area.

4. METHODOLOGY FOR THE PLANNING OF THE CORRIDOR

During the project a methodology to be adopted for the planning study of the corridor was defined. The methodology can be generalized accordingly to the study of corridors in other context/cities. The main steps of the defined have been the following ones:

- Creation of the model:
  - Traffic data collection (or alternately the analysis of available data and its updating to generate the O/D matrix);
  - Generation of the road network associating the road and other characteristics to each network element (lanes number, traffic light periods, etc.);
- Calibration of the network model concerning the current state;
- Identification of the simulation scenarios;
- Evaluation of the private traffic impacts (means delay time at the junctions approach, means queue length at the junctions approach);
- Evaluation of the PT benefits in terms of travel time and delay time (comparison of the performance between a conventional bus line and the BHLS corridor). The comparison has been made under two scenarios:
  - Dedicated lanes;
  - Mixed traffic conditions.

The simulation results have been assessed from the point of view of traffic impacts and benefits for Public transport service (comparing, among the other factors, the travel time and the delay time between the current BUS Line 1 and the designed BHLS).

4.1. Traffic Data Collection

The O/D matrix of the City object of the study can be obtained using the data collected through the last available Census. Afterwards it could be updated using the gathered data using, i.e., data traffic measures campaigns.

4.2. Road Network

The generation of the road Network requires several kind of data: road geometrics characteristics, traffic light periods, lanes number, etc.

Each one of these fundamental information can be find through different way, i.e., it is possible to find the lanes width and similar information using satellite photos or DWG files (and similar) of the City in object.

The traffic light period could be gathered through hand measures campaign or with the cooperation of the society in charge of traffic lights system management.

4.3. Network Model Calibration

In order to carry out the calibration process it has been made a comparison between the values collected through the running simulation and the values obtained using the forms defined and included in the HCM 2000 manual. In this way it has been possible to verify the correlation between the "simulated" values and the "real" values in order to show their similarity.

The considered parameters which have been considered are the delay time and the mean queue length.

The HCM 2000 defines the methodologies both in case of a un-signalized junctions and of a signalized junctions.

The calibration will be considered positive if the linear correlation factor and the Root Mean Square Error (RMSE) provide satisfactory results.

4.4. Identification of the simulation scenarios

After that the calibration process provides the expected results it is possible to proceed with the generation of the simulation scenarios. There are different fields where it is possible to intervene in order to obtain different situation and traffic flow condition, i.e. it is possible to change the road geometrics characteristics, to hypothesize different BHLS corridor, to change traffic light characteristic (cycle length, periods, etc.), and so on.

4.5. Evaluation of the private traffic impacts

The running simulation of the generated network model of the City provides indications concerning the impacts on the private traffic flow caused by BHLS corridor realization. In this way it is possible to evaluate the better solution between the different simulation scenarios identified. Also in this case it have to been considered the two parameters just seen at point 2.1.3. : delay time and mean queue length at the junctions approach. They have to be compared with the limit values defined in the HCM 2000 manual in order to have at least an acceptable Level of Service.

4.6. Evaluation of the PT benefits

The evaluation of the PT benefits can be carried out through the comparison of the travel and delay time of different public transport service (conventional buses system and BHLS system) along a shared part of the bus line. It is possible to deep the study up to find the commercial speed of both the kind of service (in this case it is required to hypothesized more parameters of the services, i.e. "Stop&Go" situation along the bus journey, time stop at the bus station, etc.).

5. THE CASE STUDY OF LIVORNO CITY

In this section the application of the above mentioned methodology to Livorno context has been described. In particular the results of the simulation work point out the relevance to join the physical measures (like dedicated corridor) and the control commands (like the demand coordinated responsive traffic light plan).

Currently several corridors are supposed to be restructured as BHLS service. One of these started from railways station to the business district; this has been the object of simulation study carried out within Tips&Info4BRT project. The corridor is introduced on one of the most important axis of Livorno public transport network in terms of passengers and headways of currently operated lines. The routing of the corridor is currently operated partially by Line 1 and partially by Line 2.

5.1. Planned BHLS Corridor in Livorno

The main mobility axis in the City of Livorno are:

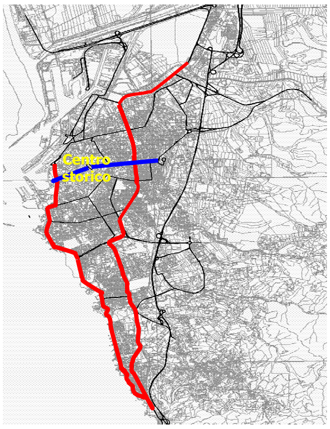

Figure 1 – Main Transport Axis of the City of Livorno

- East – West
- North – South

The Line 1 covers these two main axis, starting from Piazza Dante (Railway Station) to Miramare Ardenza.

The Line 1 service characteristics are:

- Frequency: two Buses every 15 minutes (7 minutes + 8 minutes);
- Buses Capacity: about 80 passengers;
- Path Length (From Piazza Dante to Miramare): about 7 Km.

The partial renewal of Line 1 as BHLS and the implementation of a prioritized corridor aim to increase the performances of public transport service on a main axis thus increasing the number of users and improving the mobility conditions, the overall accessibility to the city and the quality of life. The BHLS corridor is represented in the next figure.

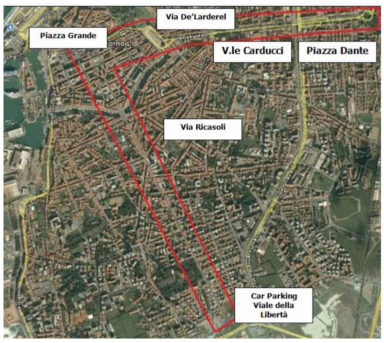

Figure 2 – Livorno City & BHLS Corridor (© 2010 Google Earth)

The BHLS Corridor is characterized by several important intersections placed along the Line which have been required a in-depth study and analysis.

5.2. Model calibration

The model calibration has been carried out using the HCM 2000 manual.

The manual present the methodologies how to calculate the values of the parameters to be compared with the values collected through the running simulation. In this way it has been possible to verify the correlation between the "real" values and the "simulated" values in order to show their similarity.

The first parameter which has been considered is the delay time.

The HCM 2000 defines the methodologies to calculate the delay time in the case of a un-signalized junction and of a signalized junction

In order to have more details it is possible to consult the HCM 2000 manual in the suitable section (section 16 for the signalized junction and section 17 for the un-signalized junction).

The correlation between the calculated values and the values collected with the running simulation is showed in the following graph:

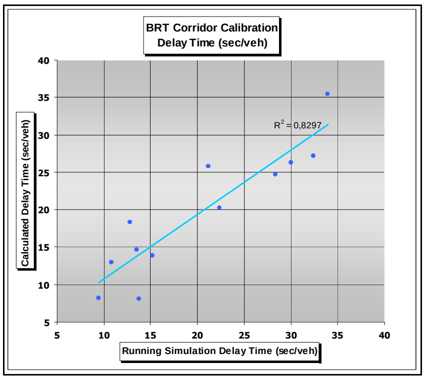

Figure 3 – Delay time Linear Correlation

As it is possible to see, the $R^2 = 0.83$. This means that there is a good linear correlation between the results above mentioned. Furthermore also the RMSE value has been calculated to verify the line inclination (a result equal to 0 means that the line inclination is 45°). The RMSE is calculated in function of the difference between the values of the first group and the values of the second group: RMSE = 3.60 sec/veh. This value confirms the good correlation and then the Network Model reliability.

After the delay time the queue length correlation is also considered. The methodologies used is based on two different formulas concerning the case of signalized junctions approach and the case of un-signalized

The correlation between the calculated values and the collected values through the running simulation is included in the following graph:

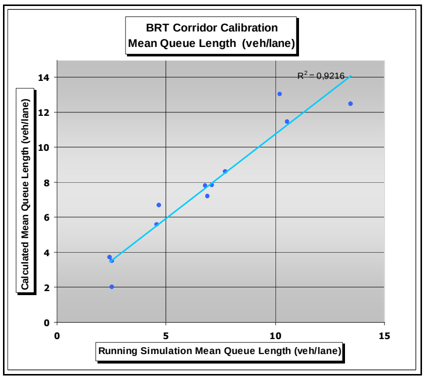

Figure 4 – Mean Queue Length Linear Correlation

The $R^2 = 0.92$. This means that there is a good linear correlation between the results above mentioned. Also in this case the RMSE value has been calculated to verify the line inclination (a result equal to 0 means that the line inclination is 45°). The RMSE = 1.30 veh/lane. This value confirms the good correlation and then the Network Model reliability.

On the basis of the collected results it is possible to conclude that the generated network model is an appropriate model of the current state.

5.2.1. Simulation Scenarios

The Future scenario has been defined including new reserved lanes building the BHLS Corridor. It is possible to point out the main change along the BHLS Line: the first one is the change of the route from Via De'Larderel to the parallel minor street of Viale Giosuè Carducci (direction: from West to East).

This is an important change for the viability and the general traffic flows, because it has required also an in-depth analysis of the traffic light time cycle length and its phases.

Furthermore the hypothesized BHLS presents the following characteristics:

- Frequency: 6'00'';
- Number of Buses: 7 vehicles operating the line (BHLS Corridor) at the same time 1 used as reserve.

The comparison between approach delay time concerning the Current State and the Future State has highlighted an important increase of the private traffic delay time. The reasons can be grouped as following:

- Viale Carducci: going on from Piazza Dante to Piazza della Repubblica there are several sections which present the same lanes number of the current state network, but one of these is reserved for the Public Transport, so the private traffic lane available get a lower capacity (this will bring more constraints for private traffic flow and higher delay time);
- The Bus line prioritization entails that during a cycle one or more phases miss their turn. So it is required that, after the prioritization end, the

traffic light controller (or the UTC system if it is present as in this case) defines the starting point of the new cycle or the strategy selected to divide the green time to the various phases. This event entails a disadvantage for the private traffic flow which must be considered in the total costs/benefits ratio together with the evaluation of the advantages for Public Transport.

In order to implement a suitable cycle time of the traffic light and the phases duration the Black Box optimization system has been used; this procedure has been developed by Engineering University of Florence, partner of the project (use for the most critical junction of the corridor).

Through the use of the available tools (simulation software, optimization procedure, etc.) it has been possible to hypothesized the necessary interventions on the road network of Livorno City (and each one of its components) so that the approach private traffic delay time at the junctions were acceptable and better than the critical limits defined in the HCM 2000 manual.

6. CONCLUSIONS

The Travel/Delay Time of the Current main Bus Line and the BHLS service has to be compared in order to evaluate the improvement of the performances of Public Transport service obtained with the BHLS corridor realization. Delay Time for Public Transport system has to be considered as “the delay time that the public vehicle accumulates compared to the optimal routing”

The main Bus Lines to analyze are the Line 1 and the Line 2. Their routing are different compared to the BHLS corridor, so the comparison between the relative Travel/Delay time is possible only in some part of the corridor (shared routing with the current lines)..

The Bus Line 1 routing starts from Central Railway Station (Piazza Dante) and arrives to “Ardenza Mare/Miramare” (and vice versa), so the routing trunk which overlaps the corridor starts from Piazza Dante and it ends in Piazza Grande.

The characteristics of the Bus Line 1 service are the following:

- Frequency of the service: 7’00’’;
- The operating Buses are 8.

The Bus Line 2 trip starts from “Chioma” and arrives to the Central Railway station (Piazza Dante). In this case the routing trunk which overlaps the corridor is from “Viale della Libertà” to Piazza Grande (and vice versa).

The characteristics of the Bus Line 2 service are the following:

- Frequency of the service: 10’00’’;
- The operating Buses are 6.

The BHLS Corridor entails Public Transport travel/delay time lower than the current Bus Service. As mentioned above the comparison has been made on the shared part of Line 1 and Line 2 with the hypothesized BHLS Corridor.

Table 1: BHLS – Bus Line 1 comparison

From Piazza Dante to Piazza Grande			
	Bus Line 1	BHLS	Difference
Travel Time	753	364	-389
Delay time	70.81	22.03	-48.78

Table 2: BHLS – Bus Line 1 comparison

From Piazza Grande to Piazza Dante			
	Bus Line 1	BHLS	Difference
Travel Time	674	400	-274
Delay time	57.90	24.99	-32.91

Table 3: BHLS – Bus Line 2 comparison

From Viale della Libertà to Piazza Grande			
	Bus Line 2	BHLS	Difference
Travel Time	451	427	-24
Delay time	21.88	15.28	-6.60

Table 4: BHLS – Bus Line 2 comparison

From Piazza Grande to Viale della Libertà			
	Bus Line 2	BHLS	Difference
Travel Time	474	379	-95
Delay time	26.44	14.59	-11.85

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DYNAMIC MODEL-BASED FOR INTELLIGENT TAFFIC OPTIMIZATION INSIDE SEAPORT TERMINALS

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ABSTRACT
This work proposes a graphical model-based for traffic optimization of Intelligent and Autonomous Vehicles (IAVs) inside confined seaport terminals. The considered IAVs are used for the routing operations of containers. From the graphical representation, static or dynamic destinations can be reached using optimal trajectories. In order to reach the target by the (n+1)th IAV, the proposed algorithm gives the optimal path from the road network containing n IAVs. This algorithm takes in consideration the position, the speed, and the status of each IAV. Finally, a co-simulation is done using an industrial virtual port simulator. This work is done in the framework of the European project InTraDE (Intelligent Transportation for Dynamic Environment).

Keywords: Dynamic Graphical modeling, Maritime ports, Traffic Network, Optimal path, Intelligent and Autonomous Vehicles

1. INTRODUCTION
In the last decade, the seaport areas have been modernized according to the world growth. One of the main problems of the development in the ports and maritime terminals is the internal traffic management. Nowadays, the almost goods are transported using containers, because they have been designed for easy and fast handling. After arrival at the port, the containers are transferred in part to logistic area in optimal time. Automatic transport solution has been implemented by different ports from the North West Europe such as Rotterdam, Düsseldorf and Hamburg, to automate the handling of goods using Automated Guided Vehicles (AGVs). This solution has resolved some relative internal traffic issues, although it has highlighted several limitations, where these vehicles should not adapt to their surrounded environment.

Thus, one of the contributions of InTraDE project (http://www.intrade-nwe.eu) is to improve the traffic management inside confined space by developing a safe and Intelligent Transportation System (ITS) (Crainic, Gendreau, and Potvin 2009) using Intelligent and Autonomous Vehicles (IAVs). The developed ITS operates in parallel with virtual simulation software (http://www.oktal.fr) allowing a robust and real-time supervision of handling and routing operations.

As a part of InTraDE project, a dynamic graphical model for road network inside ports is proposed. In order to achieve the routing missions with safety conditions, a supervision schema of an ITS inside a confined space is proposed in Khalil, Merzouki, and Ould-Bouamama (2009). This supervision model, regroups seven phases by considering the dynamic operating modes of the involved IAVs.

The IAV routing problem is a complicated optimization problem, where containers have to be shipping, by a fleet of automated vehicles, across networks between many source and destination pairs. The graph theory has shown significant performances for modeling the transportation network. Among related works, one can cite the contribution of Hu, Jiang, Wu, Wang, and Wu (2008) in modeling urban traffic by employing a dual representation of the road network. Lin, Yu, and Chou (2009) solved the truck and trailer routing problem based on a simulated annealing heuristic. In Barcos, Rodríguez, Álvarez, and Robusté (2010) a study of routing design for less-than-truckload motor is developed. Ghaziri, and Osman (2006) studied the self-organizing feature maps for the vehicle routing problem with backhauls. Almost of these models are static and they do not consider the time dimension.

2. ITS DYNAMIC MODEL
We consider an ITS composed by stations, junctions, customers and intelligent and autonomous vehicles (IAVs). These IAVs, called *RobuTainer* (Figure 1), are 4 x 4 decentralized multi inputs multi outputs system (MIMO). They can be piloted manually or full automatically.

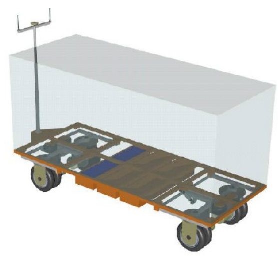

Figure 1: The IAV *RobuTainer*

Each IAV contains a real time monitoring system, makes it possible to detect and isolate the actuator and sensor faults. The MIMO structure of each IAV allows defining different control scenario to drive the IAV between two distant locations. This characteristic can be exploited to reconfigure the control system after fault diagnosis (Merzouki, Medjaher, Djeziri, and Ould-Bouamama 2007).

The dynamic model of the ITS, taking in consideration the time dimension, can be represented by a valued oriented graph $G_t(N, A, R, F_G)$, as it is shown in Figure 2, where, N is a finite set of nodes, divided in two distinct subsets: static and dynamic. The static nodes represent stations (S) and junctions (J), while the dynamic nodes represent customers (C) and vehicles (V). A is a finite set of arcs; connect static nodes to dynamic nodes. R is a finite set of arcs; connect static nodes each other, it represents roads in the transportation network.

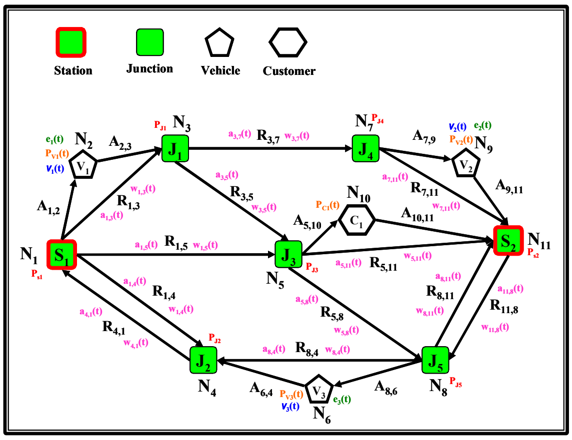

Figure 2: The ITS dynamic network $G_t(N, A, R, F_G)$

F_G is a set of time functions associated to the graph G_t. As an example, the set F_G can be described by the following functions:

- P_S and P_J are two constant functions associated to S and J respectively:

$$P_S: \quad S \rightarrow \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+$$
$$S_i \rightarrow P_S(S_i) = P_{Si} = (x_{Si}, y_{Si}, z_{Si})$$

$$P_J: \quad J \rightarrow \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+$$
$$J_j \rightarrow P_J(J_j) = P_{Jj} = (x_{Jj}, y_{Jj}, z_{Jj})$$

P_{Si} and P_{Jj} represent respectively the position of the i^{th} station and j^{th} junction. Their values are deduced from the ground mapping.

- P_C and P_V are two time functions associated to C and V respectively:

$$P_C: \quad C \times \mathbb{R}^+ \rightarrow \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+$$
$$(C_i, t) \rightarrow P_C(C_i, t) = P_{Ci}(t) = (x_{Ci}, y_{Ci}, z_{Ci})$$

$$P_V: \quad V \times \mathbb{R}^+ \rightarrow \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+$$
$$(V_j, t) \rightarrow P_V(V_j, t) = P_{Vj}(t) = (x_{Vi}, y_{Vi}, z_{Vi})$$

$P_{Ci}(t)$ and $P_{Vj}(t)$ represent respectively the position of the i^{th} customer and j^{th} vehicle at time t. Their values are deduced using appropriate laser sensors and Global Positioning System.

- V is a time function associated to V:

$$\mathsf{V}: \quad V \times \mathbb{R}^+ \rightarrow \mathbb{R}^+$$
$$(V_i, t) \rightarrow \mathsf{V}(V_i, t) = v_i(t)$$

$v_i(t)$ represents the speed of the i^{th} vehicle at time t. Its value is giving by the velocity sensor associated to the i^{th} vehicle.

- E is a time function associated to V:

$$\mathsf{E}: \quad V \times \mathbb{R}^+ \rightarrow \{V_N, V_F, V_D\}$$
$$(V_i, t) \rightarrow \mathsf{E}(V_i, t) = e_i(t)$$

$e_i(t)$ indicates the status of the i^{th} vehicle at time t. There are three status associated to the vehicle: normal V_N, failed V_F, and damaged V_D. The vehicle is considered in failed situation, when one or two of the whole actuators are damaged, except that it is capable to reconfigure itself by using the healthy actuators. The damaged vehicle is completely stopped when more then two traction actuators are damaged.

- a is a time function associated to R:

$$\mathsf{a}: \quad R \times \mathbb{R}^+ \rightarrow \{0, 1\}$$
$$(R_{i,j}, t) \rightarrow \mathsf{a}(R_{i,j}, t) = a_{i,j}(t)$$

$a_{i,j}(t)$ represents the accessibility of the road $R_{i,j}$ at time t. Its value is equal to "1" if the road $R_{i,j}$ is accessible and "0" otherwise. $R_{i,j}$ is the road relating the i^{th} node to the j^{th} one.

- W is a time function associated to R:

$$\mathsf{W}: \quad R \times \mathbb{R}^+ \rightarrow \mathbb{R}^+$$
$$(R_{i,j}, t) \rightarrow \mathsf{W}(R_{i,j}, t) = w_{i,j}(t)$$

$w_{i,j}(t)$ needed time to cross the road $R_{i,j}$ at time t. the time function W can be defined by the estimation algorithm developed below.

2.1. Estimation Algorithm

Let's consider the following assumptions:

- The experimental area is considered confined.
- The number and status of the vehicles are perfectly known at instant t.
- We suppose, for the used infrastructure, that a vehicle can't overtake another one, so, the followers will adapt their speed according to the leader.
- The waiting time at the junctions is neglected according to the limitation of the number of vehicles.

We denote by:

$n_{i,j}$: The number of involved vehicles on the road $R_{i,j}$.

$d_{i,j}$: The distance between the node N_i and the node N_j (the length of the road $R_{i,j}$).

$d_{i,Vk}$: The distance between the node N_i and the vehicle V_k.

$d_{i,Vk+1}$: The distance between the node N_i and the limit distance to react before the collision of V_k and V_{k+1}.

$t_{i,j}$: The needed time to travel the road $R_{i,j}$ in normal conditions.

$t_{i,Vk+1}$: The needed time to travel the distance $(d_{i,Vk+1}-d_{i,Vk+1})$.

$t_{Vn+1,j}$: The needed time to travel the distance $d_{Vn+1,j}$.

$\min(t_{i,Vk+1})$: The minimal value of $t_{i,Vk+1}$, with $1 \leq k \leq n_{i,j}$.

Begin
  For each $R_{i,j} \in R$
    $W_{i,j} = 0$
    If there are no vehicle on $R_{i,j}$ ($n_{i,j} = 0$) **then**
      $W_{i,j} = t_{i,j}$
    ElseIf $e_k(t) = V_N$, $\forall\ k \leq n_{i,j}$ **then**
      $W_{i,j} = t_{i,j}$
    ElseIf $\exists\ k \leq n_{i,j}$ / $e_k(t) = V_D$ **then**
      $W_{i,j} = \infty$
    Else
      Repeat
        For each $k \leq n_{i,j}$
          If $v_k < v_{k+1}$ **then**
            If $d_{i,Vk+1} \leq d_{i,j}$ **then**
              calculate $t_{i,Vk+1}$
        localize the (n+1) vehicles according to $\min(t_{i,Vk+1})$
        decrease the speed of V_{k+1} from v_{k+1} to v_k
        $W_{i,j} = W_{i,j} + \min(t_{i,Vk+1})$
      Until $d_{i,Vk+1} > d_{i,j}$, $\forall\ k \leq n_{i,j}$
      $W_{i,j} = W_{i,j} + t_{Vn+1,j}$
End

3. SIMULATION RESULTS

The simulation is realized on SCANeR studio@ (http://www.scanersimulation.com). This latter is a dynamic and real time simulator. It can be used to supervise a fleet of vehicles using a bilateral teleoperation.

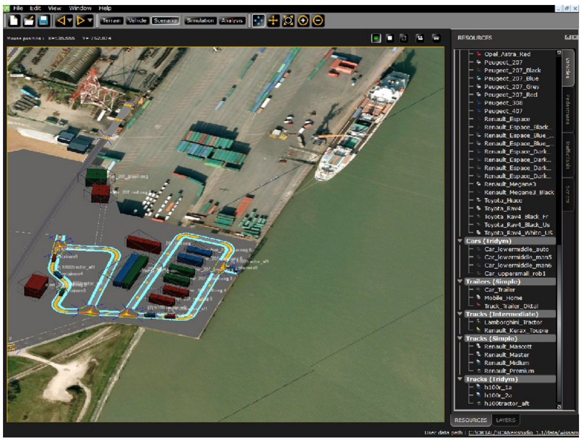

Figure 3: SCANeR studio@ for Radicatel port simulator

3.1. Terrain Description

In this section, we apply the proposed model on confined area of Radicatel terminal in Normandie (France), whose mapping is shown in Figure 3. Then, we represent the plan as an oriented valued graph in order to find the optimal path, taking in consideration the number and the status of the IAVs circulated inside the transportation network. We consider the same assumptions of the previous section.

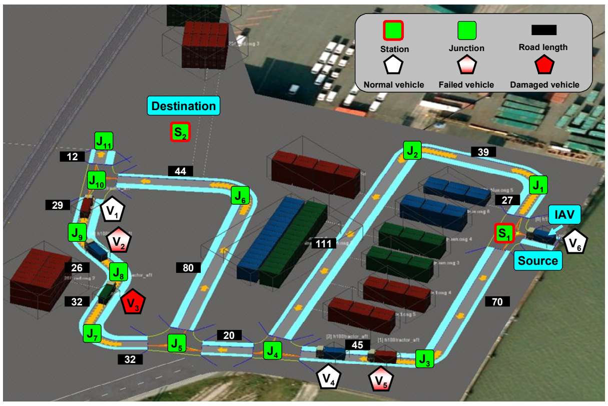

Figure 4: Port dynamic graph

3.2. Case Study

Let the graph of Figure 4, represents the studied part of the above port. As we can see, there are four possible routes relate the source S_1 to the destination S_2:

1. S_1; J_3; J_4; J_5; J_6; J_{10}; J_{11}; S_2
2. S_1; J_1; J_2; J_4; J_5; J_6; J_{10}; J_{11}; S_2
3. S_1; J_3; J_4; J_5; J_7; J_8; J_9; J_{10}; J_{11}; S_2
4. S_1; J_1; J_2; J_4; J_5; J_7; J_8; J_9; J_{10}; J_{11}; S_2

Table 1: Road lengths

Road ($R_{i,j}$)	Length (m)	Road ($R_{i,j}$)	Length (m)
S_1J_1	27	J_5J_7	32
S_1J_3	70	J_6J_{10}	44
J_1J_2	39	J_7J_8	32
J_2J_4	111	J_8J_9	26
J_3J_4	45	J_9J_{10}	29
J_4J_5	20	$J_{10}J_{11}$	12
J_5J_6	80	$J_{11}S_2$	40

Table 2: IAVs' information

IAV	Status	Relative displacement		Speed
		To	Distance (m)	(m/s)
V_1	V_N	J_{10}	7	5
V_2	V_F	J_9	11	3
V_3	V_D	J_8	9	0
V_4	V_N	J_4	15	5
V_5	V_F	J_4	30	3.5

The following scenario shows the optimal path between the source S_1 and the destination S_2, using three methods. The two first methods are classics, where the first one chooses the shortest path (the minimal distance) as optimal; the second method chooses the path, where the number of involved IAVs is the lowest, while the third one applies the estimation algorithm developed in this paper.

The road lengths of the road traffic network are showed in Table 1, while Table 2 shows some supposed information related to the five involved IAVs.

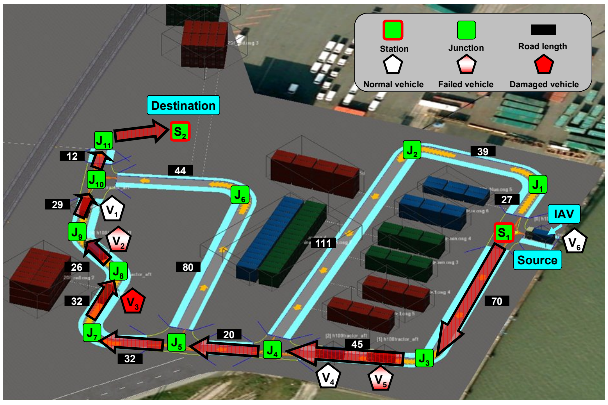

Figure 5: Optimal path according to the minimal distance

Applying the first method (shortest path), we find that S_1; J_3; J_4; J_5; J_7; J_8; J_9; J_{10}; J_{11}; S_2 is the optimal path (Figure 5), where the distance to travel is 70+45+20+32+26+29+12+40=306m in 70s.

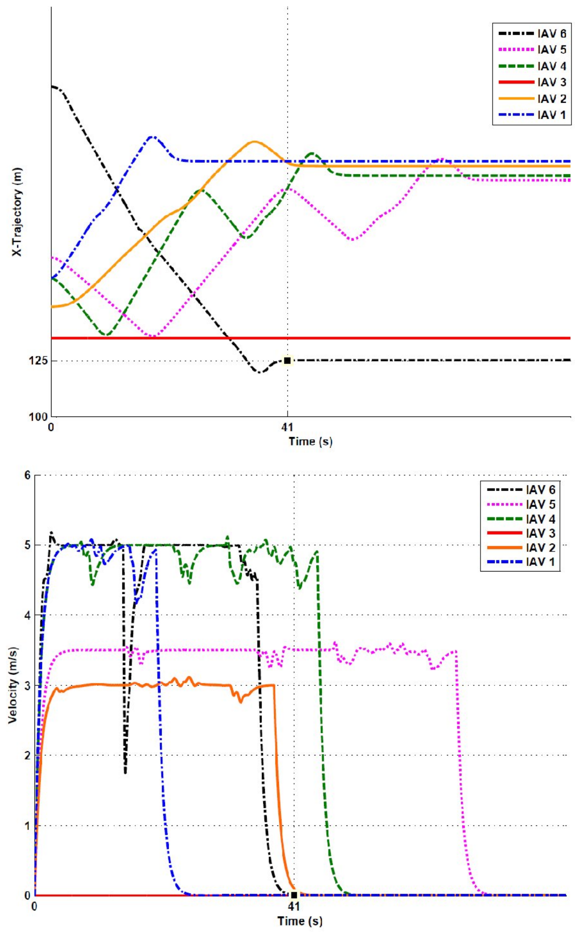

Figure 6: The vehicle V_6 can not reach its destination

In practice, the needed time to browse this path is ∞ because of the completely stopped vehicle V_3 on the road J_7J_8, which force the vehicle V_6 to stop after 41s as we can see in the simulation of Figure 6.

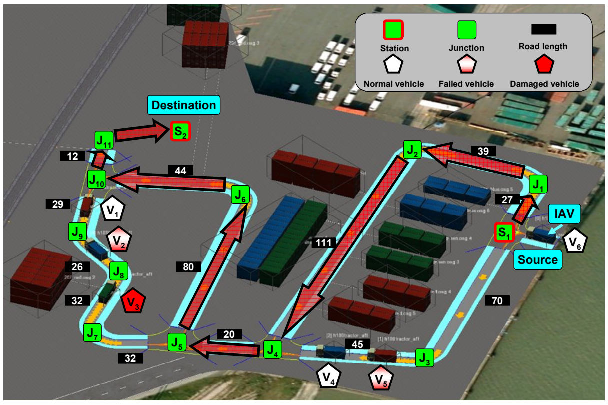

Figure 7: Optimal path according to the lowest number of involved vehicles

Applying the second method (lowest number of involved IAVs), we find that S_1; J_1; J_2; J_4; J_5; J_6; J_{10}; J_{11}; S_2 is the optimal path (Figure 7), where there aren't any IAV. Then the distance to travel become 27+39+111+20+80+44+12+40=373m in 84s.

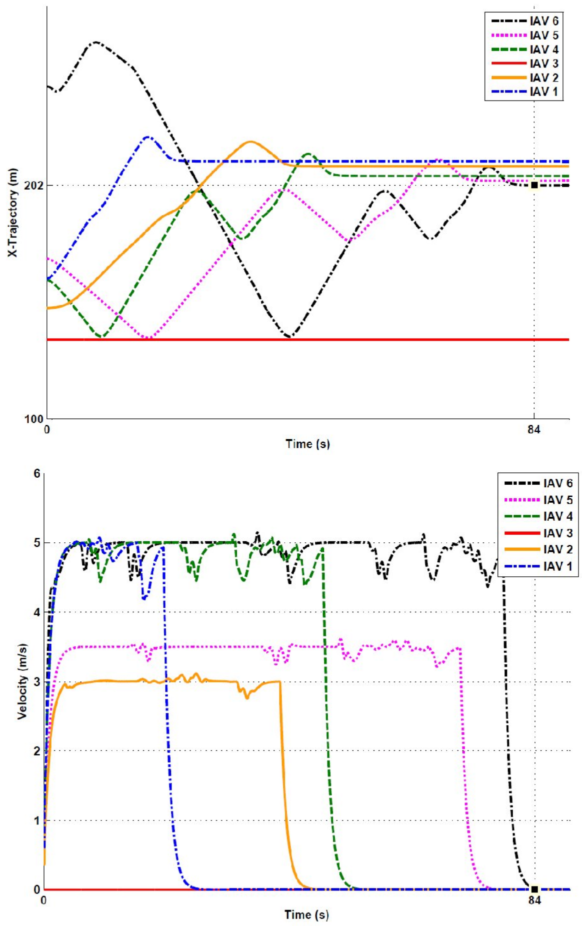

Figure 8: Reaching the destination S_2 after 84s

As we can deduce, this path is better than the first one (84s < ∞), even if the distance to travel is longer (373m > 306m).

The simulation in Figure 8 shows that the vehicle V_6 takes 84s to reach the desired destination.

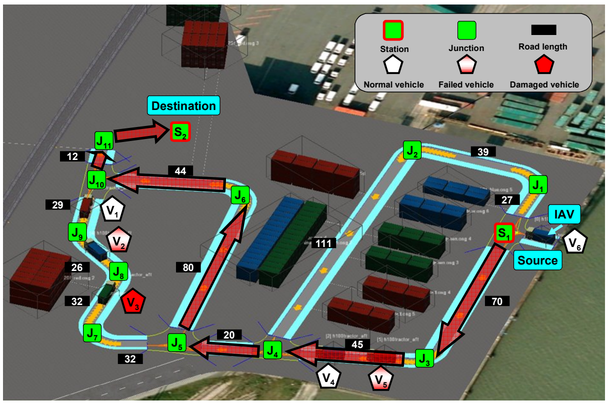

Figure 9: Optimal path according to the proposed algorithm

While, using our algorithm, we find that the optimal path is S_1; J_3; J_4; J_5; J_6; J_{10}; J_{11}; S_2 (Figure 9), where the distance to travel is 70+45+20+80+44+12+40=311m in 78s < 84s, which is the best path.

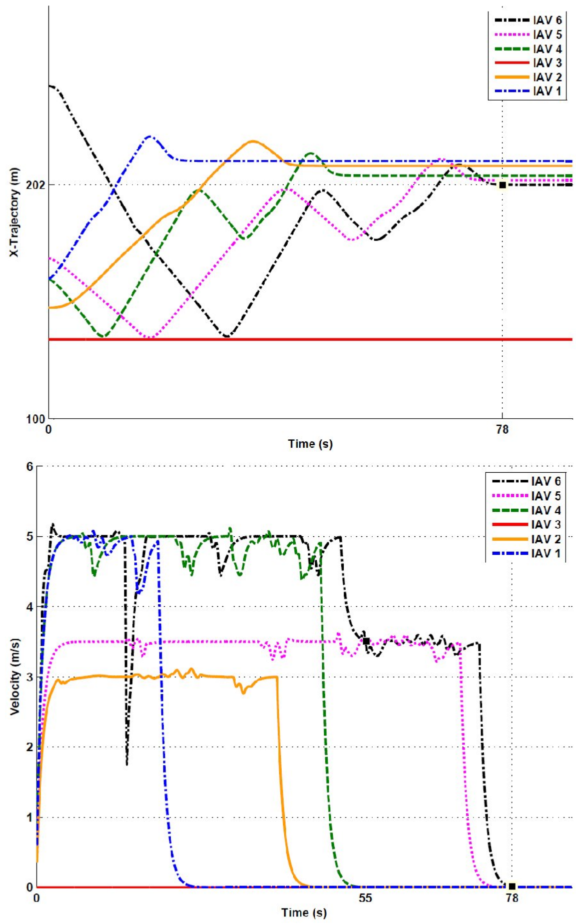

Figure 10: Reaching the destination S_2 with the optimal time

The simulation in Figure 10 shows that the vehicle V_6 takes more than 72s, the needed time to reach the desired destination in normal conditions. This delay result after the influence of the vehicle V_5 on V_6 (to avoid the collision between them), where the speed of V_6 is decreased from 5m/s to 3.5m/s at t=55s.

4. CONCLUSION

In this work, a dynamic model is developed for road traffic inside confined seaport terminal using intelligent and autonomous vehicles. This model allows implementing an adaptive estimated time algorithm for optimal path for each involved vehicle, according to the traffic and network situations. Simulation tests are done with a real mapping and traffic operations of port terminal, show the interest of dynamic model in improving the performance of the seaport internal traffic.

ACKNOWLEDGMENTS

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MODELLING EVAPORATION DUCT EFFECT IN RADAR SIMULATION

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ABSTRACT
Due to the change in the index of refraction of the atmosphere with altitude, electromagnetic (EM) waves can get trapped in a layer and travel long distances. These layers are called atmospheric ducts. Radar's performance is mostly affected by the ducts which are caused by evaporation of water. Evaporation duct changes the maximum detection range of radars operating at 3 *GHz* and above. Therefore, modelling the evaporation duct is of utmost importance in radar simulators as the frequency range in question is valid for almost all operational radars. However, analytical calculation of the ducting effect during the simulation would require allocating valuable processing time and power for this purpose. In this study, a simple but effective modelling of the ducting effect with minimum processing requirement has been developed based on the data obtained from commercial software tools utilizing complex EM propagation models for detection range calculations.

Keywords: evaporation duct, modelling ducting effect, radar simulation, refraction

1. INTRODUCTION

Tens of various radar models have been developed for evaluating radar performance since the production of the first radar. With rapidly advancing technology and growing experience, it has been possible to come up with near-real life EM propagation models that have excelled these radar models. However, perhaps as a natural outcome, these models, despite being powerful have also become extremely complex and rather slow.

Various needs may emerge from a radar model in different engineering applications; however, the most basic outcome from any radar model has been the maximum range that a specific radar can detect a target. The answer to this question has been produced by the radar range equation that was developed based on the attenuation in free space. Radar range equation simply calculates maximum range that a target can be detected utilizing the amount of the EM energy emitted by the transmitter, reflected from the target and received at the receiver. Naturally, losses caused by atmospheric and meteorological conditions during the EM propagation can also be utilized in this equation. The fact that how complicated should the radar equation be depends on the application.

Full EM propagation model in radar equation can be used in applications where there is no time constraint, such as the determination of the coverage area of a radar. On the other hand, the full propagation model may prove too slow in applications where a radar on a mobile platform is supposed to calculate probability of detection for many mobile targets. A much simpler radar range equations are needed for latter applications.

Refraction is the bending of electromagnetic waves caused by a change in the density of the medium through which the waves are passing. Because the density of the atmosphere changes with altitude, the index of refraction changes gradually with height. Like density, the temperature and moisture content of the atmosphere also decrease uniformly with an increase in altitude. However, under certain conditions the temperature may first increase with height and then begin to decrease. Such a situation is called temperature inversion. An even more important deviation from normal may exist over the ocean. Since the atmosphere close to the surface over large bodies of water may contain more than a normal amount of moisture, the moisture content may decrease more rapidly at heights just above the sea. This effect is referred to as moisture lapse.

Either temperature inversion or moisture lapse, alone or in combination, can cause a large change in the refraction index of the lowest few-hundred meters of the atmosphere. The result is a greater bending of the radar waves passing through the abnormal condition. The increased bending in such a situation is referred to as ducting and may greatly affect radar performance. The radar horizon may be extended or reduced, depending on the direction the radar waves are bent. The ducting that has the greatest effect on radar performance is the one that is caused by evaporation of water. The evaporation duct affects radar detection ranges at frequencies of approximately 3 *GHz* and above. Since the frequency range in question is the range in which almost all radars operate, it is of utmost importance that this effect be modelled. However, in a simulation, analytically calculating the ducting effect in every simulation cycle would require substantial computational time and processing power. In a radar simulation with a very large coverage area and hundreds of objects, this simply would be unrealizable.

In this study, we have developed a model for ducting effect that is simple, fast and requires minimum processing power. The proposed model is based on real radar data and outputs of commercial software tools that calculate radar range under different conditions.

The structure of the paper is as follows; atmospheric ducts, evaporation duct models, the commercial software tools whose outputs are used in the proposed model are described in Section 2. Section 3 outlines the factors that change the evaporation duct and details the proposed model. Finally, some concluding remarks are given in Section 4.

2. ATMOSPHERIC DUCTS

An electromagnetic duct is a channel/atmospheric layer, caused by the variation of index of refraction for EM waves that varies with altitude, in which EM waves can propagate over great ranges.

Ducts not only give extended radar detection ranges to radar within the duct, but they may also have other dramatic effects. For example as it can be seen in Figure 1, an airborne target that would normally be detected may be missed if the radar is within or just above the duct and the target is just above the duct. Also an airborne target that would normally be missed due to be located beyond the horizon may be detected as a result of the extended range (Skolnik 2008).

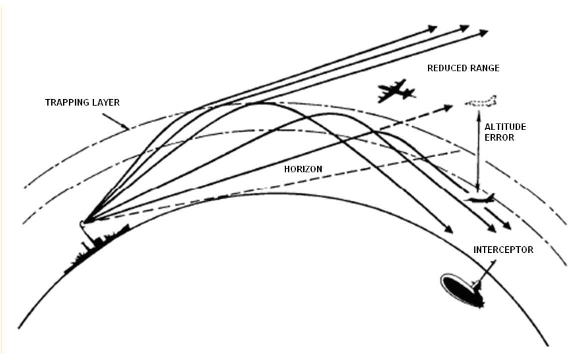


Figure 1: Ducting Effect on Radar Performance (Skolnik 2008)

Although ducts act like a waveguide for the energy, this waveguide does not have rigid and impenetrable boundaries. Therefore, energy is continually leaking from the duct.

Several meteorological conditions will lead to the forming of ducts. Ducts take different names and have different effects on EM waves according to the way and altitude they form. There are four different types of ducts, namely (Patterson et al. 1994)

- Surface ducts
- Surface-based ducts
- Elevated ducts
- Evaporation ducts

This study focuses on evaporation ducts that have the most effect on radar performance in terms of detection range.

2.1. Evaporation Duct

A change in the moisture distribution without an accompanying temperature change can lead to a trapping refractivity gradient. The air in contact with the ocean's surface is saturated with water vapour. A few meters above the surface the air is not usually saturated, so there is a decrease of water vapour pressure from the surface to some value well above the surface. The rapid decrease of water vapour initially causes the modified refractivity, *M*, to decrease with height. However, at greater heights the water vapour distribution will cause *M* to reach a minimum and, thereafter, increase with height. The height at which *M* reaches a minimum is called the evaporation duct height, as illustrated in Figure 2.

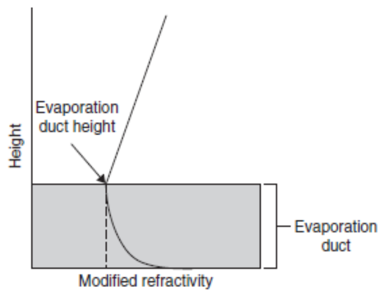


Figure 2: Refractivity for Evaporation Duct (Skolnik 2008)

Evaporation ducts exist over the ocean, to some degree, almost all the time. The duct height varies from a meter or two in northern latitudes during winter nights to as much as 40 *m* in equatorial latitudes during summer days. According to Engineer's Refractive Effects Prediction System (EREPS) Surface Duct Summary (SDS) database, on a world average, the evaporation duct height is approximately 13.1 *m* and evaporation ducts occur between 6-20 *m* at 72% of the time. Because the evaporation duct is much weaker than the surface-based duct, its ability to trap energy is highly dependent on frequency. Generally, the evaporation duct is only strong enough to affect electromagnetic systems above 3 *GHz*.

2.1.1. Evaporation Duct Models

Evaporation duct heights can be measured directly or calculated from meteorological measurements such as atmospheric pressure, air temperature and humidity at the air/sea interface.

Direct measurement devices are quite expensive and complicated. Direct measurement should not be attempted because, due to the turbulent nature of the troposphere at the ocean surface, a refractivity profile measured at one time would most likely not be the same as one measured at another time, even when the two measurements are seconds apart (Patterson et al. 1994).

For these reasons today's all modern evaporation duct height determination methods are raised from applications of meteorological measurements on techniques developed based on Monin-Oboukhov similarity theory (Monin 1954). Monin-Oboukhov similarity theory is a semi-empirical theory and its parameters are determined experimentally. An application of theory like Jeske technique (Jeske 1973) predicts the duct height with an *rms* error exceeding 7 *m* and the Paulus-Jeske correction (Jeske 1973; Paulus 1984, 1985, 1989) predicts the duct height with an error of 4.5 *m* (Ivanov 2006).

EREPS and Advanced Refractive Effects Prediction System (AREPS – A software tool developed to examine EM system performance) utilize Paulus-Jeske correction to determine evaporation duct height (Patterson et al. 1994, AREPS UM).

In literature, there are many studies analysing the effects of evaporation ducts on the radar performance. Paulus (1984) has developed the first evaporation duct model for IREPS (Integrated Refractive Effects Prediction System), Marom (1988) has analysed the effects of evaporation ducts on radar detection performance and presented some design and operational considerations which can improve the detection performance of radar, Reilly and Dockery (1990) has studied effects of evaporation ducts on radar sea return and therefore radar detection performance and presented a model for radar sea return, Paulus (1990) has considered existing radar sea return models and investigated the effects of evaporation ducts on grazing angles, Patterson et al. (1990) has applied IREPS model to EREPS, Paulus (1994) has compared EREPS model outputs with real data and Lin and Yong-gang (2008) has analysed effects of horizontally heterogeneous evaporation ducts on radar detection performance.

All of these studies are conducted to analyse the effects of evaporation ducts on radar performance, in order to improve radar designs and operational considerations and to present models of realistic EM propagation in the presence of evaporation duct. So all of the models resulted from these studies emerge as inappropriately complex and slow for a radar simulation desired to produce results fast. This causes a necessity to develop a simple, accurate and fast modelling of the evaporation duct effect unlike the ones present in the current literature. For this purpose the outputs of the complex and most commonly used EREPS, AREPS and Computer-Aided Radar Performance Evaluation Tool (CARPET - developed by an independent Dutch research organization called TNO) (Huizing & Theil) models are analysed.

EREPS, AREPS and CARPET software tools all have incorporated evaporation duct effects into their models. All of these three tools use Patterson et al.'s (1990) model for evaporation duct, developed for Naval Oceans System Centre (NOSC) and EREPS. This model first defines the propagation factor (F) in terms of height and gain equations and then defines range and height gain equations in the regions of evaporation duct effect as many other models do. The propagation factor which is the base of all advanced propagation models is also a part of the basic radar equation.

Careful examination of these equations will reveal that these equations depend basically on the radar frequency, duct height, radar and target heights. Moreover, analysis of the propagation factor curves produced by CARPET for various atmospheric and meteorological data has shown that, when ducting is present, the propagation factor also depends on only these four parameters. This fact provides means for developing a simple yet efficient model for the evaporation duct effect, details of which are presented in the following section.

3. PROPOSED EVAPORATION DUCT MODEL

In order to fully understand the effects of the parameters, namely, radar frequency, radar height, target height and ducting height on the propagation factor curves many different simulations have been run for various values of the parameters. It has been observed that all of the curves can be easily represented by three linear equations that are defined in three different regions, thus the curves can be defined by three points at maximum.

Based on these results, we conducted some studies on generating a baseline data set for propagation factor curves each defined by three points using predetermined data and reproducing the propagation factor curve for a given set of input data based on the baseline data set.

Note that, producing the baseline data set is of utmost importance for minimizing the errors of the curves that will be reproduced based on the baseline data set. Therefore, effects of these four variables on the propagation factor in the presence of evaporation duct have been analysed in detail.

3.1. Effect of the Radar Frequency

It was mentioned that the evaporation duct affects radar detection ranges at frequencies of approximately 3 *GHz* and above. Propagation factor curves with respect to the detection range for radar frequencies 3.5, 5, 7, 9, 11 and 15 *GHz* are shown in Figure 3 and the analysis of Figure 3 corroborates with the lower limit of 3 *GHz*.

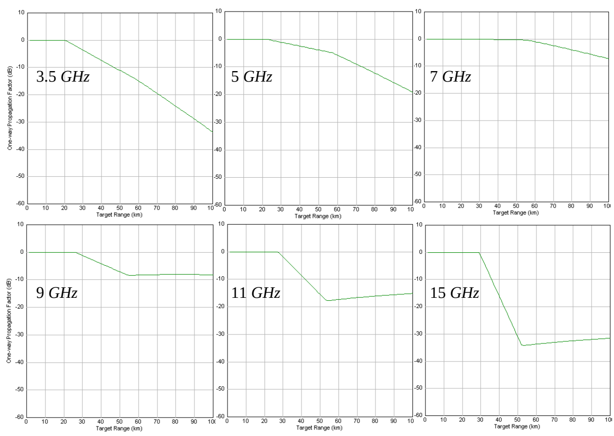


Figure 3: Radar Frequency Effect on Propagation Factor

The results from the CARPET software suggest that the baseline data set should contain at least one propagation factor curve for each radar band between 2.5 *GHz* and 15 *GHz*, i.e. E, F, G, H, I, J bands.

3.2. Effect of Evaporation Duct Height

Figure 4 illustrates the detection probability produced by CARPET for two different radars located at 20 *m* operating at 2.5 *GHz* and 8 *GHz* for the evaporation duct heights of 10 *m* and 25 *m*. In the figure the detection probability varies from 100% for the red colour to 0% for blue. As it can be seen from the top left and bottom right subfigures, the 10 *m* duct does not have a major effect on 2.5 *GHz* radar and the 25 *m* duct does not have a major effect on 8 *GHz* respectively. On the other hand, as it can be seen from top right and bottom left subfigures, the effects of 10 *m* duct on 2.5 *GHz* and 25 *m* duct on the 8 *GHz* radars are rather substantial respectively. As these results indicate, evaporation ducts forming at high altitudes are effective in low frequencies whereas they are effective in high frequencies, when they form at lower altitudes.

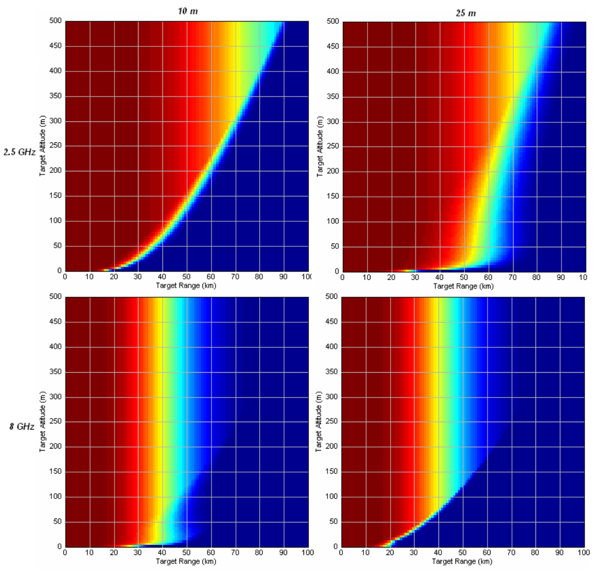


Figure 4: Evaporation Duct Height Effect on Radar Coverage

Average evaporation duct height around the world is 13.1 *m* and this height has the most effect for the frequencies between 6-9 *GHz* (H-I Bands) at which most of the surface and navigation radars operate. When these facts are considered, it is intuitive to set the evaporation duct height to the average duct height of 13.1 *m* in the baseline data set.

With further analysis it is noticed that when evaporation duct is elevated, similar effects are observed in lower frequency ranges. This effect can be observed on the coverage diagrams in Figure 5. As an example the coverage diagrams of 15 *m* duct on 5 *GHz*, 13 *m* duct on 6 *GHz* and 10 *m* duct on 8 *GHz* are quite similar. This implicates that the effects of different duct heights can be obtained by shifting the radar frequency in accordance with the difference between the duct height and 13.1 *m*.

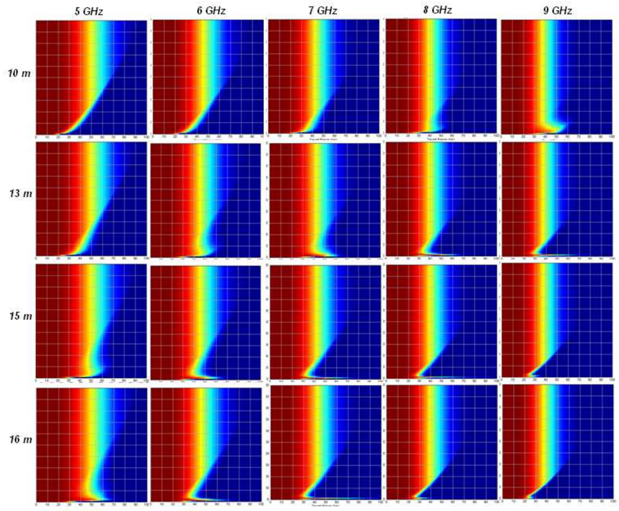


Figure 5: Evaporation Duct Height, Radar Frequency Range Relation

3.3. Effect of Radar and Target Height

In Figure 6, radar coverage diagrams are given for 13.1 *m* evaporation duct and 10 *m*, 20 *m* and 30 *m* radar heights respectively. In can be seen that the radar being located above or below the duct height creates no apparent difference in radar performance as the height difference between a ship borne radar and evaporation duct is usually negligible and the angles between the transmitted EM waves and duct borders are usually narrow enough for allowing the duct to bend these waves.

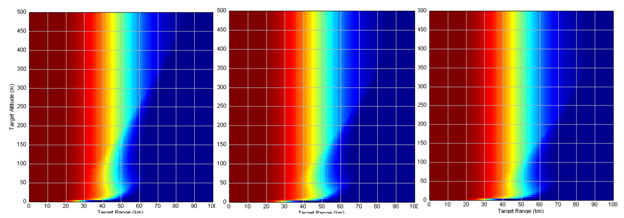


Figure 6: Radar Height Effect on Radar Coverage

The equations for the propagation factor usually include the height gain twice in order to account for the target and radar heights. For example, propagation factor for diffraction region can be defined as follows, where $V(r)$ is range gain function, $U(Z_r)$ and $U(Z_t)$ are height gain functions for radar and target heights respectively.

$$F^2 = V(r)U(z_r)U(z_t) \tag{1}$$

This suggests that both the radar and target heights have the same effect on the propagation factor curve at those heights. That is, the propagation factor curve for a scenario where the radar is located at 10 *m* and the target at 30 *m* will be the same as the propagation factor curve for the scenario with the radar located at 30 *m* and target at 10 *m*. In other words, the detection probability for a target at 30 m altitude by a radar at 10 *m* is exactly the same as the detection probability for a target at 10 *m* altitude by radar at 30 *m*.

3.4. The Proposed Model

The proposed model for the evaporation duct involves using tabulated data that are produced utilizing the outcomes detailed in previous subsections. The tabulated data was previously referred to as the baseline data set and is given in Table 1. Table 1 presents the propagation factor curves, employed as the baseline data set, as obtained from the CARPET software for 13.1 *m* evaporation duct height, 20 *m* radar height, E, F, G, H, I and J radar band frequencies and 3 different target altitude intervals.

The curves given in Table 1 serve as an extension to the radar simulation for modelling effect of evaporation duct to the radar signal propagation and detection distance. During the simulation, the propagation factor is linearly interpolated from the values given in Table 1 to the operator defined duct and target heights and radar frequency. This way, very efficient, accurate and simple modelling of the ducting effect is achieved without increasing the computational load of the radar simulator. Adding new functions to an intrinsically complex and computationally loaded simulator without elevating the load is desirable.

The proposed model has been tested by comparing the propagation factor curves obtained through the evaporation duct model added radar simulator and the ones produced by the CARPET software. An example comparison is given in Figures 7 and 8 for a radar operating at 5.5 *GHz* on a 20 *m* high target. As it is seen from figures both outcomes are very similar and the difference is small enough to be ignored.

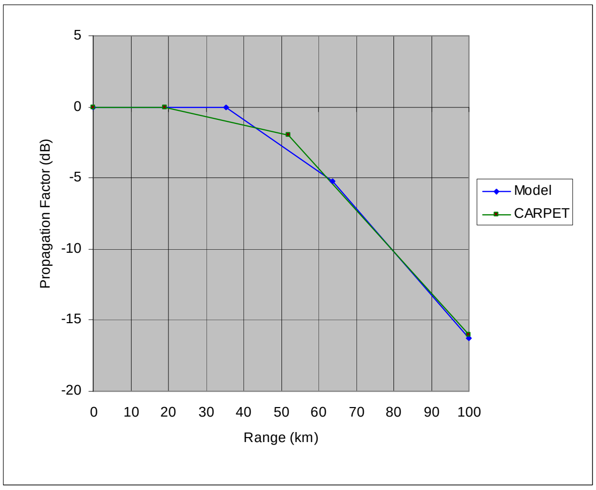


Figure 7: Comparison of Proposed Model and CARPET Output in terms of Propagation Factor

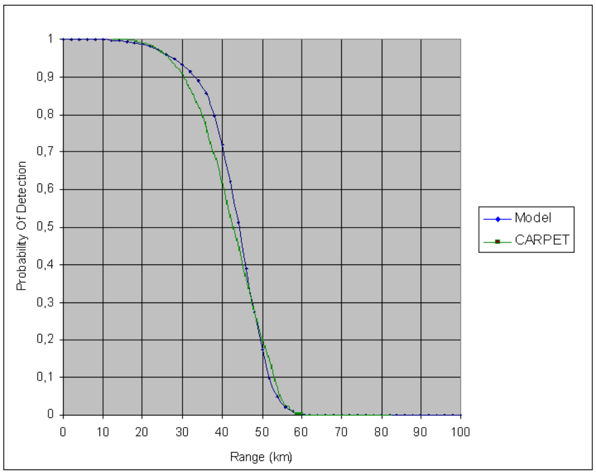
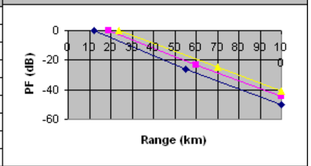
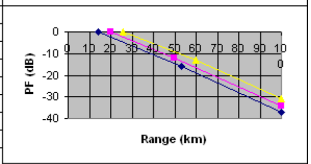
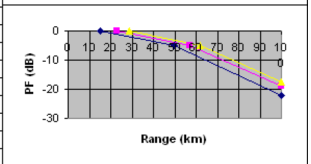
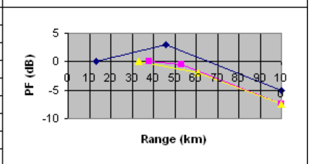
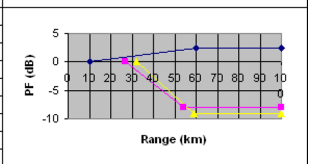
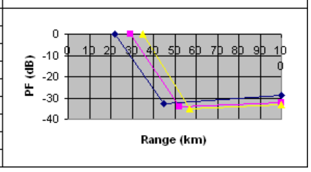


Figure 8: Comparison of Proposed Model and CARPET Output in terms of Detection Probability

Table 1: 13.1 m Evaporation Duct Propagation Factor Curves

13.1 m Evaporation Duct Height Propagation Table					
Band	**Frequency (GHz)**	**Target Height (m)**	**Range (km)**	**PF (dB)**	**Graph**
E	2,5	15	12	0	
			55	-26	
			100	-50	
		30	19	0	
			60	-23	
			100	-44,5	
		45	24	0	
			70	-25	
			100	-41	
F	3,5	15	14	0	
			53	-16	
			100	-37	
		30	20	0	
			50	-12	
			100	-34	
		45	26	0	
			60	-13	
			100	-31	
G	5	15	15	0	
			50	-5	
			100	-22	
		30	23	0	
			57	-5	
			100	-19	
		45	29	0	
			62	-5	
			100	-17,5	
H	7	10	13	0	
			46	3	
			100	-5	
		30	38	0	
			53	-0,5	
			100	-7,5	
		45	33	0	
			61	-2	
			100	-7,5	
I	9	5	10	0	
			60	2,5	
			100	2,5	
		30	27	0	
			54	-8	
			100	-8	
		45	32	0	
			59	-9	
			100	-9	
J	15	15	22	0	
			45	-32,5	
			100	-29	
		30	29,5	0	
			52	-34	
			100	-32	
		45	35	0	
			57	-35	
			100	-33	

4. CONCLUSIONS

In this study, a simple, efficient and accurate yet computationally cheap modelling of evaporation duct effects has been presented. The possibility of occurrence of evaporation ducts is very high and their effects to radar model are significant. Therefore, it is rather important to come up with an accurate and simple model that does not increase the already elevated computational load of the simulator. The proposed model is a tabulated extension to a big radar simulation where hundreds of radars take observations from hundreds of targets. The baseline tabular data have been obtained utilizing commercial software tools such as CARPET, AREPS and EREPS. The baseline data of the propagation factor curve has been obtained depending on the radar frequency, duct height, radar height and target height and employed in the radar simulator instead of utilizing online complicated and signal level calculations. The proposed model has produced near perfect results compared to the commercial modelling tool called CARPET. Application of the effects of different atmospheric ducts is left as further study.

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CONVEX EXTENSION OF DISCRETE-CONVEX FUNCTIONS AND APPLICATIONS IN OPTIMAL DESIGN OF COMPLICATED LOGISTIC, MANUFACTURING AND PROCESSING ENVIRONMENTS

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ABSTRACT
A method of description and optimal design of the structure of complicated multi-level processing systems is presented. The set of feasible structures for such class of systems is defined. The representation of this set is constructed in terms of the graph theory. For the reduced statement two types of variable parameters are defined: for the level size and for the relations of adjacent levels. The choice of variable parameters guarantees the discrete-convexity of objective function. A class of iteration methods for solving the discrete-convex programming problem is derived. The method based on the extension of discrete-convex function to the convex function and on extension of discrete-convex programming problem to the convex programming problem. On each step of the iteration the calculation of the value of objective function is required only on some vertices of unit cube. The considered approach is illustrated by an academic example of modelling and optimal design of the multi-level manufacturing system.

Keywords: discrete manufacturing and processing environment, optimal multi-level partitioning, discrete-convex function, nonlinear integer programming.

1. INTRODUCTION

Large-scale problems can be decomposed in many different ways (Mesarovic et al. 1970; Bruzzone et al. 2007). The current approach for describing and optimizing the structure of hierarchical systems is based on a multi-level partitioning of given finite set in which the qualities of the system may depend on the partitioning.

Examples of problems of this class are aggregation problems, structuring of decision-making systems, database structuring, the problems of multiple centralization or decentralization, multi-level selection problems, multi-level tournament systems (Laslier 1997), multi-level distribution systems, different clustering problems (Bruzzone et al. 2009).

In a multi-level distribution system each element is a supplier for some lower level elements and a customer for one higher-level element. The zero-level elements are only customers and the unique top-level element is only a supplier. The choice of optimal number of suppliers-customers on each level is a mathematically complicated problem.

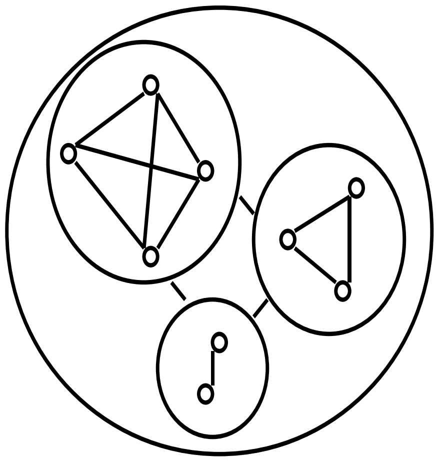

Figure 1: Multi-Level Partitioning of a Set of 9 Elements.

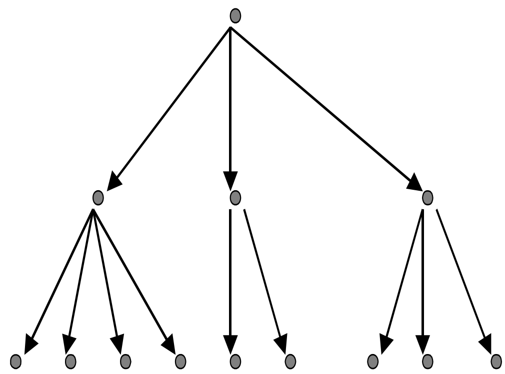

Figure 2: Hierarchy of Multi-Level Partitioning of a Set of 9 Elements

The tournament system (Laslier 1997) is a relatively simple special case of a multi-level processing system. To consider this system, the number of games (pair-wise comparisons) is a quadratic function of the number of participants. This is a quickly increasing function. If the number of participants is large, the number of games is very large. This is a reason why the multi-level approach is useful for the selection of the winner. From the tournaments of the first level the winners are distributed between the tournaments of the next level. The second level tournaments winners are going to the third level, until the winner is selected. Suppose the goal is to minimize the number of all games. If the price for all games is the same, the solution is well known. Each tournament has two participants and one game is played. If the prices of games for different levels are different or constraints to the number of levels are active, a relatively complicated nonlinear integer-programming problem arises.

Simulation model of logistic processes in container terminals allows considering terminal operation at three different partitioning levels (Merkuryev et al. 2003).

The main difficulty from the point of view of optimization is that the number of subsets of partitioning is a variable parameter. This means for corresponding optimization problem that upper limit of summation, the number of summands (integer valued parameter) is a variable parameter. It is hard to solve that kind discrete programming problem.

The advantage of the considered approach is that this choice of variables enables to extend the structure optimization problem to the convex programming problem. A finite steps algorithm converging to the global solution of this problem is presented.

2. FEASIBLE SET OF HIERARHIES

Consider all *s*-levels hierarchies, where nodes on level *i* are selected from the given nonempty and disjoint sets and all selected nodes are connected with selected nodes on adjacent levels. All oriented trees of this kind form the feasible set of hierarchies (Riismaa 1993). The illustration of this formalism is given in Figure 3.

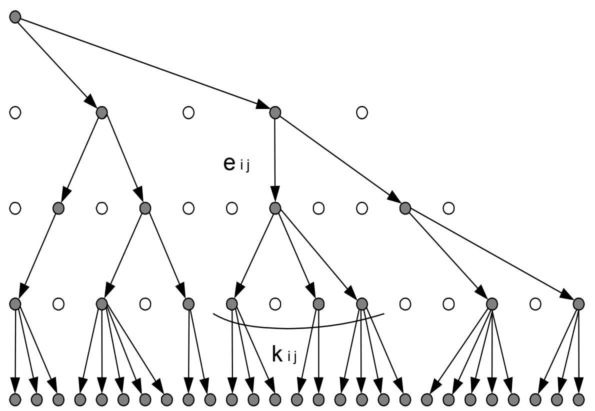

Figure 3: Feasible Set of Structures

Suppose $m_i \times m_{i-1}$ matrix $Y_i = \left(y^i_{jr}\right)$ is an adjacent matrix of levels *i* and $i-1$ $(i = 1,...,s)$ where

$$y^i_{jr} = \begin{cases} 1, \, j-th\ element\ on\ level\ i\ connected \\ \quad with\ r-th\ element\ on\ level\ i-1 \\ 0, otherwise \end{cases} .$$

Suppose m_0 is the number of 0-level elements (level of object, level of non-ordered set).

Theorem 1. All hierarchies with adjacent matrixes $\{Y_1,...,Y_s\}$ *from the described set of hierarchies satisfy the condition*

$$Y_s \cdot \ldots \cdot Y_1 = (\underbrace{1,\ldots,1}_{m_0})$$

The assertion of this theorem is determined directly (Riismaa et al. 2003).

The illustration of multiplication of adjacency matrices is given on Figure 2. To the multiplication of adjacent matrices correspond the annihilation of levels. To the presentation an adjacent matrix as a product of two adjacent matrices correspond the creation a new level.

To the sequence of adjacent matrices $\{Y_1, Y_2, Y_3, Y_4\}$ corresponds the hierarchy where the arcs are described with continuous lines. To the sequence of adjacent matrices $\{Y_1, Y_3 \cdot Y_2, Y_4\}$ correspond the hierarchy where the arcs between the first and the second levels are described with dash lines and other arcs are described with continuous lines.

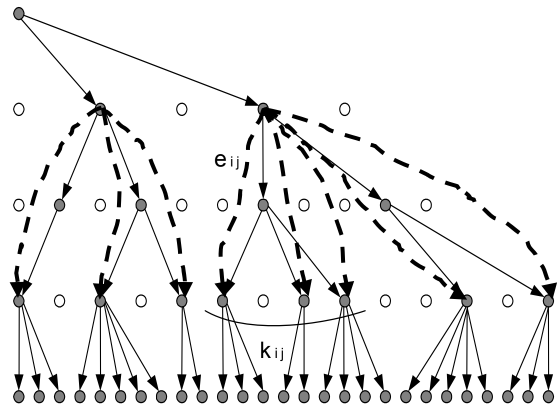

Figure 4: The Creation and annihilation of Levels

3. THE STATEMENT OF GENERAL PROBLEM OF STRUCTURE OPTIMIZATION

The general optimization problem is stated as a problem of selecting the feasible structure that corresponds to the minimum of total loss given in the separable-additive form:

$$\min_{Y_1,\dots,Y_S}\left\{\sum_{i=1}^{s}\sum_{j=1}^{m_i}\mathrm{h}_{ij}\left(\sum_{r=1}^{m_{i-1}} d^{\,i}_{jr}\, y^{\,i}_{jr}\right)\middle|\begin{array}{l} Y_s\cdot\ldots\cdot Y_1 = \\ =\underbrace{(1,\ldots,1)}_{m_0}\end{array}\right\}. \quad (1)$$

Here $h_{ij}(\cdot)$ is an increasing loss function of *j*-th element on *i*-th level and $d^{\,i}_{jr}$ is the element of $m_i \times m_{i-1}$ matrix D_i for the cost of connection between the *i*-th and (*i*-1)-th level.

The meaning of functions $h_{ij}(k)$ depends on the type of the particular system.

4. REDUCED PROBLEM OF STRUCTURE OPTIMIZATON

Now an important special case is considered where the connection cost between the adjacent levels is the property of the supreme level: each row of the connection cost matrices between the adjacent levels consists of equal elements.

There is a possibility to change the variables and to represent the problem so that

$$d^{\,i}_{jr}=1;\quad i=1,\dots s;\;\; j=1,\dots,m_i;\;\; r=1,\dots,m_{i-1}.$$

Now the total loss depends only on sums $\sum_{r=1}^{m_{i-1}} y^{\,i}_{jr}=k_{ij}$, where k_{ij} is the number of edges beginning in the *j*-th node on *i*-th level.

Recognize also that $\sum_{j=1}^{m_i} k_{ij}=p_{i-1},\;\; i=1,\dots,s$, where p_i is the number of nodes on *i*-th level. If to suppose additionally that $h_{i1}(k)\le\cdots\le h_{im_i}(k)$ for each integer k, the general problem (1) transforms into the two mutually dependent phases:

$$\min_{p_1,\dots,p_{S-1}}\left\{\sum_{i=1}^{s} g_i(p_{i-1},p_i)\,\middle|\; p_0\ge\ldots\ge p_s,\;\; p_s=1\right\} \quad (2)$$

where

$$g_i(p_{i-1},p_i)= =\min_{k_{i1},\dots,k_{ip_i}}\left\{\sum_{j=1}^{p_i} h_{ij}(k_{ij})\,\middle|\,\sum_{j=1}^{p_i} k_{ij}=p_{i-1}\right\} \quad (3)$$

Free variables of the inner minimization (3) are used to describe the connections between the adjacent levels. Free variables of the outer minimization (2) are used for the representation of the number of elements at each level.

5. CONVEX EXTENSION OF DISCRETE-CONVEX FUNCTIONS

This statement has some advantages from the point of view of the optimization technique. It is possible to adapt effective methods of the convex programming for solving outlined special cases.

The function $f: Z^n \to R$ is called discrete-convex (Riismaa 1993; Murota 2003) if for all

$z_i \in Z^n\,(i=1,\dots,n+1)$, $\quad Z^n=\underbrace{Z\times\ldots\times Z}_{n}$,

$Z=\{\dots,-2,-1,0,1,2,\dots\}$, $\lambda_i\ge 0,(i=1,\dots,n+1)$

and

$$\sum_{i=1}^{n+1}\lambda_i=1;\;\sum_{i=1}^{n+1}\lambda_i z_i\in Z^n$$

holds

$$f\Big(\sum_{i=1}^{n+1}\lambda_i z_i\Big)\le\sum_{i=1}^{n+1}\lambda_i f(z_i).$$

The use of all $n+1$ elements convex combinations follows from the well-known theorem of Caratheodory (Rockafellar 1970).

The graph of a discrete-convex function is a part of the graph of a convex function.

The convex extension f_c *of function* $f: X\to R\,(X\subset R^n)$ *is the majorant convex function* $f_c: conv\,X\to R$, *where* $f_c(x)=f(x)$ *if* $x\in X$.

Theorem 2. The function $f: X\to R$ $(X\subset R^n)$ *can be extended to convex function on* $convX$ *if* f *is discrete-convex on* X. *The convex extension* f_c *of* f *is*

$$f_c(x)=\min\left\{\sum_{i=1}^{n+1}\lambda_i f(x_i)\,\middle|\,\begin{array}{l} x=\sum_{i=1}^{n+1}\lambda_i x_i;\;\sum_{i=1}^{n+1}\lambda_i=1;\\ \lambda_i\ge 0\;(i=1,\dots,n+1),\\ x_i\in X\;(i=1,\dots,n+1)\end{array}\right\}$$

over $x_i, \lambda_i \, (i = 1,\dots,n+1)$.

Assertion of this theorem is determined directly (Riismaa 1993).

Theorem 3. The convex extension f_C *of* f *is*

$$f_c(x) = \begin{cases} \max\limits_{a,b} \left\{ \langle a,x\rangle + b \,\middle|\, \begin{array}{l} \langle a,y\rangle + b \le f(y), \\ y \in X \end{array} \right\}, \text{if } x \notin X \\ f(x), \text{if } x \in X \end{cases}$$

Assertion is determined directly.

From theorem 2 or theorem 3, the convex extension is so called point-wise maximum over all linear functions not exceeding the given function.

From theorem 2 or theorem 3, the convex extension of a discrete-convex function is a piecewise linear function.

From theorem 2 and/or 3, each discrete-convex function has a unique convex extension.

From theorem 2 or theorem 3, the class of discrete-convex functions is the largest one to be extended to the convex functions.

Theorem 4. If $h_{ij}(k)(i = 1,\dots,s;\, j = 1,\dots,m_i)$ *in (3) are discrete-convex functions then* $\sum\limits_{i=1}^{s} g_i(p_{i-1}, p_i)$ *in (2) is a discrete-convex function.*

The proof of this theorem is not very complicated but needs a lot of secondary results and can be found in (Riismaa 1993).

Considered theorem 2 or theorem 3 and theorem 4 enable to extend the objective function (2), (3) to the convex function.

6. ALGORITHM OF LOCAL SEARCHING FOR THE REDUCED PROBLEM OF STRUCTURE OPTIMIZATION

The particular choice of the variables (2), (3) enables to construct a class of methods for finding the global optimum. In this paper it is only declared that the objective function of such integer programming problem is a discrete-convex function.

Recall of (2)

$g(p_0, p_1, \dots, p_{s-1}, 1) = \sum\limits_{i=1}^{s} g_i(p_{i-1}, p_i)$ and denote $p_k^{(s)} = \left(p_{k1}^{(s)}, \dots, p_{ks-1}^{(s)}, 1\right)$ $(k = 0,1,\dots)$.

Consider following finite-step algorithm:

$p_0^{(s)} = (\underbrace{1,\dots,1}_{s})$, and $p_k^{(s)} = p_{k-1}^{(s)} + x_k^{(s)}(q,t)$, $(k = 1,2,\dots)$.

It is assumed that

1)

$x_k^{(s)}(q,t)$ are lexicographically ordered by (q,t):

$$x_k^{(s)}(q,t) = \left(\overbrace{\left(\underbrace{0,\dots,0}_{t}\right), \left(\underbrace{1,\dots,1}_{q}\right), 0,\dots,0}^{s} \right),$$

$$(q = 1,\dots,s-t-1;\, t = 0,\dots,s-2); \tag{4}$$

2)

$$p_0 \ge p_{k1}^{(s)} \ge \dots \ge p_{ks}^{(s)} = 1 \tag{5}$$

3)

$x_k^{(s)}(q,t)$ is lexicographically the first that satisfies the condition

$$\begin{aligned} & g\left(p_0, p_{k1}^{(s)}, \dots, p_{ks-1}^{(s)}, 1\right) \le \\ & \le g\left(p_0, p_{k-11}^{(s)}, \dots, p_{k-1s-1}^{(s)}, 1\right) \end{aligned} \tag{6}$$

Remark 1. Consider the vertices with integer valued coordinates of the s-dimensional unit cube where:

- the nearest vertex to the s-dimensional zero-point is $p_{k-1}^{(s)} = \left(p_{k-11}^{(s)}, \dots, p_{k-1s-1}^{(s)}, 1\right)$;
- other vertices $p_{k-1}^{(s)} + x_k^{(s)}(q,t)$ satisfy the condition (4).

The number of that kind of vertices (4) is $\frac{1}{2} \cdot s(s-1)$. The number of vertices (4), (5) is no more than $\frac{1}{2} \cdot s(s-1)$.

The condition (4) puts in order all vertices of described unit cube.

Remark 2. On the iteration step *k* the value of goal function is computed on ordered vertices (4), (5) of unit cube until the first value satisfying (6) is found. If that kind of a value does not exist, one of the solutions of problem (2) - (3) has been found.

7. ACADEMIC EXAMPLE: OPTIMIZATION THE STRUCTURE OF COMPLICATED MULTI-LEVEL MANUFACTURING SYSTEM

Consider the processing of *n* parts (Riismaa et al. 2003). In case of one processing unit the overall processing and waiting time for all n parts is proportional to n^2 and is a quickly increasing function. For this reason the hierarchical system of processing can be suitable. From zero-level (level of object) the parts will be distributed between p_1 first-level processing units and processed (aggregated, packed etc.) by these units. After that the parts will be distributed between p_2 second-level processing units and processed further and so on. From p_{s-1} (s - 1)-level the units will be sent to the unique s-level unit and processed finally. The cost of processing and waiting on level i is approximately

$$g_i(p_{i-1}, p_i) = (d_i\, l_{i-1} p_{i-1}/p_i)^2\, p_i + a_i\, p_i$$
$(i = 1,...,s)$.

Here l_i is the number of aggregates produced by one robot on level i (a number of boxes for packing unit), d_i is a loss unit inside the level i, and a_i is the cost of i-th level processing unit. The variable parameters are the number of processing units on each level $p_i(i = 1,...,s)$.

The goal is to minimize the total loss (processing time, waiting time, the cost of processing units) over all levels:

$$\min \sum_{i=1}^{s} \left((d_i l_{i-1})^2 \left(\begin{array}{l} \left(p_i \left(\left[\frac{p_{i-1}}{p_i} \right] + 1 \right) - p_{i-1} \right) \left[\frac{p_{i-1}}{p_i} \right]^2 + \\ + \left(p_{i-1} - p_i \left[\frac{p_{i-1}}{p_i} \right] \right) \left(\left[\frac{p_{i-1}}{p_i} \right] + 1 \right)^2 \end{array} \right) + a_i p_i \right)$$

over natural $p_i(i = 1,...,s)$.

Here $[p]$ is the integer part of p. The goal function of this discrete programming problem is discrete-convex. It is possible to extend this function to convex function (Theorem 2) and get a solvable convex programming problem using the method of local searching.

8. CONCLUSION

Many finite hierarchical structuring problems can be formulated mathematically as a multi-level partitioning procedure of a finite set of nonempty subsets. This partitioning procedure is considered as a hierarchy where to the subsets of partitioning correspond nodes of hierarchy and the relation of containing of subsets define the arcs of the hierarchy. The feasible set of structures is a set of hierarchies (oriented trees) corresponding to the full set of multi-level partitioning of given finite set.

Each tree from this set is represented by a sequence of Boolean matrices, where each of these matrices is an adjacency matrix of neighboring levels. To guarantee the feasibility of the representation, the sequence of Boolean matrices must satisfy some conditions – a set of linear and nonlinear equalities and inequalities.

The formalism described in this paper enables to state the reduced problem as a two-phase mutually dependent discrete optimization problem and construct some classes of solution methods. Variable parameters of the inner minimization problem are used for the description of connections between adjacent levels. Variable parameters of the outer minimization problem are used for the presentation of the number of elements on each level.

The two-phase statement of optimization problem guarantees the possibility to extend the objective function to the convex function and enables to construct algorithms for finding the global optimum. In this paper for finding the global optimum the method of local searching is constructed. On each step of iteration the calculation of the value of objective function is required only on some vertices of some kind of unit cube.

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EXTENDED GREAT DELUGE APPROACH FOR THE INTEGRATED DYNAMIC BERTH ALLOCATION AND CRANE ASSIGNMENT PROBLEM

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ABSTRACT
Globalization has quickly increased the volume of commodity flows using all modes of transport. Specifically, since the 1970s, containerization has increasingly facilitated the transport of goods throughout the world, and every major port is expected to double, and possibly triple, its container traffic by 2020. In order to accommodate the growth in international container transport, terminals must make significant changes to keep pace with increasing demand. One important manner in which existing terminal capacity could be increased would be through an increase in their efficiency. In this paper, we consider terminal efficiency from the perspective of simultaneously improving both berth and quay crane scheduling. The approach is applied to a modeling scheme found in the literature, and this study contributes to knowledge by improving the results found using a new metaheuristic and a crane transfer refinement procedure.

Keywords: Berth allocation, Quay crane assignment, Extended Great deluge metaheuristics, Optimization.

1. INTRODUCTION

Container terminals are the areas where containers are transported from one point to another using different pieces of handling equipment. Such terminals are continually growing in importance as maritime transport faces the challenge of using new technologies to build larger and larger ships. Moreover, transport frequency is only rising as commercial exchanges are developed to meet economic growth. To be able to compete within this environment, container terminals must be managed efficiently. To that end, managers must concentrate on the Berth, which is the most critical resource for determining container terminal capacity. An alternative approach to increasing Berth capacity involves improving its productivity through its efficient use (Park and Kim, 2003). One of the components of such efficient utilization is a focus on quay cranes, which are the main equipment used to move containers at terminals.

2. BERTH ALLOCATION AND CRANE ASSIGNMENT PROBLEM (BACAP)

More and more studies are being dedicated to the examination of container terminals and efficient operations that improve their productivity. Among them, studies dealing with berths and cranes are increasingly of interest to more and more researchers.

Recently, other studies have examined the two problems simultaneously, because they are actually encountered and interact in a port. In fact, the goal of a CAP (Crane Assignment Problem) is to determine the total time of docking at the quay (including the time of service: loading/unloading and waiting time), which represents an input of the Berth allocation problem (BAP). Modeling both problems simultaneously thus approximates the reality of the harbor; consequently, resolving the joint problem would be allow immediate application by a harbour manager.

The combination of both the BAP and the CAP leads to an interesting problem called the BACAP (Berth Allocation and Crane Assignment Problem); this combination has seldom been examined in the literature, but is beginning to attract the interest of the researchers in the field.

The concept was pioneered by Park and Kim (2003), who modeled the problem in its static-continuous variant in Integer Programming, and adopted a two-phase resolution. Meisel and Bierwirth (2006) were interested in the continuous-dynamic variant, and classified the problem as a Resource Constrained Project Scheduling Problem (RCPSP). A discrete dynamic variant was studied by Liang et al. (2008, 2009a), Liang et al. (2009b) and Liang et al. (2009c), who modeled the problem based on a mono-objective and multi-objective approach, and in both cases, adopted the genetic algorithm for the resolution. Imai et al. (2008) focus on the version discrete-dynamic. Their modeling objective was the minimization of the total time of service, including the constraints of the CAP. The resolution was based on the genetic algorithm, which is chosen for its ability to solve such problems using commercial mathematical programming tools. Miseil and Bierwirth (2009) used the model suggested by the pioneers Park and Kim (2003), and proposed a one-phase resolution based on the construction of a feasible solution, which was then further improved by metaheuristics.

In a recent publication, Bierwirth and Meisel (2010) were interested in the review of the literature on the integration of BAP and CAP problems. They listed the models formulated for the BACAP (Berth allowance and Crane Assignment Problem) and those used in resolutions been proposed over the last five years. They concluded that there is growing interest in such problems relating to in harbor management, and thus encourage future researchers to find new models more realistic and new effective resolution methods.

3. BACAP PROBLEM FORMULATIONS

3.1. Liang's Problem (2009)

The authors approached the problem to determine the exact position and the berthing time of each ship arriving at the quay of a port, as well as the exact number of Quay Cranes assigned to each of them in order to minimize the total time of accosting to the quay (including the time of loading/unloading, waiting and the time associated with the difference between the end of the service and the time of departure of the container ship estimated and programmed by the managers). Their model was implemented on a real harbour terminal in china.

The assumptions below were advanced for the formulation of the problem:

- Each container ship has a maximum number of cranes to be assigned.
- The time service of a container ship is directly dependent on the number of cranes assigned
- It is assumed that the time of arrival of the ship container to the port is known in advance, but the ship cannot berth before the expected arrival time
  → Which leads to the dynamic aspect of the problem.
- Loading/unloading operations must be carried out without interruption.
- Each zone of accosting must be able accommodate a maximum of one container ship.
  → Which leads to the discrete aspect of the problem.
- The crane transfer time is ignored.

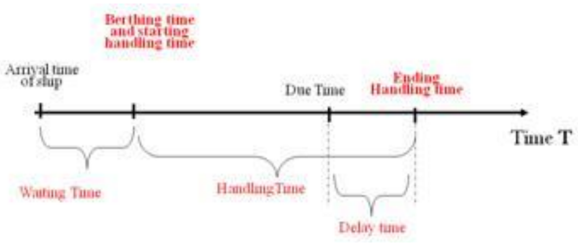


Figure 1: Ship's Timeline

$$Min\ \mathbf{Z} = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{n}\frac{c_i}{\nu.h_j}x_{ijk} + \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{n}(s_i - a_i)x_{ijk} + \sum_{j=1}^{n}\sum_{k=1}^{m}\left(s_i + \frac{c_i}{\nu.h_j} - d_i\right)x_{ijk} \quad \mathbf{(1)}$$

Subject to:

$$\sum_{j=1}^{m}\sum_{k=1}^{n}x_{ijk} = 1 \quad \forall i \in (1,2....n) \quad \mathbf{(2)}$$

$$\sum_{i=1}^{n}x_{ijk} = 1 \quad \forall j \in (1,2....m)\mathbf{,}\ \forall \mathbf{k} \in \mathbf{(1,2,.....n)} \quad \mathbf{(3)}$$

$$\left(s_i + \frac{c_i}{\nu.h_j}\right)x_{ij,k-1} \le s_l x_{ljk} \quad , \quad \forall \mathbf{i,k,l} \in \mathbf{(1,2,...n),} \quad \forall j \in (1,2....m) \quad \mathbf{(4)}$$

$$\sum_{j=1}^{m}h_j = H \quad \mathbf{(5)}$$

$$x_{ijk} = 1 \quad or \quad 0 \qquad \forall i,k,j \in (1,2....n) \quad \mathbf{(6)}$$

$$s_i \ge a_i \qquad \forall i \quad \mathbf{(7)}$$

$$h_j : \text{integer} \quad \forall j \quad \mathbf{(8)}$$

Where:

Indices:

- i (= 1, 2…n) ϵ V set of ships
- j (= 1, 2…m) ϵ B set of berths
- k (= 1, 2…n) ϵ O set of service orders

Parameters:

- .n : number of ships
- .m : number of berths
- .Wi : subset of V such that ship p with sp > ai
- .ν : working speed of the cranes
- H : the total number of cranes available in the port
- $.a_i$: arrival time (estimated) of ship i
- $.c_i$: number of containers required for loading/unloading for the ship i
- $.d_i$: due departure time of ship i

Decision Variables:

- $.s_i$: starting time for i loading/unloading of ship i
- $.h_i$: number of cranes assigned to ship i
- $.x_{ijk}$ $\begin{cases} 1\text{, if the ship i is served as the } k^{th} \text{ ship at the berth j} \\ 0\text{, otherwise} \end{cases}$

The modeling above very simply and comprehensively represents the BACAP in its discrete-dynamic variant. The total time minimization objective makes the model very generalizable, and capable of being applied to most harbour situations.

The authors proposed a hybrid evolutionary algorithm based on a genetic algorithm to find an approximate optimal solution for the problem.

4. METHODOLOGY FOR THE PROPOSED APPROACH

The proposed model represents hard constraints that make the resolution by metaheuristics meeting much of non-feasible solutions that the algorithm must circumvent. For this reason, a population method such as the genetic algorithm is not fully appropriate for such problems.

In this paper, and to mitigate the obstacle above, we propose to solve Liang's BACAP with a new metaheuristic method based on neighbourhood search.

The Extended Great Deluge metaheuristic is then applied. Prior to that, a heuristic is constructed to find the first feasible solution, which is gradually improved with the exploration of the neighbourhood by the metaheuristic algorithm.

This is what differentiates the approach suggested in this research from the resolution suggested by the authors, which sets on a random initial solution.

The construction of the initial feasible solution aims to increase the rate of acceptance of the metaheuristic within the resolution, which also results in increasing the efficiency and speed of the resolution.

Besides the application of another type of algorithm to solve the problem, we integrate the priority aspect for the resolution. In fact, unlike Liang's approach, we add constraint relatively to the priority service in case of arbitrage between two arrivals. The approach suggested in this paper is to first adopt the FCFS rule, and then the Most charged First rule OR Less Charged First rule in the case of arbitrage. Such a context could arise in order to satisfy some customers. The harbor manager could then have different scheduling scenarios and XXX

To refine the optimal solution found by the metaheuristic, we apply a procedure that allows the transfer of cranes between berths under certain circumstances (conditions). Such transfers can minimize handling time for some ships, and consequently, total service time.

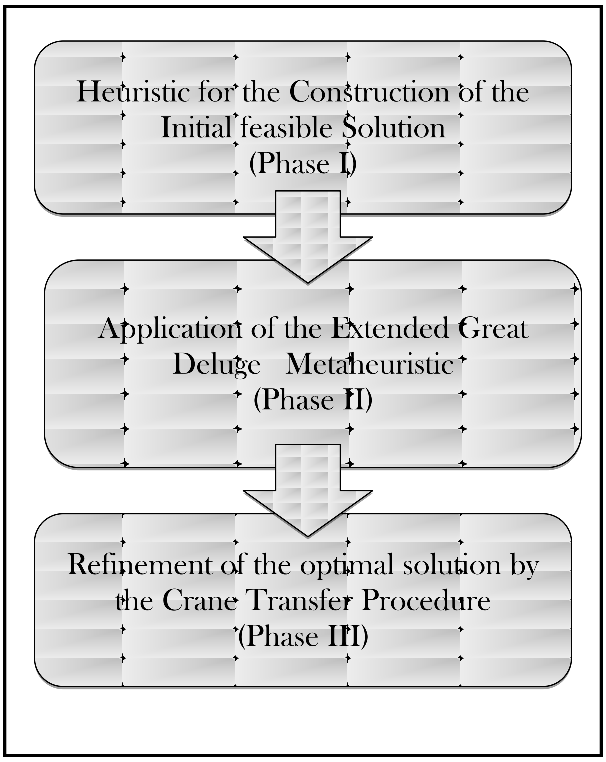


Figure 2: BACAP Resolution Approach

4.1. Heuristic for the initial solution

Before the application of the metaheuristic, a heuristic is constructed to find the first feasible solution, which is gradually improved with the exploration of the neighbourhood by the metaheuristic algorithm.

This is what differentiates the approach suggested in this research from the resolution suggested by the authors, which sets on a random initial solution.

The construction of the initial feasible solution is aimed at increasing the rate of acceptance of the metaheuristic within the resolution, which also results in increasing the efficiency and speed of the resolution.

Figure 3 illustrates the proposed heuristic used to find the first feasible solution to the problem.

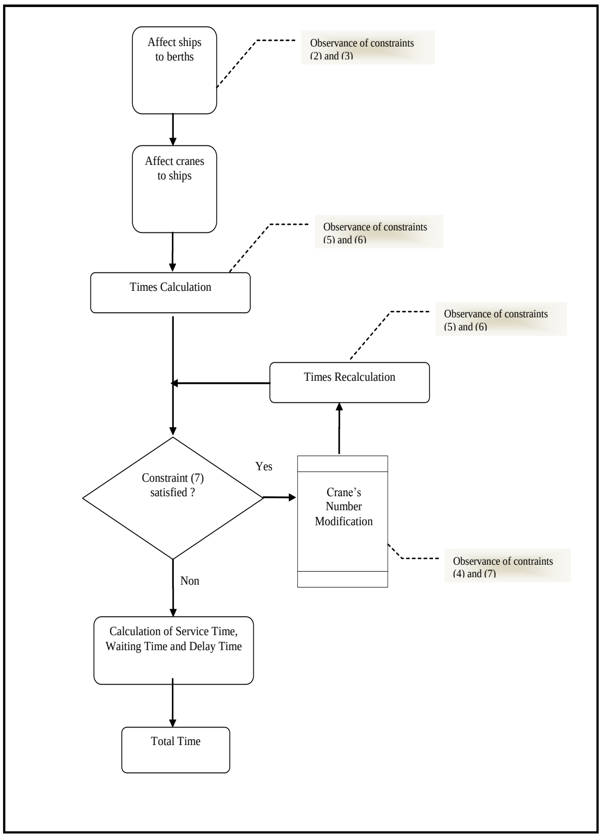


Figure 3: Proposed heuristic to construct the initial solution

4.2. Extended Great Deluge metaheuristic

As explained above, the choice of the metaheuristic that will improve the initial solution was related to a local search or neighbourhood metaheuristics. To that end, we explored the relatively new Extended Great Deluge (EGD) (Burke et al., 2004).

For the application of this algorithm to our problem, we needed:

1. The initial solution S found by the heuristic.
2. The definition of the neighbourhood N(S) of this solution.

Table 1: Extended Great Deluge method

Extended Great Deluge Method

Set the initial solution ***S***
Calculate initial cost function ***f(s)***
Initial ceiling ***B=f(s)***
Specify input parameter Δ***B=?***
While not stopping condition do
    Define neighbourhood ***N(s)***
    Randomly select the candidate solution $S^* \in N(s)$
    If $(f(s^*) \leq f(s))$ or $(f(s^*) \leq B)$
    Then Accept S^*
    Lower the ceiling $B = B - \Delta B$
End while.

The neighbourhood was created while making minor modifications to the initial solution S, such as to the permutation between two container ships taken randomly. The permutation was done for both the berth and the cranes assignment. Following the modifications, the algorithm applied tests on the neighbourhood solution to check if all the constraints were satisfied.

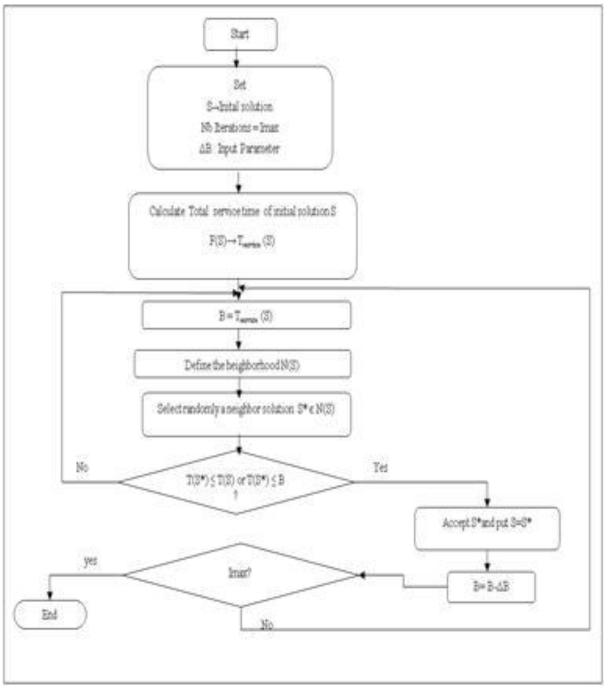


Figure 4: Proposed heuristic to construct the initial solution

5. PRIORITY RULES INCLUDED IN THE MODEL

In this paper, unlike with Liang et al.'s approach (2009a), we include priority rules.

1. Like Liang's approach: Give FCFS rule for the initial solution and then randomly generate neighbourhood solutions.
2. FCFS rule that is governing even the neighbourhood solutions.
3. FCFS rule like (b) and when 2 ships assigned to the same berth have the same time arrival, we prioritize the Most charged one.
4. FCFS rule like (b) and when 2 ships assigned to the same berth have the same time arrival, we prioritize the less charged one.

5.1. Constraints added to the model

For each of the configurations above, a constraint that guarantees the priority rule is added.

a) FCFS-Rule:

b) FCFS-Rule followed by the most charged ship rule in case of arbitrage:

(9*i*)

c) FCFS-Rule followed by the less charged ship rule in case of arbitrage:

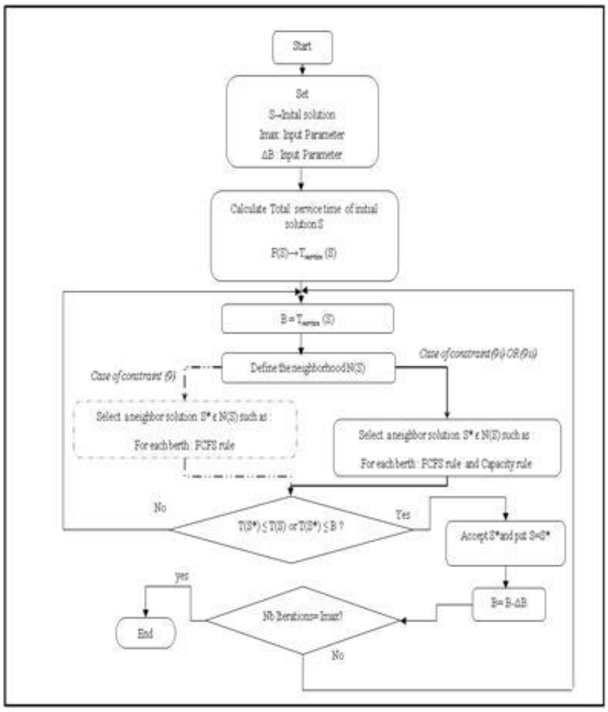


Figure 5: Extended Great Deluge algorithm

6. THE REFINEMENT PROCEDURE BY CRANE TRANSFER

After obtaining the optimal solution by the EGD metaheuristic, we try to improve the result by transferring some cranes, when permitted, in order to minimize some ships' service time. The assumptions below are considered:

1. The adjustment of cranes during service time (charging or discharging of ships) is allowed.
2. Cranes are transferred from one berth to another when handling is completed for ship *A*, and at the same time, another ship *B* on the other berth is still under service. The transfer thus minimizes the remaining time of service for ship *B*.
3. Crane transfer is permitted between two consecutive berths or between berths via others if the latter are not engaged in ship loading or unloading.
4. After servicing the k^{th} ship in a berth, the cranes used can be transferred totally or partially to the $k+1^{th}$ ship in the same berth, when permitted.
5. Time of transfer is ignored for the moment, but can be calculated considering the number of cranes or the distance of transfer.

7. EXPERIMENTS AND RESULTS

The authors applied their methods to solve a real case, at a Shanghai container terminal company in China. In that case, there were 4 berths and 7 quay cranes. The working speed of the quay crane was common to all the cranes and was set at 40TEU/h. The data concerning the arrival time, the time due and the capacities of the ships are shown in the Table2.

In our case, we will use the EGD, preceded by the initial solution construction heuristic to first compare the optimal solution found by Liang et al. (2009a) to the EGD solution. We then present the scheduling in both the Most Charged First and Less Charged First cases. Finally, we present the refined solution found by application of the transfer crane procedure. The parameter settings for the metaheuristic were: Nb iterations = 200,000 and delatB =0.005.

The approach is coded in Matlab R2009b, on a Pentium 4 processor (2-GHz clock) computer.

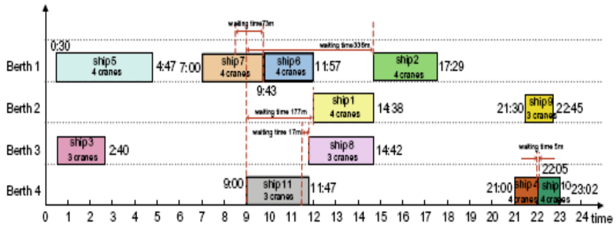
Table 2: Ship Information

	Ship name	**Arrival Time**	**Time Due**	**Total number of container loading/unloading (TEU)**
1	MSG	09:00	20:00	428
2	NTD	09:00	21:00	455
3	CG	00:30	13:00	259
4	NT	21:00	23:50	172
5	LZ	00:30	23:50	684
6	XY	08:30	21:00	356
7	LZI	07:00	20:30	435
8	GC	11:30	23:50	350
9	LP	21:30	23:50	150
10	LYQ	22:00	23:50	150
11	CCG	09:00	23:50	333

7.1. Optimal solution for Liang's problem

The authors solved the problem and found an approximate optimal solution, 2165 min, that minimizes the total service time. Figure 6 illustrates the Gantt chart for that solution.

Figure 6: Gantt chart for Liang's solution (2009a)



7.2. Optimal solutions for the EGD approach

In this paper, and when we apply the FCFS rule for the initial solution and randomly generate the neighbourhood solutions during the metaheuristic resolution, we improved the optimal solution to 1857.4 min. as total service time. That represents 307.6 min or about more than 5 hours less than the authors' optimal solution. The distribution of times in minutes is: 1103.7 min for the handling, 749.7 for the waiting, and 4 min as delay time. The Gantt chart for the solution is shown in Figure 7.

The EGD metaheuristic is then a practical and powerful method resolving the problem. In our Gantt, the number of the quay cranes transfers is lower than in Liang's solution.

We also obtain the solutions below for the FCFS rule, and for the FCFS with the two handling priority rule cases.

For the FCFS rule: Gantt chart in Figure 8.
Total service =1803.1 min., Handling = 1350.6 min, Waiting = 452 min. and Delay = 0 min

For the FCFS with the Most charged ship priority, we obtain an optimal solution as: (Figure 9)
S={berth1, berth2, berth3, berth4}
= {Ship 8;
Ship 3, Ship9;
Ship5;
Ship7, Ship6, Ship2, Ship1, Ship11, Ship4, Ship10}
with total times in min. as:1915.6 for the total service, 1403.8 for Handling, 511.7 for waiting and no Delay.

For the FCFS with the Less charged ship priority, we obtain an optimal solution as: (Figure 10)
S={berth1, berth2, berth3, berth4}
= {Ship7, Ship6, Ship10;
Ship8;
Ship3, Ship5, Ship9;
Ship11, Ship1, Ship2, Ship4}
with total times in min. as:1914.1 for the total service, 1337 for Handling, 577 for waiting and no Delay.

To apply our Crane transfer procedure, we choose the optimal solution found by the EGD in the random context (see Figure 7). The transfer steps considered are as follows:

1. For berth 2, and after using 7 cranes for the first and the second ships served, which are ships 7 and 6, we can add 2 cranes to serve the ship 11, which only has 5 cranes.
2. After serving ship 9 in berth 3, we can transfer the cranes used (totally or partially) to berth 1 to serve ship 4, such that the handling is

minimized and ship 10 arrives at 9 PM and waits before service can begin.

3. For berth 4, and after using 7 cranes for the first ship served, which is ship 3, we can add 3 cranes to serve ship 5, which has only 4 cranes.

After transferring the cranes from ship to ship and berth to berth, we obtain a more optimal solution. The cranes or resources are then best dispatched between the ships. The Total service time is then 1559.9 min against 1857 before the transfer. The times distributions are: 879.2 min. 680.7 min. and no Delay. (Figure 11)

8. CONCLUSION

In this paper, we solve a BACAP in its discrete-dynamic variant. The approach used is based on an Extended Great Deluge metaheuristic preceded by a heuristic to construct the initial feasible solution. A transfer crane procedure is added to enhance the quality of the solution.

The proposed approach provides very satisfactory results, particularly when we compare it with the hGA approach proposed by Liang et al. (2009a). The EGD metaheuristic gave interesting results for the multiobjective case as well. In fact, tests were applied to solve the Liang and Al. (2009b), and the results were very satisfactory.

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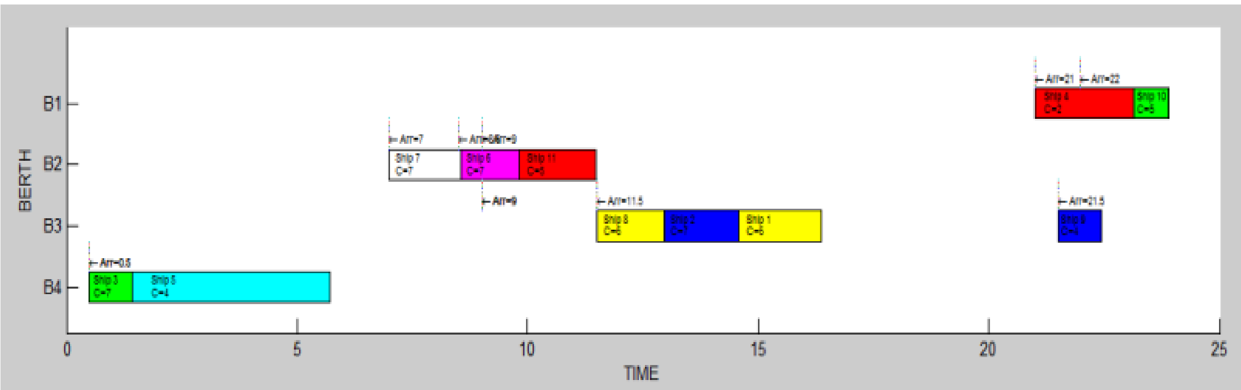

Figure 7: Gantt Chart for the randomly context

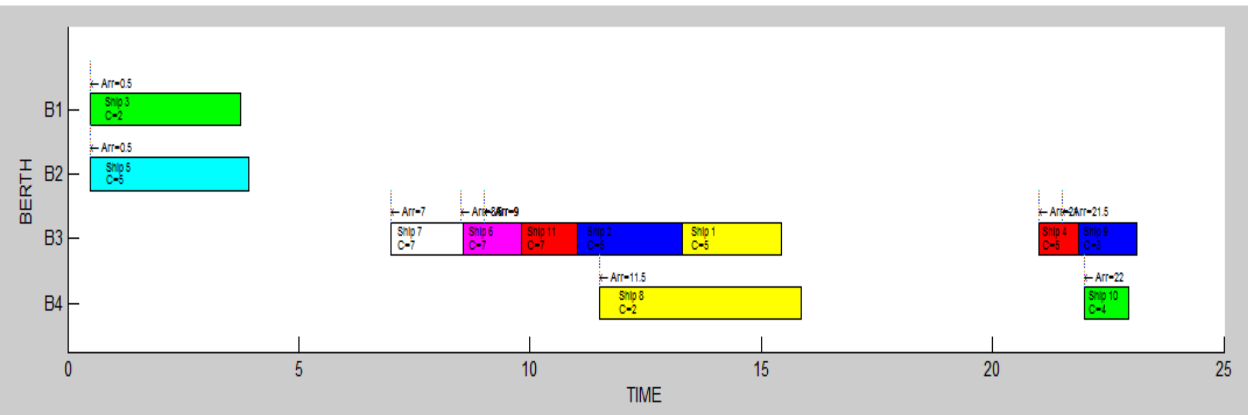

Figure 8: Gantt Chart for the FCFS context

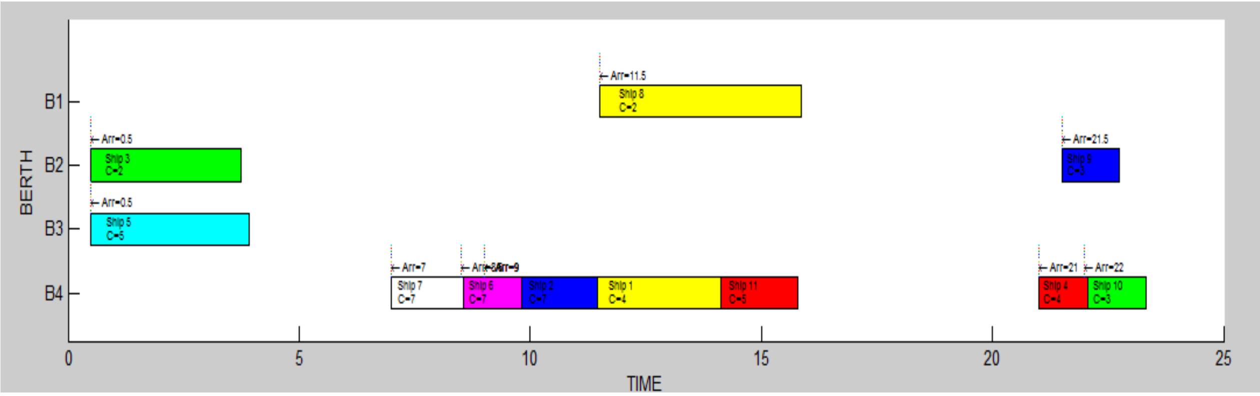

Figure 9: Gantt Chart for the FCFS with Most Charged first

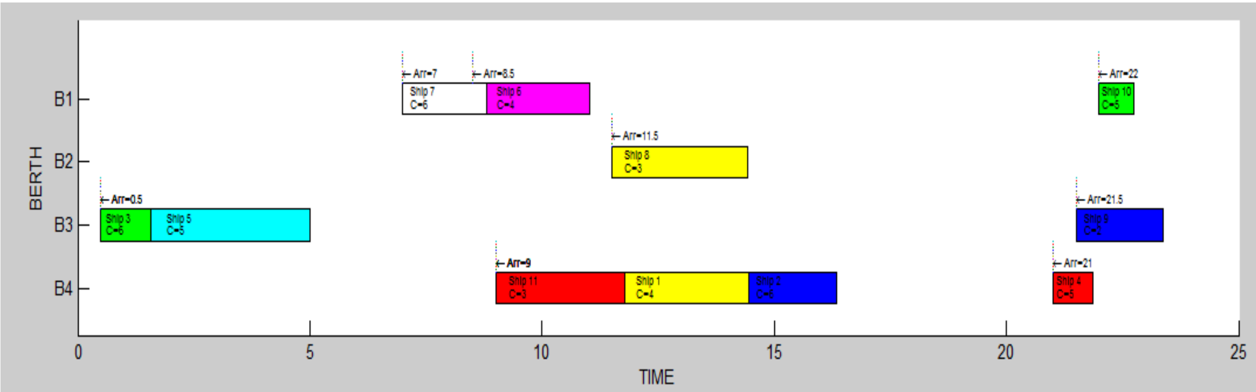

Figure 10: Gantt Chart for the FCFS with Less Charged first

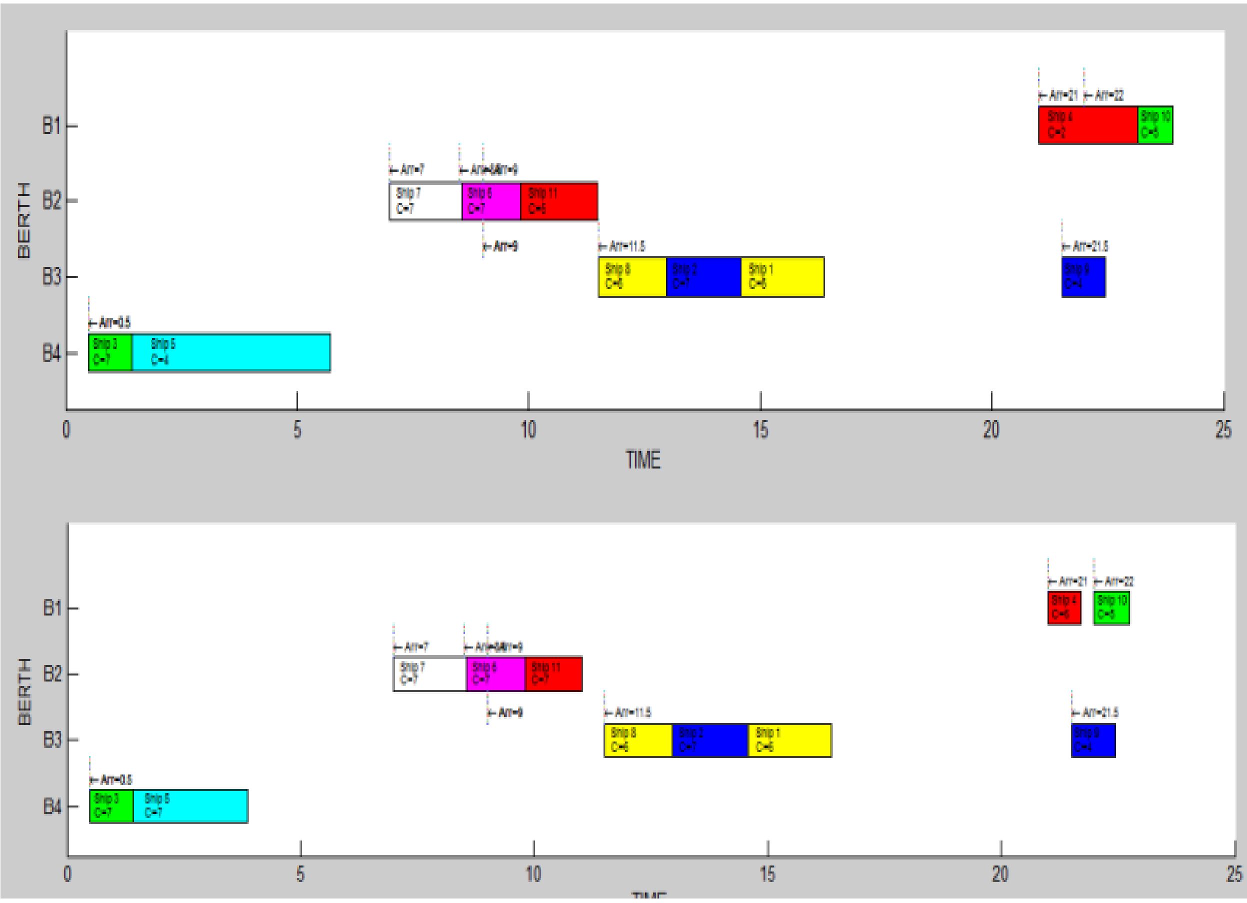

Figure 11: Gantt Charts for the optimal solution before and after crane transfer procedure

RECURSIVE ALGORITHM FOR OPTIMIZATION THE STRUCTURE OF COMPLICATED LOGISTIC, MANUFACTURING AND PROCESSING ENVIRONMENTS

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ABSTRACT
A method of description and optimization of the structure of complicated multi-level processing systems is presented. The set of feasible structures for such class of systems is defined. The representation of this set is constructed in terms of the graph theory. The creation and annihilation of levels using the adjacent matrix is presented. A recursive algorithm is constructed to solve the general optimization problem of the structures. For the reduced statement two types of variable parameters are defined: for the level size and for the relations of adjacent levels. For solving the reduced problem the recursive algorithm is constructed, where index of level is the index of recursion. Modelling and optimization of the structure of multi-level processing system illustrate the considered approach.

Keywords: discrete manufacturing and processing environment, optimal multi-level partitioning, optimal restructurization, recursive optimization algorithm.

1. INTRODUCTION

Large-scale problems can be decomposed in many different ways. The current approach for describing and optimizing the structure of hierarchical systems is based on a multi-level partitioning of given finite set in which the qualities of the system may depend on the partitioning.

Examples of problems of this class are aggregation problems, structuring of decision-making systems, database structuring, the problems of multiple distribution or centralization, multi-level tournament systems, multi-level distribution systems, optimal clustering problems.

In a multi-level distribution system each element is a supplier for some lower level elements and a customer for one higher-level element. The zero-level elements are only customers and the unique top-level element is only a supplier. The choice of optimal number of suppliers-customers on each level is a mathematically complicated problem.

The multi-level tournament system (Laslier 1997) is a relatively simple special case of a multi-level processing system. To consider a tournament system, the number of games (pair-wise comparisons) is a quadratic function of the number of participants. This is a very quickly increasing function. If the number of participants is large, the number of games is very large. This is a reason why the multi-level approach is useful for the selection of the winner. From the tournaments of the first level the winners are distributed between the tournaments of the next level. The second level tournaments winners are going to the third level, until the winner is selected. Suppose the goal is to minimize the number of all games. If the price for all games is the same, the solution of the problem is well known. Each tournament has two participants and only one game is played. If the prices of games for different levels are different or constraints to the number of levels are active, a relatively complicated nonlinear integer programming problem arises.

Simulation model of logistic processes in container terminals allows considering terminal operation at three different partitioning levels (Merkuryev et al. 2003).

The optimal structuring procedure considered in this paper is based on the full set of hierarchical trees of a feasible structure that could be composed from the given set of elements (Riismaa 1993). In the context of this statement an element is considered as a logical part of the processing system that is carrying out an identifiable mission and obeys the necessary functionality and autonomy (Berio and Vernadat 1999; Littover et al. 1999; Mesarovic et al. 1970, 1975; Miyawaki et al. 2005; Bruzzone et al. 2007).

The hierarchical structure is considered as a hierarchical tree. The variable parameters are also parameters that describe this tree. The feasible set of structures is a set of hierarchical trees. The arising optimization problem is an integer mathematical programming problem. In general, the solving process is exposed as a systematized selection of all possible feasible variations.

The assembling problem as well as a broad class of design and implementation problems, such as component selection in production systems, reconfiguration of manufacturing structures, optimization of the hierarchy of decision making systems, multi-level aggregation, creation and cancellation of levels (Riismaa and Randvee 2003), etc. can be mathematically stated as a multi-level selection problem (Randvee et al. 2000; Riismaa and Randvee 1997; Vain et al. 2005, 2002, 1999).

The main difficulty from the point of view of optimization is that the number of subsets of partitioning is a variable parameter. For corresponding optimization problem it means that upper limit of summation, the number of summands (integer valued parameter) is a variable parameter. The search for a solution to this nonlinear integer programming problem is considered mathematically complicated.

2. FEASIBLE SET OF STRUCTURES

Consider all *s*-levels hierarchies, where nodes on level *i* are selected from the given nonempty and disjoint sets and all selected nodes are connected with selected nodes on adjacent levels. All oriented trees of this kind form the feasible set of hierarchies (Riismaa 2003, 1993; Riismaa and Randvee 2002; Riismaa et al. 2003).

The illustration of this formalism is given in Figure 1 (Riismaa 2005a).

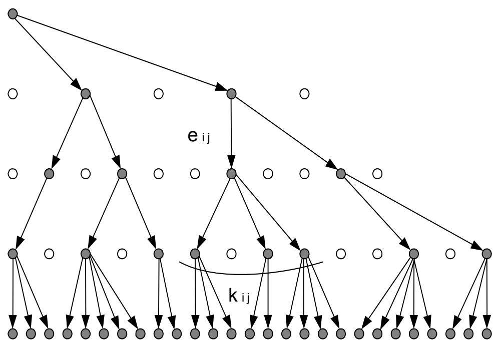

Figure 1: Feasible Set of Structures

Suppose Y_i is an adjacent matrix of levels *i* and $i-1$ $(i=1,...,s)$. Suppose m_0 is the number of 0-level elements (level of object).

Theorem 1. All hierarchies with adjacent matrixes $\{Y_1,...,Y_s\}$ *from the described set of hierarchies satisfy the condition*

$$Y_s \cdot \ldots \cdot Y_1 = (\underbrace{1,\ldots,1}_{m_0}) \tag{1}$$

The assertion of this theorem is determined directly (Riismaa 2003).

3. OPTIMAL MULTI-LEVEL PARTITIONING

The general optimization problem is stated as a problem of selecting the feasible structure which corresponds to the minimum of total loss given in the separable-additive form:

$$\min_{Y_1,\ldots,Y_s} \left\{ \sum_{i=1}^{s} \sum_{j=1}^{m_i} \mathrm{h}_{\mathrm{ij}} \left(\sum_{r=1}^{m_{i-1}} d^{\,i}_{jr}\, y^{\,i}_{jr} \right) \middle| \begin{array}{l} Y_s \cdot \ldots \cdot Y_1 = \\ = (\underbrace{1,\ldots,1}_{m_0}) \end{array} \right\} \tag{2}$$

Here $h_{ij}(\cdot)$ is an increasing loss function of *j*-th element on *i*-th level and $d^{\,i}_{jr}$ is the element of $m_i \times m_{i-1}$ matrix D_i for the cost of connection between the *i*-th and (*i*-1)-th level (Littover et al. 2001).

The meaning of functions $h_{ij}(k)$ depends on the type of the particular system.

By the optimization of the structure of multi-level tournament system, the loss inside the *j*-th tournament on *i*-th level is

$$h_{ij}(k_{ij}) = d^{\,i}_{j} k_{ij}(k_{ij}-1),$$

where k_{ij} is the number of participants of *j*-th tournament of *i*-th league.

By complexity optimization of hierarchically connected subsystems, the loss inside the *j*-th set of partitioning on *i*-th level may be defined as follows:

$$h_{ij}(k) = \sum_{q=1}^{k} a_{ijq} \frac{k!}{q!(k-q)!}.$$

In this case the value of the function $h_{ij}(k)$ describes the number of all nonempty subsystems inside the *j*-th set of partitioning on *i*-th level.

Mathematically this problem is an integer programming problem with a non-continuous objective function and with a finite feasible set. For solving this kind of nonlinear integer programming problems only non-effective classical methods are known.

4. RECURSIVE ALGORITHM FOR SOLVING THE GENERAL PROBLEM OF SRTUCTURE OPTIMIZATION

In this part the algorithm that selects the feasible structures corresponding to the minimum of total loss will be introduced.

Denote

$$N_1 = \left\{ Y_1 \middle| \sum_{j=1}^{m_1} y^1_{jr} = 1(r=1,\ldots,m_0) \right\},$$

$$N_i = \left\{ Y_i \middle| Y_i \cdot \ldots \cdot Y_1 = (\underbrace{1,\ldots,1}_{m_0}) \right\} (i=2,\ldots,s).$$

The set N_i contain all i-th elements Y_i of feasible presentations $\{Y_1,\ldots,Y_s\}$ $(i=1,\ldots,s)$.

Define the functions

$$f_1(Y_1)=\left\{\sum_{j=1}^{m_1} h_{1j}\left(\sum_{r=1}^{m_0} d_{jr}^1 y_{jr}^1\right)\middle|\sum_{j=1}^{m_1} y_{jr}^1=1\right\},$$

$$f_i(Y_i)=$$

$$=\min_{Y_{i-1}}\left\{\begin{array}{l} f_{i-1}(Y_{i-1})+ \\ \\ +\sum\limits_{j=1}^{m_i} h_{ij}\left(\sum\limits_{r=1}^{m_{i-1}} d_{jr}^i y_{jr}^i\right)\end{array}\middle|\begin{array}{l} Y_{i-1}\in N_{i-1}; \\ Y_i\cdot\ldots\cdot Y_1= \\ =\underbrace{(1,\ldots,1)}_{m_0}\end{array}\right\}$$

$$(i=2,\ldots,s).$$

The function $f_i(Y_i)$ represents the minimum loss on levels $1,\ldots,i$ for adjacent matrix Y_i.

Define the sets

$$P_i(Y_i)=$$

$$=Arg\min_{Y_{i-1}}\left\{\begin{array}{l} f_{i-1}(Y_{i-1})+ \\ \\ +\sum\limits_{j=1}^{m_i} h_{ij}\left(\sum\limits_{r=1}^{m_{i-1}} d_{jr}^i y_{jr}^i\right)\end{array}\middle|\begin{array}{l} Y_{i-1}\in N_{i-1}; \\ Y_i\cdot\ldots\cdot Y_1= \\ =\underbrace{(1,\ldots,1)}_{m_0}\end{array}\right\}$$

$$(i=2,\ldots,s);$$

$$\tilde{P}_s(Y_s^*)=Arg\min\{f_s(Y_s)|Y_s\in N_s\}.$$

The set $P_i(Y_i)$ is a set of adjacent matrixes Y_{i-1} minimizing the loss on levels $1,\ldots,i$ for this adjacent matrix Y_i.

The solution in terms of defined sets is sequential:

Step 1. For each $Y_1\in N_1$ compute the function $f_1(Y_1)$ and construct the set

$P_1(Y_1)=Arg\min\{f_1(Y_1)|Y_1\in N_1\}.$

Step i. For each $Y_i\in N_i$ construct recursively by the index i the sets

$P_i(Y_i)\quad (i=2,\ldots,s-1).$

Step s. For each $Y_s\in N_s$ construct the set

$\tilde{P}_s(Y_s^*)=Arg\min\{f_s(Y_s)|Y_s\in N_s\}.$

Now the following set is constructed:

$$U_s^*=\left\{\{Y_1^*,\ldots,Y_s^*\}\middle|\begin{array}{l} Y_s^*\in\tilde{P}_s(Y_s^*), \\ Y_{s-1}^*\in P_s(Y_s^*), \\ \ldots \\ Y_1^*\in P_2(Y_2^*)\end{array}\right\}.$$

This set contain formally all presentations of optimal structures from the feasible set.

On step i for each adjacent matrix Y_i find the optimal adjacent matrixes Y_{i-1} must be founded. It means that this minimization method is very general, but time-consuming and applicable for small-dimensional problems. For this reason we further slightly restrict the class of problems by simplifying the functional dependencies in the objective function.

5. REDUCED PROBLEM OF STRUCTURE OPTIMIZATION

Now an important special case is considered where the connection cost between the adjacent levels is the property of the supreme level: each row of the connection cost matrices between the adjacent levels consists of equal elements.

There is a possibility to change the variables and to represent the problem so that

$$d_{jr}^i=1;\quad i=1,\ldots s;\ \ j=1,\ldots,m_i;\ \ r=1,\ldots,m_{i-1}.$$

Now the total loss depends only on sums $\sum_{r=1}^{m_{i-1}} y_{jr}^i=k_{ij.}$, where k_{ij} is the number of edges beginning in the j-th node on i-th level.

Recognize also that $\sum_{j=1}^{m_i} k_{ij}=p_{i-1},\quad i=1,\ldots,s$, where p_i is the number of nodes on i-th level. If to suppose additionally that $h_{i1}(k)\le\cdots\le h_{im_i}(k)$ for each integer k, the general problem (2) transforms into the two mutually dependent phases:

$$\min\left\{\sum_{i=1}^{s} g_i(p_{i-1},p_i)\,\middle|\,(p_1,\ldots,p_{s-1},1)\in W^s\right\}$$

$$\text{over}\quad p_1,\ldots,p_{s-1}$$

(3)

where

$$g_i(p_{i-1}, p_i) = \min\left\{ \sum_{j=1}^{p_i} h_{ij}(k_{ij}) \,\middle|\, \sum_{j=1}^{p_i} k_{ij} = p_{i-1} \right\}$$

$$\text{over } k_{i1}, \ldots, k_{ip_i} \tag{4}$$

$$W^s = \{(p_1, \ldots, p_{s-1}, 1) \,|\, 1 \le p_i \le p_{i-1}\}.$$

Free variables of the inner minimization (4) are used to describe the connections between the adjacent levels. Free variables of the outer minimization (3) are used for the representation of the number of elements at each level.

6. RECURSIVE ALGORITHM FOR SOLVING THE REDUCED PROBLEMOF STRUCTURE OPTIMIZATION

Consider the functions that represent the minimum loss on levels 1, 2,…, *i*, if there are exactly p_i nodes on *i*-th level:

$$G_1(p_1) = g_1(p_0, p_1),$$

$$G_i(p_i) =$$
$$= \min\{G_{i-1}(p_{i-1}) + g_i(p_{i-1}, p_i) \,|\, p_{i-1} \in A_{i-1}\}$$
$$\text{over } p_{i-1}$$

and

$$A_i = \{1, \ldots, m_i\}, \quad i = 1, \ldots, s.$$

For each $p_i \in A_i$ define the sets

$$B_i(p_i) =$$
$$= Arg\min\{G_{i-1}(p_{i-1}) + g_i(p_{i-1}, p_i) \,|\, p_{i-1} \in A_{i-1}\}$$
$$B_1(p_1) = \{p_0\}$$

and for each $p_{i-1} \in B_i(p_i), \quad p_i \in A_i$ the sets

$$T_i(p_{i-1}, p_i) = \{(k_{i1}, \ldots, k_{ip_i}) =$$
$$= Arg\min\left(\sum_{j=1}^{p_i} h_{ij}(k_{ij}) \,\middle|\, \sum_{j=1}^{p_i} k_{ij} = p_{i-1} \right) \}.$$

For each $p_i \in A_i$ denote

$$T_i(p_i) = \cup T_i(p_{i-1}, p_i),$$
$$\text{over all } p_{i-1} \in \mathrm{B}_i(p_i), i = 1, \ldots, s.$$

The solution in terms of defined sets is sequential:

Step 1. For each $p_1 \in A_1$ compute the function $G_1(p_1)$ and construct the set $T_1(p_0, p_1)$.

Step i. For each $p_i \in A_i$ construct recursively by the index i

$G_i(p_i), \quad B_i(p_i)$ and

$$T_i(p_i) = \cup T_i(p_{i-1}, p_i) \text{ over } p_{i-1} \in B_i(p_i),$$
$$i = 2, \ldots, s.$$

As a result of the application of given steps we have for every $p_i \in A_i$

all $G_i(p_i), \quad B_i(p_i), \quad T_i(p_i)$, $i = 2, \ldots, s$.

Now let us consider following sets:

$$V_s = \left\{ (p_1^*, \ldots, p_{s-1}^*, 1) \,\middle|\, \begin{array}{l} p_{s-1}^* \in B_s(1), \\ p_{s-2}^* \in B_{s-1}(p_{s-1}^*), \\ \ldots \\ p_1^* \in B_2(p_2^*) \end{array} \right\}.$$

Each vector $(p_1^*, \ldots, p_{s-1}^*, 1) \in V_s$ defines a target set:

$$Q_s = \left\{ \left\{ \begin{array}{l} T_1(p_0, p_1^*), \\ T_2(p_1^*, p_2^*), \\ \ldots \\ T_{s-1}(p_{s-2}^*, p_{s-1}^*), \\ T_s(p_{s-1}^*, 1) \end{array} \right\} \,\middle|\, (p_1^*, \ldots, p_{s-1}^*, 1) \in V_s \right\}$$

Each element from the set Q_s corresponds to all feasible representations $\{Y_1^*, Y_2^*, \ldots, Y_s^*\}$ that do not modify the minimal value of the cost function.

7. ACADEMIC EXAMPLE: OPTIMIZATION THE STRUCTURE OF MULTI-LEVEL PROCESSING SYSTEM

Consider the processing of *n* parts (Riismaa 2002, 2005b). In case of one processing unit the overall processing and waiting time for all n parts is proportional to n^2 and is a quickly increasing function. For this reason the hierarchical system of processing can be suitable. From zero-level (level of object) the parts will be distributed between p_1 first-level processing units and processed (aggregated, packed etc.) by these units. After that the parts will be distributed between p_2 second-level processing units and processed further and so on. From p_{s-1} (s - 1)-level the units will be sent to the unique s -level unit and processed finally. The cost of processing and waiting on level i is approximately

$$g_i\left(p_{i-1}, p_i\right) = \left(d_i\, l_{i-1}\, p_{i-1} / p_i\right)^2 p_i + a_i\, p_i$$
$$(i = 1,\dots, s).$$

Here l_i is the number of aggregates produced by one robot on level i (a number of boxes for packing unit), d_i is a loss unit inside the level i, and a_i is the cost of i-th level processing unit. The variable parameters are the number of processing units on each level $p_i\left(i = 1,\dots, s\right)$.

The goal is to minimize the total loss (processing time, waiting time, the cost of processing units) over all levels:

$$\min \sum_{i=1}^{s} \left((d_i l_{i-1})^2 \left(\begin{array}{l} \left(p_i\left(\left[\dfrac{p_{i-1}}{p_i}\right]+1\right) - p_{i-1}\right)\left[\dfrac{p_{i-1}}{p_i}\right]^2 + \\ + \left(p_{i-1} - p_i\left[\dfrac{p_{i-1}}{p_i}\right]\right)\left(\left[\dfrac{p_{i-1}}{p_i}\right]+1\right)^2 \end{array} \right) + a_i p_i \right)$$

over natural $p_i\left(i = 1,\dots, s\right)$. Here $\left[p\right]$ is the integer part of p. The goal function of this discrete programming problem is discrete-convex (Theorem 4). It is possible to extend this function to convex function (Theorems 2 and 3) and get a solvable convex programming problem using the method of local searching.

8. CONCLUSION

Many discrete or finite hierarchical structuring problems can be formulated mathematically as a multi-level partitioning procedure of a finite set of nonempty subsets. This partitioning procedure is considered as a hierarchy where to the subsets of partitioning correspond nodes of hierarchy and the relation of containing of subsets define the arcs of the hierarchy. The feasible set of structures is a set of hierarchies (oriented trees) corresponding to the full set of multi-level partitioning of given finite set.

Each tree from this set is represented by a sequence of Boolean matrices, where each of these matrices is an adjacency matrix of neighboring levels. To guarantee the feasibility of the representation, the sequence of Boolean matrices must satisfy some conditions – a set of linear and nonlinear equalities and inequalities.

Examples of problems of this class are aggregation problems, structuring of decision-making systems, database structuring, multi-level tournament systems, multi-level distribution systems.

The recursive algorithms considered in the paper are double-cycle optimization algorithms. The inner cycle increases the number of elements inside of the current level by one unit, and outer cycle on each step increases the number of levels by one unit. On each iteration step a one-parameter integer programming problem must be solved.

The formalism described in this paper enables to state the reduced problem as a two-phase mutually dependent discrete optimization problem and construct some classes of solution methods. Variable parameters of the inner minimization problem are used for the description of connections between adjacent levels. Variable parameters of the outer minimization problem are used for the presentation of the number of elements on each level.

The two-phase statement of optimisation problem guarantees the possibility to extend the objective function to the convex function and enables to construct algorithms for finding the global optimum. In this paper for finding the global optimum the method of local searching is constructed. On each step of iteration the calculation of the value of objective function is required only on some vertices of some kind of unit cube.

The approach is illustrated by a multi-level production system example.

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USING SIMULATED SENSOR IMAGES FOR OBJECT RECOGNITION OF UNIVERSAL GOODS FOR AUTOMATIC UNLOADING OF CONTAINERS

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ABSTRACT
Unloading of standard sea containers is a time- and cost-expensive process step within global supply chains. Until now, existing solutions for automatic unloading are limited to goods of cubical shape. The main challenge in developing a robotic system for universal logistic goods is object recognition of goods that differ in size, shape and orientation. A common approach for object recognition systems is the comparison of sensor data to a model database. This paper presents a simulation system of sensor images for universal logistic goods. The objective of simulating sensor images is generating a model database and create training data for classification. Additionally, sensor images of complete packaging scenarios can be simulated for evaluating the object recognition algorithm with ideal sensor data that does not contain measurement noise or other inaccuracies. The simulation system is explained in detail by modelling of cubical objects.

Keywords: technical logistics , container unloading, sensor simulation, object recognition

1. INTRODUCTION

The dynamical development of global flow of goods in complex worldwide logistics networks creates challenging requirements for logistic service providers (Aden 2008). As for instance, the pressure of providing efficient logistic processes causes a request of technical systems for automation within the supply chain. The transported goods are generally packed in standardized packaging and loaded in carriers as containers, swap bodies and Uniform Load Devices (Echelmeyer 2008). Loading and unloading processes of containers are still a non-automated process in logistic markets and generates bottlenecks in efficiency (Burwinkel 2009). This paper focuses on the automatic unloading process.

In Europe, about 64% of the imported goods are suitable for automatic unloading due to their size, shape and weight (Akbiyik 2009). Hence, the economic relevance of automatic unloading is very high. The main shapes of packaged goods can be summarized to cubical, cylindrical and sack-shaped (Akbiyik 2009). Concerning cubical goods, the successful market launch of the 'Parcel Robot' (Scholz-Reiter 2008) has shown the feasibility of automatic unloading of cubical goods. The crucial step to extend the unloading system to universal goods is, amongst gripping technologies, the development of a suitable object recognition system, that is able to detect and classify different goods inside a container. The automatic unloading process for universal goods refers to the bin-picking problem and is not completely solved today (Kirkegaard 2006).

For an accurate determination of position and orientation of the goods, the sensor system must deliver 3D information about the scene. Instead of reconstructing 3D information from 2D images, a suitable sensor technology for object recognition inside a poorly lighted container is Time-of-Flight (TOF) laser scanning (Uriarte 2010). The resulting images store the depth information instead of grey-scale values. The following object recognition process analyses the images for significant characteristics and compares them with characteristics of predefined models of determined object classes.

This paper focuses on the simulation of the sensor images for an object recognition system for universal goods. These simulated sensor images will be used in two different approaches for object recognition in future research work. Afterwards, the two approaches will be evaluated and the result will be compared. The first approach considers the generation of a model database that is used for comparison of the real sensor images with models of every predefined object class. The models are generated by simulating the sensor measurement principle of a TOF laser scanner by means of standard computer graphic techniques. For every object class, several images from different positions are simulated and are stored in the model database. Due to possible occlusions in the packaging scenario, even models of object parts are generated. The second approach will use the simulated sensor images as training data for a classification task. Classification is the assignment of an input set to a finite number of discrete categories (Bishop 2006). Considering an automatic unloading system, the input set are 3D images of logistic goods. The classifier that is trained with the simulated sensor data, assigns each image to a predefined object class.

Additionally, simulating sensor images of entire packaging scenarios is also possible. These images can be used for evaluating object recognition algorithms. In order to determine the theoretical performance of different object recognition algorithms, the sensor image of the packaging scenario can be simulated without influence of negative measurement effects.

2. STATE OF THE ART

This paper presents a simulation methodology for TOF sensors in order to use it in the object recognition process of universal logistic goods. Therefore, the state of the art contains the TOF sensor technology and related work that use simulation techniques for this measurement principle.

2.1. TOF Laser Scanning

In order to identify universal goods inside a container under unfavourable lightning conditions, sensor systems which provide depth information by TOF laser scanning are suitable for image acquisition (Uriarte 2010). These sensors measure the distance between the object and the sensor by sending a light ray from a light source to the object to be measured. The light is emitted and partially reflected from an object to the sensor, which detects it. The sensor measures the time between sending and receiving the ray and by knowing the speed of light the distance to the object point can be calculated. The acquired data is usually delivered as a set of points with (x,y,z) coordinates for each point. The LMS-200 from Sick is a frequently used ToF scanner, with a rotating mirror. It has an angle of 180° and a angular resolution of 0,25° and a measuring range from 0.1 to 30 m. The lateral resolution of this scanner is about 22 mm when measuring objects at 5 m. Figure 1 illustrates the measuring principle of the sensor.

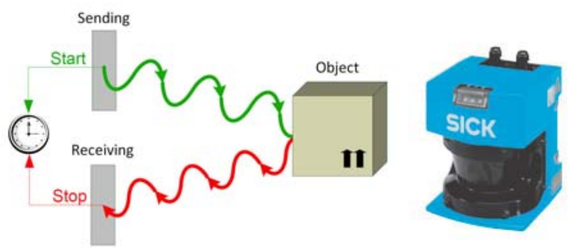

Figure 1: TOF Scanning (Uriarte 2010)

Since the LMS 200 works line-based, the camera is mounted on a pitch device in order to scan the whole packaging scene.

2.2. TOF Sensor Simulation

Simulation of TOF sensors can avoid the development of cost expensive prototypes. Thereby, the design of sensor hardware and application development can be realized by simulation. Common algorithms that are tested and evaluated by simulated are in the area of sensor calibration and sensor data processing (Keller 2007).

In order to verify a calibration tool, *Meissner et al.* have generated a realistic 3D simulation of an urban intersection and simulate several 4-layer laser scanner (Meissner 2010). A simulation system for system analysis and algorithm development is given by *Kukko et al.* (Kukko 2007). The purpose of this work is providing a tool for analyzing systematic properties of scanning systems and algorithm development.

Simulating TOF sensor images of complex 3D scenes is a time expensive processing step. In order to perform the simulation in real time, *Keller* makes use of the programmability of modern Graphic Processing Units (GPUs) (Keller 2009). Their simulation approach is motivated in particular by physics of Photonic Mixing Device (PMD) sensors, which are a specific type of TOF sensor. Additionally, they consider typical measurement inaccuracies like deviation errors and resolution artefacts. An approach in which simulating TOF images are used as training data for classification is presented by *Shotton et al.* (Shotton 2011). They use simulated TOF images of humans of many shapes and sizes in highly varied poses for human pose recognition. They also use GPU programming techniques for recognition in real-time.

Considering the field of automatic unloading of containers, none of the existing approaches for cubical goods use simulated sensor images whether for evaluation of algorithms, generating a model database or classifier training.

3. SYSTEM ARCHITECTURE

This section describes the complete architecture of an object recognition system for universal logistic goods. The system identifies the shape of logistic goods and determines their position and orientation (pose). The object recognition process and the use of simulated sensor images is explained in detail.

3.1. Architecture

The system architecture covers the complete logistic process of automatic unloading of containers. For handling of logistic goods a mechanical robotic system is used. Figure 2 illustrates the system architecture. The process is starting with a packaging scenario that is made up with logistic goods with shapes from all predefined object classes. In the first step, a 3D image from the scenario is acquired by a TOF sensor. The sensor delivers a point cloud from which a 3D range image can be generated. A range image contains distance information instead of grey scale values. Afterwards, this image is analysed by object recognition

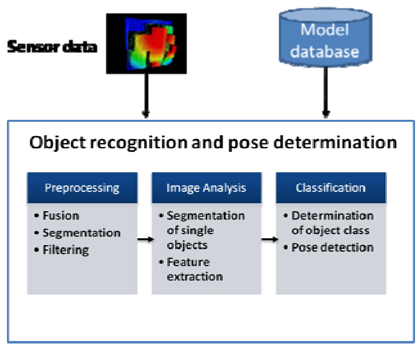

Figure 2: System Architecture

techniques that are described in the following subsection. The result of object recognition are position and possible gripping points of logistic objects that are suitable for automatic unloading by the mechanical robot system. Unloading another logistic good requires a new image acquisition process, because gripping by the mechanical robot may have influences on the complete packaging scenario.

3.2. Object Recognition

The object recognition system consists of three parts. First, the image is preprocessed. In this step, inaccuracies that are caused by the image acquisition process are reduced by applying filter algorithms. Additionally, an initial segmentation step is performed to distinguish between container body and container content. The distinction is necessary for a collision detection during the unloading process. For object recognition the distinction is not mandatory. However, due to a reduced image size the computation time of the image analysis step reduces. In the case of using more sensor that scan the same packaging scenario from different point of views, a fusion step is necessary. This is realized by performing a registration between the sensor images. Image registration techniques define a transformation that maps the first point set onto the second one (Forsyth 2002).

After preprocessing, an image analysis step identifies characteristic features of logistic objects. This requires another segmentation step in order to identify regions that represent single logistic objects. Then, feature extraction is performed. A feature is a characteristic attribute in the image that can describe a specific object. Usual features of objects are geometric characteristics like corner points, surfaces, patches and related areas.

In the last step the detected object is classified according to a related object class. Therefore, the detected features of a segmented region are compared to features of predefined model class. The geometric models of logistic objects from all predefined shape classes are stored in a model database.

The simulated sensor images will be used in the object recognition process in two different ways. The first approach uses the simulated sensor images for generation of the model database. This means for real automatic unloading processes, the sensor data will be analyzed, and single regions that possibly contain a logistic object are compared to the model database by matching operations. The second approach uses a different classification concept. Here, a learning algorithm is trained with simulated sensor images of single logistic objects. After the training phase, the classifier should be able to distinguish between the predefined object classes. For processing in real-time both approaches will be implemented by using GPU programming techniques.

4. SENSOR SIMULATION

This section describes the simulation of the TOF measurement principle by reference to the laser scanner LMS 200 from the company SICK. The objectives of sensor simulation are creating 3D images for every predefined object class in various scanning directions. Additionally, sensor images of individual parts of objects classes are generated. This is useful in case when objects are partially occluded by other objects in the scene.

One benefit of simulating sensor images is the generation of sensor images without scattering effects or measurement noise. Thereby, the object recognition system can be tested under ideal conditions and the theoretical performance can be evaluated. The simulated sensor data is generated by a simulation software that is implemented in MATLAB. The user is able to create different packaging scenarios with objects from predefined object classes. Afterwards, the sensor parameters like scan resolution and sensor position can be set. Figure 3 illustrates the scene generator of the simulation software.

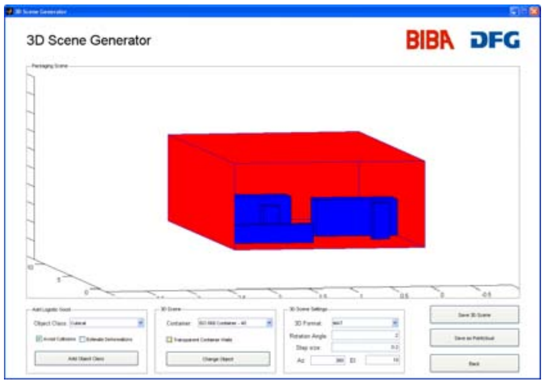

Figure 3: Screenshot of the 3D Scene Generator

In real scanning processes, the light ray from the sensor unit is emitted sequentially over the whole scene. The sensor has a scan angle of 180° degrees and the angular resolution can be chosen from 0.25°, 0.5°, 1°. The light ray of the sensor is modelled by a line g like equation 1 with a position vector $\vec{p}$ and a direction vector $\vec{v}$.

$$g: \vec{x} = \vec{p} + \lambda \vec{v} \tag{1}$$

For each ray the intersection between the ray and the objects in the scene is computed. Therefore, the objects must be described geometrically. Actually, the simulation platform is able to simulate packaging scenarios with cubical goods. Implementing geometric models for the other objects will be one following step of the research work.

4.1. Modelling of Cubical Objects

A cubical object consists of four vertices and linking edges. The vertices defines the corner points of the cubical objects. The cubical object is limited by six faces that are described by equation 2. A face f in coordinate form is described by a normal vector $\vec{n}$ and a real number b.

$$f: \vec{n}\vec{x} = b \tag{2}$$

Within the simulation platform, all kinds of cubical logistic objects can be defined and placed inside the standard container. Collisions of cubical objects inside the container are prevented by a collision check algorithm. For simplification reasons, deformations of the objects are not considered.

4.2. Generation of the point cloud

The TOF sensor output is a point cloud with (x,y,z) coordinates. In order to simulate the point cloud, the intersection of each ray with cubical logistic objects is computed. These intersection points represent the point cloud of a virtual TOF sensor. As the packaging scenario is made up with cubical objects, the intersection of each ray with every cubical object has to be determined. For a cubical object, that implies a possible intersection computation with six faces. In the case of a packaging scenario with many logistic objects and a high scanning resolution the calculation time increases significantly.

Therefore, visible surface determination algorithms from the field of computer graphic techniques are applied. A suitable algorithm is back face elimination. A back face is an oriented face with respect to a vector v (mostly the view direction of the camera) if the angle between its normal vector n and v is between 0 and 90 degrees. Expressed mathematically, the dot product between n and v must be greater or equal zero. Figure 4 illustrates the principle of back face culling for a cubical object. (Agoston 2005)

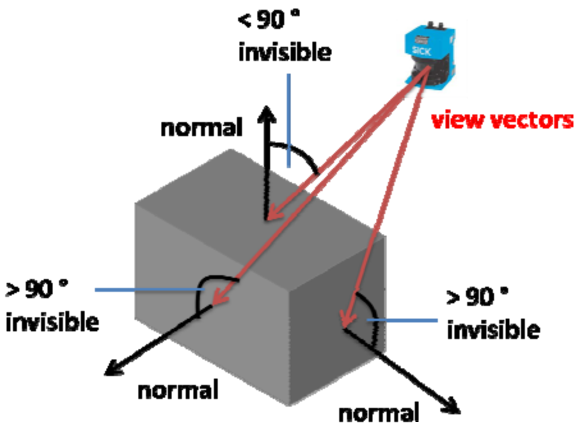

Figure 4: Back face culling for a cubical object

Result of the back face culling operation is a reduced set of visible surfaces for which the intersection with the ray must be computed. However, back face culling is a local operation, therefore it could be possible that a surface that is defined as visible can be occluded by another logistic object. This issue is addressed in the following subsection.

Computing intersection points of a ray and all visible surfaces of a logistic object requires methods from the field of analytical geometry. The intersection between a line and a face has to be computed. Therefore, equation 1 is inserted in equation 2 which results in equation 3.

$$\vec{n}(\vec{p} + \lambda\vec{v}) = b \tag{3}$$

Equation 3 is solved for lambda. This value is inserted in equation 1 and thereby the possible intersection point is computed. As the face is in principle infinite, the intersection point is checked whether it is within the boarder of the face of the cubical object. After the checking the intersection with every object of the packaging scenario, each ray has a set of intersection points. The number of elements of the set reaches from zero till the number of all faces of logistic objects in the packaging scenario. Because of the possible long computation time, the intersection computations are implemented in C-Code instead of using the script language of MATLAB.

4.3. Sensor Image Generation

The generation of a TOF sensor image requires a processing step that identifies from the set of intersection points the closest point to the position of the sensor for each simulated ray. For this purpose, a standard computer graphic technique is used again. A z-buffer algorithm is a two-dimensional array that saves current depth information for each pixel (Agoston 2005). Here, the number of columns of the z-buffer is equal to the number of scanning points per line of the simulated sensor. The number of rows depends to the settings of the rotating unit of the sensor. The z-Buffer can store a value for each ray that is simulated. In order to generate the simulated sensor image, the virtual packaging is scanned line by line. The distance of the scan points depends on the angular resolution of the simulated sensor. If an intersection between a ray and a face of a logistic object is detected, the distance from sensor to intersection points is computed and stored in the z-buffer. When another intersection point of the same ray with another face is detected, the distance is computed again and compared with the one in the z-buffer. In the case of a closer intersection point, the distance stored in the z-buffer is overwritten with the new distance value. Thereby, the closest intersection point for every ray is determined and the TOF sensor image that contains depth information is simulated.

4.4. Experiments

For evaluating the simulation methodology, complete packaging scenarios with cubical logistic objects are imported in the simulation platform and a TOF sensor image is simulated. For illustration two test scenarios are presented. The first one represents a simple packaging scenario with a few cubical logistic objects. Figure 5 illustrates the packaging scenario and the corresponding TOF sensor image.

The second scenario is generated within the context of (Scholz-Reiter 2009). It represents a preferably optimal loading solution of packaging plan by using wall building approaches. Through the two examples, the simulation platform is validated whether the simulation methodology is suitable to generate realistic simulated sensor images of virtual packaging scenarios. The simulation results of the second scenario are illustrated in figure 6.

a) b)

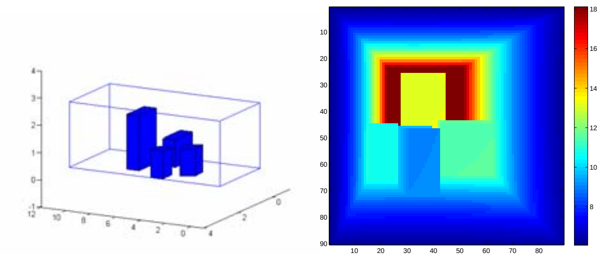

Figure 5: a) Packaging Scenario b) Sensor Image

The packaging scenario of experiment 1 has 4 logistic objects and 10 visible faces to be scanned. The computation time was 0.04 seconds. The sensor scanned 8011 points including container walls. Figure 5b visualizes the simulated sensor image that contains depth information. The depth is coded by colour, whereby reds represents more remote distance than blue.

a) b)

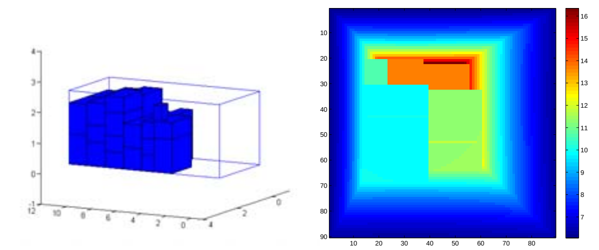

Figure 6: a) Packaging Scenario b) Sensor Image

Experiment 2 has 25 logistic objects and 51 visible faces to be scanned. The computation time was 0.19 seconds. Since the sensor setting was the same like experiment 1, the number of scanned points including container wall was equal to 8011 points. In this experiment, a great challenge for object recognition becomes visible. The two closest logistic goods that are stacked directly above each other on the left side of the container can be a great problem for an object recognition system. Based on the 3D sensor image, figure 6b, the object recognition system cannot distinguish whether it is a large object or several smaller objects. This issue must be solved by a suitable segmentation algorithm during the image analysis step.

5. CONCLUSION

Automatic unloading of universal logistic goods out of a container is a big technical challenge, because of undefined size and shape of goods. In order to identify the position and orientation of a good, a suitable object recognition system is necessary. Therefore, a new approach is presented that uses simulated sensor images. These images are generated by using standard computer graphic techniques. They will be used in two different ways. Firstly, they will be used for creating a model database for template matching. Secondly, they will be applied as training data for a classification procedure. These two aspects will be implemented and evaluated independently from each other.

The next step in the presented research work will be the integration of geometric models for cylindrical logistic objects and sacks. After integration, suitable intersection algorithms must be implemented in order to simulate the TOF measurement principle. Additionally, object recognition algorithms will be tested with ideal sensor images that are created by the simulation platform. Furthermore, a demonstrator platform will be constructed in future research activities. Then, realistic packaging scenarios with logistic objects can be generated and scanned from a TOF scanner. By recreating and scanning the same scenario in the simulation platform, a comparison of the real and virtual sensor image can be performed.

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LOGISTIC MODEL FOR THE DISTRIBUTION OF GOODS IN THE E-GROCERY INDUSTRY: A NEW ADAPTATION OF THE VEHICLE ROUTING PROBLEM

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ABSTRACT

The increasing use of internet and the growing penetration of e-commerce in households have brought the need to redefine the business models and supply chains to achieve profitability in a sector in which logistics costs rises to 10-15%. The grocery industry is considered pioneer in home delivery service. Nevertheless, e-grocers haven't been still able to find the model of success that ensures profitability to their businesses.

This paper deals with the problem of distribution of goods in the grocery retail industry associated with e-commerce.

The problem has three main components that make the cost optimization difficult: the decisions about order filling (whether the picking should be made in stores closest to customers or in warehouses, and the definition of the level of automation in picking in warehouses), as well as the Vehicle Routing Problem with Time Windows, referred to as VRPTW.

The paper examines the solutions being adopted by companies in this sector, identifying best practices, deciding on the variables on which to act and making a proposal for the mathematical model to describe the problem.

Keywords: Logistics, e-commerce, e-grocery, supply chain, VRPTW, routing, MDVRP.

1. INTRODUCTION

During the last few years, and especially after the financial crisis, e-commerce has emerged and grown significantly. The speed of this growth together with the fact that the cost of logistic operations to sell products over the Internet to the final consumer (Business to Consumer industry, also called B2C) can reach 10-15% of total revenues, justify the efforts made in reducing logistic costs associated with the delivery of purchases through the network and consequently, in optimizing the supply chain that manages the flow of materials and information for the B2C business.

For year 2011, an increase of 18.9% is expected. This will mean an income of 680,000 million dollars in the world (Schonjeld 2010).

In 2009, the number of internet users grew from 58.3% up to 64% and the number of shoppers in the network was increased from 40.3% to 41.5% in Spain. That means 10.4 million of shoppers on line in 2009 and 7,760 million euro in sales over the internet in 2010.

In 2000, within the e-commerce, grocery retailing industry expected to have the highest growth rate (Rowlands, 2001). Then, the growth in food sales over the Internet generated great incomes. In the United Kingdom for example, this sector experienced a growth of 75%.

In Spain, e-grocery represents 10.5% of total e-commerce industry, which in 2010 was estimated at 7,760 million euro. According to this information, the sales volume of e-grocer sector in Spain stands between 81,5 and 122 million euro.

However, the problems associated with the logistics involved in selling this type of product through the Internet have not been surpassed yet, and the appropriate supply chain model still has not been found. Herefore, the real growth is far from expectations and there have been cases such as that of Streamline in the U.S., which after being launched in 1993 as the second on-line shop for food, had to close.

Compared to the traditional grocery retail sector, the Internet retail sector (e-grocery) requires new models of supply chain in order to be profitable.

In the supply chain for traditional business, the goods are sent to the shops where customers make their orders by themselves, picking for delivery to their homes. Nevertheless, in the e-commerce business, and specifically in e-grocery, the higher costs come from labor of picking and final delivery to the consumer (Lewis 2001). Defining an efficient supply chain model that minimizes costs and provides greater convenience to clients is the challenge to be met in this study.

Despite the strong interest generated by electronic commerce in food, very few research studies can be found in the area of logistics in the e-grocery (Auramo Aminoff and Punakivi 2002).

2. BACKGROUND

2.1. Home Delivery

According to Taniguchi and Van Der Heijden, from a logistical point of view, the existing operational models can be classified into four main combinations (Tanskanen 2000).

- Attended reception and order picking in central warehouse.
- Attended reception and order picking in store.
- Unattended reception and order picking in central warehouse.
- Unattended reception and order picking in store.

However, after 10 years of experience since that publication, there have been new intermediate models. Currently, these are the main existing methods of picking preparation:

- Order picking in central distribution center.
- Order picking in specially designed storage areas for typical e-grocer orders (orders characterized by having a lot of lines per order and few articles per line)
- Order picking in shops.

While 10 years ago delivery was only classified as attended (home delivery) or unattended (reception boxes), we now find a new model already in operation. It consists of giving the client the choice of collecting his order in the supermarkets. According to this, the main existing methods of delivery are shown as follows:

- Home delivery.
- Reception boxes.
- Collection at supermarkets.

Despite the logistical alternatives studied, the winning combination has not been found yet (Punakivi, 2003). However, the knowledge of how to implement the logistic model of an e-grocer is a critical factor to achieve profitability.

2.2. Best Practices

From the traditional perspective of supply chain, there are two possible general models for e-grocery (Kamarainen, y Punakivi 2001).

From the traditional perspective of supply chain, there are two possible general models for e-grocery (Kamarainen and Punakivi 2001). Traditionally, those stores which have physical presence and have started to take part in the e-commerce have used their shops to attend their customers. The customers are attended to from their nearby shops. This is the most common model today, and up to now, it has also been successful as an added-value service offered by typical supermarkets, (Kämäräinen, Saranen, and Holmström 20001). However, the shops have been bound to seek for much more efficient solutions with the growing of the sector and the increase of the number of users of this service. Let us take Caprabo, they traditionally supplied their customers from their 325 shops, but their e-business already means more than 1% of their income, and they have had to redefine their strategy, and combine their current service with order picking preparation in their warehouse in Sant Boi de Llobregat.

The decentralizing setting of the orders seems to be the model adopted by the most successful businesses on the net.

On the other hand, other players directly started the e-commerce without having a real network of shops supporting them and they decided to set up big automated warehouses from the beginning. In this model the preparation of the orders is far more efficient. The organization of the layout of the warehouse and the processes depending on the kind of order provides speed to the picking. However, it also implies high investments (Holmström, Tanskanen and Kämäräinen 1999).

But this preparation of orders from centralized warehouses is frequently seen as a synonym of failure when experiences such as the one of Streamline are remembered.

In the US, purely virtual players started the e-grocery industry. However, in Europe the e-commerce was started by big brick-and-mortar grocery stores (Lewis and Allen 2000).

A lot of American e-grocers have failed, but some Europeans, thanks to their physical network, were able to gradually start in the sector. They have even invested in the USA in order to grow their .com business.

Today, Ahold, the traditional Dutch store, owns Peapod, one of the pioneers in the pure virtual e-grocer, and Tesco, the European grocery chain, bought Groceryworks in 2001 for the sum of 22 million dollars (Prior 2001).

Peapod has already experienced all the models in use. At the beginning, they used to buy the products in supermarkets which already existed, later they opened their own warehouse and they distributed the products which they bought from suppliers in the areas with a high demand. Finally it was bought by Royal Ahold, and they improved their demand, and went on with their supply chain strategy, which consisted on working simultaneously from warehouses and stores belonging to the new company (Royal Ahold).

Nevertheless, Tesco has chosen to supply their customers from their stores. It is not the most efficient model, but they take fewer risks in terms of investment. In 2006, Tesco had to start to operate from a central warehouse, as their shops were not ready to satisfy the demand. Now they keep a mixed model, but with special attention to picking in their shops. For Tesco, the biggest success comes from the fact that they have been able to integrate their data into the web. This way their customers may have information about their shopping on line (Rowland 2001).

The Streamline experience is different. It is the story of failure with a very simple explanation; high investment in automated central warehouses, in a business which is still immature.

Nowadays, the demand is high enough to offer good results in businesses based on working through central warehouses. What is more, it seems to be the natural tendency; even if they have physical shops, they are not able to meet their customers' demand.

In Spain the tendency has followed the same process as in the rest of Europe. At first, when the market leaders started the web business, they used their shops to get their orders ready. However, they have grown and matured, which has lead to different strategies of supply chain.

Carrefour has all the order picking preparation organized in two main platforms. From Guadalix, 10,000 sqm, it supplies more than 10,000 order lines to their customers on line. And from L'Hospitalet de Llobregat, it meets the demand in Cataluña

Condisline has centralized the preparation of their customer orders from Cataluña area in their warehouse in Pallejá (3,000 sqm). Nevertheless, in Madrid, they supply their orders from their shops.

El Corte Inglés warehouse is in Valdemoro. This platform supplies mass market and the goods which go to their shops daily. It is the regional warehouse which gets the goods from their suppliers and sends them to their own shops (Hipercor, El Corte Inglés, Opencor, Supercor…). The orders on line are provided from their shops.

Mercadona also used their shops to supply the orders on line. However, Caprabo, which started on Internet using only their shops, and delivering its orders in 40 regions in Spain, has had to open a new warehouse to be able to meet the growing demand. From Baix Llobregat they prepare the orders from Cataluña.

The success and failure mentioned above give evidence to the theory that the mixed model is the one which must be chosen to ensure profitability.

The model we propose in this paper is the one used by Peapod or Royal Ahold, the biggest chain in the U.S. today, or by Tesco, Caprabo or Condis, which are mixed models that work from their warehouses and stores at the same time seeking the most successful solution.

2.3. The Vehicle Routing Problem

Transport and distribution of goods can be addressed in the simplest model like the VRPTW. Nevertheless, the supply chain issues associated with electronic commerce in the retailing grocery industry increase the difficulty of the problem.

Decisions must be taken about the size and degree of warehouse automation, sites to prepare orders and position from which to make distribution to customers.

If a mixed model of combined distribution from the stores and warehouses is applied, the problem turns to a multi-depot VRP. In the event that customers are pre-assigned and grouped around each depot, the problem is simplified because it is divided into several VRPs. Yet, the flexibility required in the real world due to rapidly-changing demands and intermixing of customers and deposits, doesn't favor pre-allocation of depots to achieve better results. In this case the problem is highly complex, resulting in the vehicle routing problem with multiple depots (Multi-Depot Vehicle Routing Problem, or MDVRP).

If this problem is well suited to the particularities of the e-grocer, the result is a new and highly complex model.

The literature on this type of problems is quite sparse. This approach has led the authors to the definition of the problem as e-MDVRPTW, vehicle routing problem with time windows associated to e-commerce business and specifically to the grocery industry.

3. HYPOTHESIS

Hypothesis 1

The mixed solution, which consists of the combination of distribution centres and stores to prepare the orders, is more effective than the only use of warehouses. It provides flexibility and allows a greater performance; up to 90-100% with less investment.

Hypothesis 2

The decision of assignment of the orders to a warehouse or store should not be considered a static decision, in which we assign a customer to a warehouse only because of its proximity, but a dynamic decision which must be introduced in the optimization model on the premises of getting the best solution.

Hypothesis 3

Level of automation of warehouses for picking fulfillment should be considered medium-low in order to give the necessary flexibility and to assure the ROI (Return On Investment).

Hypothesizes 1 and 2 of this paper have been proved thanks to the e-grocers examples, success and failure stories.

The proposed mixed model is related to the successful models of Peapod/Royal Ahold, Tesco, Caprabo or Condis, which work simultaneously in stores and warehouses in order to keep flexibility, find high profitability in places with a dense population, and consequently a high demand, and at the same time, to be able to get to more areas of actuation, through the preparation of the orders in the stores in case of immature demand areas.

The continuous geographic change of customers and orders makes it difficult to find a balance between cost and efficiency when delivering the goods. Besides, the changing tendency and the quick evolution show that the perfect model of delivering goods is the one which may offer profitability today, and allow an easy growth tomorrow The multidepot model that we propose, adapts to this condition when we consider the choice of the place from which we attend to the customer as an operative variable.

Hypothesis 3 is also justified in this paper through the study of the existing models. The automated warehouses are only convenient to great demands in mature markets. Webvan, for example, made a mistake when they lost flexibility on devoting big investment to the design of the warehouses. Since, today, it is impossible to find a country which has a homogeneous demand, the right solution consist on a mixture of low – medium automatic warehouses together with stores to be able to get to all the customers efficiently.

Hypothesis 4

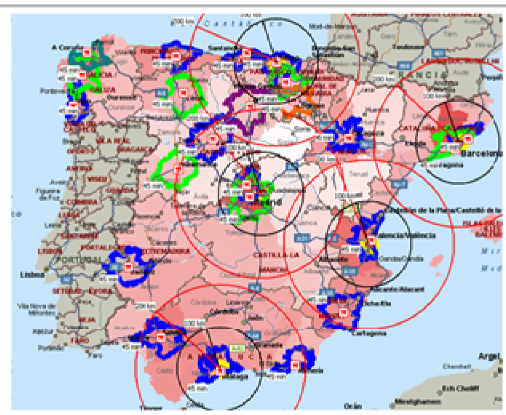
The traditional VRP is not good to this paper research and it has been formulated again to adapt it to the real model as it is proposed with its constraints and peculiarities of e-grocer. It will be called e-MDVRPTW. It has been proposed by the authors, and it appears in bibliography for the first time through this paper.

4. NETWORK DESIGN ADAPTED TO REALITY

The proposed network adapts to the sector needs and has the following characteristics:

- It is highly flexible and scalable because of the dynamic assignment of the clients to depots which can function on different levels of activity.
- With the designed network it is possible to cover almost the entire population of Spain or, at least, the most densely populated areas or those where the internet activity is higher. Apart from that, it is the same customer service in all the geographic locations, which contributes to the maximum level of customer satisfaction.
- It ensures the achievement of compromise between the efficiency and ROI, and work on a mixed solution where the proper stores are involved as network depots and the warehouses have low or medium level of automation. This contributes to the achievement of profitability in a market still immature and changing.
- Latest technology is also to be integrated in the solution, so the model has a higher level of adaption to reality.

The designed network covers the demand in Spain for the size of an e-grocer leader which annual turnover from grocery sales in internet is about 60 million euro.



Fuentes: Informe Anual de Sociedad de la Información en España 2008 [U08] y MapPoint

Figure 1: Network Design in Spain.

After analyzing the best experiences there was chosen a mixed model, which works like a chain formed of small and medium warehouses with medium level of automation and stores suitable for the order preparation and distribution to customers.

In order to be efficient, it is estimated that one store can serve up to 2 million euro. Considering that the average order value is 118,56 euro and that each order has about 45 lines, it corresponds to 2.875 lines a day. With productivity of 1,22 in-store orders per hour, there would be necessary 6,97 persons to meet this demand. It is understood that more people working in online order shop would be inconvenient for the daily progress of the other activities in the store.

The store which is capable to prepare orders and then deliver them to customer from the same establishment is called e-fit. Those are the shops with clear cost advantages because of their geographical location, annual turnover, space, service capacity and lay out. These stores also could make cross docking orders, once prepared in the warehouse, they would be sent to a store at night for further distributing along with the other orders during the following day.

The more stores are considered e-fit, the more freedom will be given to the execution process and therefore better solutions could be found.

Speaking about the distribution centers in order to guarantee ROI, the stores will have to work at least with 50% of their capacity (400 orders/day), which means preparing daily at least 200 orders and 2.376.000 lines per year. Each store would be designed for a maximum of 400 orders a day.

These data were obtained from the simulation of store performance at different levels of possible activity and the calculation of Net Present Value savings from the preparation of orders in warehouse over store preparation, subtracting the investment which is necessary to install the warehouse. On the other hand, these savings come from improved productivity in preparing orders in the warehouse.

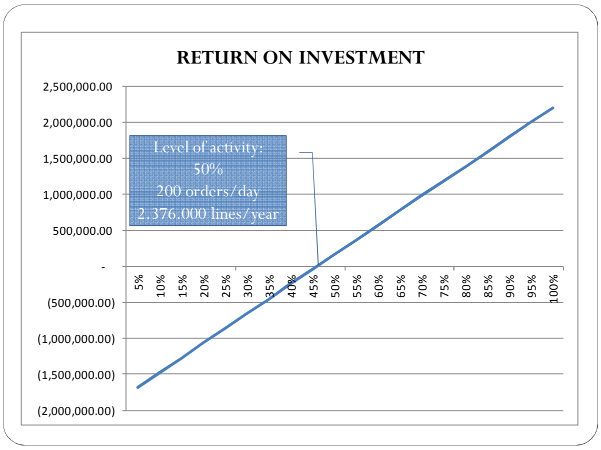


Figure 2. Breakeven point in the activity level of the warehouse with medium/low automation.

If 5 warehouses are installed in the most mature areas with high density of demand, the minimum demand of 31,3 million euro should be covered by these centers (considering the minimum order value is 118,56euro/order). In addition there should be 14 stores more to meet the demand.

The designed network aims to reach almost entire Spanish territory and make the search for the optimal solution more flexible. It consists of 5 warehouses and 21 stores. The location of the centers was decided depending on the internet activity and population density.

5. E-MDVRPTW MODEL

5.1. The Description of the Model

After analyzing the best practices, the authors opt for a mixed model that relies on a network of small / medium warehouses with medium automation level and stores considered suitable for the preparation of customer orders and their distribution. Through this flexible model, the growing and unpredicted demand is covered more efficiently.

As defined above, the model proposed by the authors is a MDVRPTW model which includes new additional restriction per depot: the minimum level of use in each automated warehouse in order to ensure the return on investment, the maximum capacity of the warehouses according to the design of the warehouse and the level of investment and the maximum activity allowed in the stores in order to keep acceptable levels of efficiency.

The shops are introduced in this problem like new depots. These stores must be set up for the picking preparation and distribution to consumers and the assignment of clients to depots is considered a dynamic variable covering the MDVRP in a single phase.

In addition, the new model raises new options and restrictions associated with the problem of logistics in e-grocery, such as the use of specific vehicles with compartments for different temperatures, or even the possibility of distributing orders from stores that have been previously prepared at distribution centers, new in the MDVRP literature.

Information on turn restrictions, prohibited addresses and traffic conditions is also used in this model. Impedance matrices are built with times instead of distances by using Geographic Information System (GIS),queries to Google Maps (http://maps.Google.es/maps/api/directions/xml?origin=c/ direccion1,ciudad1&destination=c/direccion2,ciudad2&sensor=false) and queries to the Traffic Department in Spain (DGT) (http://dgt.es/incidencias.xml)

5.2. Mathematical Model

5.2.1. Indices and Parameters

G=(C, α, τ, A, W)

Where:

G is the graph associated to the model.

τ: set of stores that are considered suitable for the preparation of customer orders and their distribution (1,...,e)

α: set of warehouses (e+1,…,m)

C: set of clients (m+1, ..., n).

A: the arc set. Each arc is represented as (i, j) where $i \neq j$. It represents the path between depots and clients and between clients.

W: set of travel times associated to each arc. It is represented as t_{ij}.

t_{ij}=travel time to go from i to j + service time in i.

c_{ij}: set of costs associated to each arc (i, j).

V_α y V_τ fleet of vehicles departing from a warehouse, α, or a store, τ.

q-: negative cold capacity of the compartments of the vehicles

q+: room temperature capacity of the compartments of vehicles.

d_i^-: negative cold demand of the client i.

d_i^++: demand of products at room and refrigerated temperature for the client i.

r_α^{min} lower level of activity for the warehouses to guarantee the ROI.

r_α^{max} maximum level of activity for the warehouses.

All warehouses are assumed homogeneous, as well as the e.fit stores.

p_τ capacity or higher level of activity allowed for the stores.

If the client i is located at a lower distance than D (a predetermined constant) from the warehouse α, then the delivery of his order could be made from this warehouse α and the variable $Y_{i\alpha}^{Dist}$ would take the value

$$Y_{i\alpha}^{Dist} = \begin{cases} 0 & \textit{if customer order i cannot be delivered by warhouse } \alpha \\ 1 & \textit{if customer order i can be delivered by warhouse } \alpha \end{cases}$$

If the client i is located at a lower distance than E (a predetermined constant) from the e-fit store τ, then the delivery of his order could be made from this store and the variable $Y_{i\tau}^{Dist}$ would take the value 1.

$$Y_{i\tau}^{Dist} = \begin{cases} 0 & \text{if customer order i cannot be delivered by store } \tau \\ 1 & \text{if customer order i can be delivered by store } \tau \end{cases}$$

If $Y_{i\tau}^{Dist} = 1$, then there is a possibility that the order is prepared in the store or the warehouse although the final delivery is executed from the store.

$$Y_{i\alpha}^{Prep\ Ped} = \begin{cases} 0 & \text{if customer order i cannot be prepared in warehouse } \alpha \\ 1 & \text{if customer order i can be prepared in warhouse } \alpha \end{cases}$$

$$Y_{i\tau}^{Prep\ Ped} = \begin{cases} 0 & \text{if customer order i cannot be prepared in store } \tau \\ 1 & \text{if the customer order i can be prepared in store } \tau \end{cases}$$

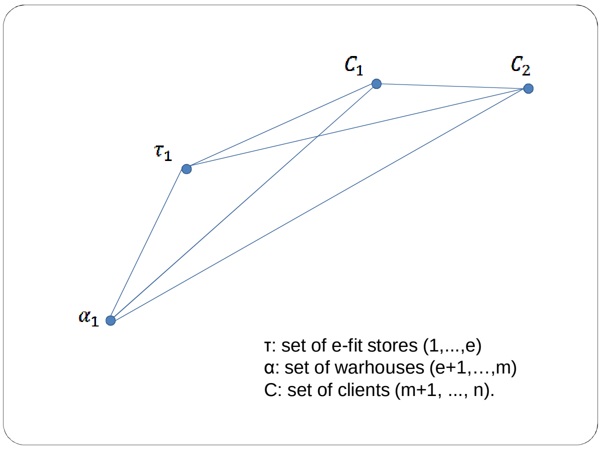


Figura 3.e-MDVRPTW

$[a_i, b_i]$: time window for the client i. The vehicle must arrive to the client i before b_i and it can arrive before a_i but then, it should wait.

$e, m, n, t_{ij}, c_{ij}, v_\alpha, v_\tau, q^+, q^-, d_i^+, d_i^-$ are non negative integers.

The triangle inequality is satisfied for costs c_{ij} and times t_{ij}. For three vertex, i, j y l, $c_{ij} + c_{jl} \geq c_{il}$ and $t_{ij} + t_{jl} \geq t_{il}$.

5.2.2. Variables and Constraints

The model contains three binary variables: x, s and z.

$s_{ik} \in \{0,1\}\ \forall i \in N, \forall k \in V$

For each arc (i, j), where $i \neq j$, if $i \in (l, \dots, m) \Rightarrow j > m$ and if $j \in (l, \dots, m) \Rightarrow i > m$. That is to say, arcs between depots cannot be considered in this model.

A decision variable is defined for each vehicle k, x_{ijk}, which represents the routing solution when customers i and j are attended by the vehicle k in its route and client i immediately precedes client j:

$$x_{ijk} = \begin{cases} o\ if\ vehicle\ k\ doesn't\ go\ from\ i\ to\ j \\ 1\ if\ vehicle\ k\ goes\ from\ i\ to\ j \end{cases}$$

$x_{ijk} \in \{0,1\}\ \forall\ i, j\ \in N,\ \forall k \in V$

The decision variable s_{ik} is defined for each node i and each vehicle k. It represents the moment in which the vehicle k begins to serve the client i

$s_{ik}\ \in\ \{0,1\}\ \forall i \in N, \forall k \in V$

In the event the vehicle k does not serve the customer i, the variable has no meaning.

$\forall$ K, $s_{ik} = 0$; $i \in (l, \dots, m)$.

The decision variables $z_{i\alpha}$ and $z_{i\tau}$ represents the place where the client i is attended from:

$$z_{i\alpha}^{Dist} = \begin{cases} 0\ if\ client\ i\ is\ not\ delivered\ from\ warehouse\ \alpha \\ 1\ if\ client\ i\ is\ delivered\ from\ warehouse\ \alpha \end{cases}$$

$$z_{i\tau}^{Dist} = \begin{cases} 0\ if\ client\ i\ is\ not\ delivered\ from\ store\ \tau \\ 1\ if\ client\ i\ is\ delivered\ from\ store\ \tau \end{cases}$$

$$z_{i\alpha}^{Prep\ Ped} = \begin{cases} 0\ if\ client\ order\ i\ is\ not\ prepared\ in\ warhouse\ \alpha \\ 1\ if\ client\ order\ i\ is\ prepared\ in\ warhouse\ \alpha \end{cases}$$

$$z_{i\tau}^{Prep\ Ped} = \begin{cases} 0\ if\ client\ order\ i\ is\ not\ prepared\ in\ store\ \tau \\ 1\ if\ client\ order\ i\ is\ prepared\ in\ store\ \tau \end{cases}$$

$$z_{i\alpha}^{Dist}, z_{i\tau}^{Dist}, z_{i\alpha}^{Prep\ Ped}, z_{i\tau}^{Prep\ Ped} \in \{0,1\}\ \forall\ i, j\ \in N, \forall\ \alpha \in (e+1, \dots, m), \forall \tau \in (1, \dots, e)$$

This way, every choice to give service to the clients has been covered:

$$z_{i\tau}^{Dist} \begin{cases} 0 \\ 1 \begin{cases} z_{i\alpha}^{Prep\ Ped} \begin{cases} 0 \\ 1\ if\ distribution\ is\ made\ from\ store\ \tau\ but\ picking\ fulfillment\ from\ \alpha \end{cases} \\ z_{i\tau}^{Prep\ Ped} \begin{cases} 0 \\ 1\ if\ distribution\ and\ picking\ for\ client\ order\ i\ are\ fulfilled\ from\ store\ \tau \end{cases} \end{cases} \end{cases}$$

5.2.1. Objective Function and Constraints

The first part of the objective function represents fixed costs of each vehicle taking into account that there will be the same number of vehicles as routes. The second part, shows variable costs.

Variable costs combine three cost terms: distribution and picking preparation in warehouse, distribution from store and in-warehouse picking preparation and distribution and picking preparation in store.

Thus, the e-MDVRPTW is mathematically formulated as follows:

Objective function: (1)

$$\min\left(\sum_{k}\sum_{j>m}\sum_{i\in(1,\dots,m)} H_k x_{ijk} + \sum_{\tau}\sum_{\alpha}\sum_{k}\sum_{j}\sum_{i}\left(c_{ij}x_{ijk}z_{i\alpha}^{Dist} + \left(C_{PEN}^{Dist} + c_{ij}\right)x_{ijk}z_{i\tau}^{Dist}z_{i\alpha}^{Prep\ Ped} + \left(C_{PEN}^{Prep\ Ped} + c_{ij}\right)x_{ijk}z_{i\tau}^{Dist}z_{i\tau}^{Prep\ Ped}\right)\right)$$

Where $C_{PEN}^{Prep\ Ped}$ represents cost penalty for picking fulfillment in stores and C_{PEN}^{Dist} is cost penalty for the orders which are distributed from stores while picking has been fulfilled in warehouse.

$$C_{PEN}^{Dist} = c_{\alpha\tau} / \sum_i z_{i\tau}^{Dist}\, z_{i\alpha}^{Prep\ Ped} \quad (2)$$

Restrictions:

$$\sum_k \sum_{j>m} \sum_{i\in(1,\dots,m)} x_{ijk} = \sum_k \sum_{i>m} \sum_{j\in(1,\dots,m)} x_{ijk} \quad (3)$$

$$\sum_\tau Z_{i\tau}^{Dist} + \sum_\alpha Z_{i\alpha}^{Dist} = 1\ \forall i \in C \quad (4)$$

$$\sum_\tau Z_{i\tau}^{PrepPed} + \sum_\alpha Z_{i\alpha}^{PrepPed} = 1\ \forall i \in C \quad (5)$$

$$z_{i\tau}^{Dist}\, y_{i\tau}^{Dist} = z_{i\tau}^{Dist} \quad \forall\tau\ y\ \forall i \in \quad (6)$$

$$z_{i\alpha}^{Dist}\, y_{i\alpha}^{Dist} = z_{i\alpha}^{Dist} \quad \forall\alpha\ y\ \forall i \in C \quad (7)$$

$$z_{i\tau}^{PrepPed}\, y_{i\tau}^{PrepPed} = z_{i\tau}^{PrepPed} \quad \forall\tau\ y\ \forall i \in \quad (8)$$

$$z_{i\alpha}^{PrepPed}\, y_{i\alpha}^{PrepPed} = z_{i\alpha}^{PrepPed} \quad \forall\tau\ y\ \forall i \in \quad (9)$$

$$\sum_{k\epsilon V} \sum_{j>m} x_{ijk} = 1 \quad \forall i \in C \quad (10)$$

$$\sum_{k\epsilon V} \sum_{i>m} x_{ijk} = 1 \quad \forall j \in C \quad (11)$$

$$\sum_{i\in N} \sum_{j>m} d_j^+ x_{ijk} \le q_k^+ \quad \forall k \quad (12)$$

$$\sum_{i\in N} \sum_{j>m} d_j^- x_{ijk} \le q_k^- \quad \forall k \quad (13)$$

$$\sum_{i\in C} d_i z_{i\tau}^{Prep\ Ped} \le p_\tau \quad \forall\tau \quad (14)$$

$$r_\alpha^{min} \le \sum_{i\in C} d_i z_{i\tau}^{Prep\ Ped} \le r_\alpha^{max} \quad \forall\alpha \quad (15)$$

$$\sum_{j>m} x_{ijk} = 1\ \forall k \in V\ y\ \forall i \in (1,\dots,m) \quad (16)$$

$$\sum_{i>m} x_{ihk} - \sum_{j>m} x_{hjk} = 0 \quad \forall h = 1,\dots,m, \forall k \in V \quad (17)$$

$$\sum_{i>m} x_{ijk} = 1\ \forall k \in V\ y\ \forall j \in (1,\dots,m) \quad (18)$$

$$\sum_i \sum_j t_{ijk} x_{ijk} \le T_k \quad \forall k \in V \quad (19)$$

$$s_{ik} + t_{ij} - T_k(1 - x_{ijk}) \le s_{jk}\ \forall i = m+1,\dots,n, \forall j, \forall k \quad (20)$$

$$a_i \le s_{ik} \le b_i \quad \forall i = m+1, \dots n\ y\ \forall k \in V \quad (21)$$

$$H_k = \delta_k H_K + (1-\delta_k)H/2 \quad (22)$$

Subject to:

H_k represents fixed cost of each outsourced vehicle and it includes the cost of driver.

δ_k is a binary variable which can take values 0 or 1 depending on the vehicle to perform half or full time.

$$\delta_k = \begin{cases} 1\ si\ \sum_i \sum_j t_{ijk} x_{ijk} \ge \frac{T_k}{2} \\ 0\ otherwise \end{cases} \quad (23)$$

There should be balance between departing vehicles from depots and arriving vehicles to depots (3). Each client can be attended only from one warehouse or store (4)(5). In addition, the variable z has to be linked to y, that is to the association of the customers to default radius of influence for each store or warehouse (6)(7)(8)(9). Each client can be visited once and each client order can be only prepared once (10)(11). Vehicle compartments capacity must not be violated (12)(13). Maximum and minimum levels of activities for warehouses and stores must be respected (14)(15). Each vehicle must departure from one depot (warehouse or store) (16). There should be balance between the number of departing routes and the number or arriving routes for each depot (17). Each vehicle must arrive to the depot to finish the route (18). Each vehicle mustn't work more time than agreed (19). Each vehicle k, must arrive to j after $s_{ik} + t_{ij}$ (20). Client windows must be honored (21)

6. CONCLUSIONS AND FUTURE WORK

This paper tries to define the problem of distribution of goods associated with e-commerce in the grocery industry. It is a complex model because it tries to reflect reality:

- Have been introduced new cost criteria related not only to the transport costs, but also to the order preparation.
- The level of automation of the warehouses was considered.
- The mixed network with heterogeneous deposits (stores and warehouses) and different costs of order preparation was designed.
- There were introduced vehicles with compartments at different temperature.
- The problem solution not only indicates from which deposits and with which vehicle must be made delivery, but also the place where the order should be prepared; which doesn´t have to be the same place from where the capillary distribution starts. This way the stores can function not only like conventional MDVRP

depots, but also like cross docking centers from where the distribution starts to lower transport costs.

From the intersection between the real and the academic worlds emerges the e-MDVRPTW – a highly complex problem. The model works with the peculiarities of the logistics associated with the food sale via Internet, as well as with the studies and software of the traditional transport problem.

Different algorithms were analyzed to solve the MDVRPTW problem and considering the results, there could be formulated different variants of meta-heurestic algorithms and compared solutions and the effects of different variables over problem solution, for example, automation level of warehouses.

A priori, the existence of binary variables in the mathematical formulation inclines future research towards adapting and testing the most important algorithms in solving the MDVRPTW: Ant Colonies, Simulated Annealing, Tabu Search, GRASP, Guided Local Search and Genetic Algorithms.

The authors are in the testing phase of conventional meta-heuristic and design of a new bio-inspired algorithm in order to obtain a good scenario to reduce the overall distribution costs in the sector.

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AN LPV MODEL FOR A MARINE COOLING SYSTEM WITH TRANSPORT DELAYS

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ABSTRACT
We address the problem of constructing a linear parameter varying (LPV) model for a nonlinear marine cooling system with flow dependent delays. We focus on the choice of scheduling variables for the LPV model to represent important nonlinear dynamics, and to preserve the flow dependency of the transport delays in the system. To this end, we redefine one of the system inputs to obtain a scheduling parameter that describes the time-varying operating point for this input, and also make some simple, but justifiable approximations in order to keep the number of scheduling variables low. A simulation example is provided to illustrate the performance of the LPV model compared to the original nonlinear model.

Keywords: Nonlinear systems, LPV modeling, Transport delay, Marine systems

1. INTRODUCTION

In this paper we consider the nonlinear marine cooling system with flow dependent delays that was first introduced in (Hansen, Stoustrup and Bendtsen 2011). The cooling system is used aboard container vessels for cooling the main engine and auxiliary components such as main engine scavenge air coolers, turbo chargers, diesel generators, etc. The motivation for considering this system is the potential energy savings that can be obtained by improving the currently implemented control, which is very energy inefficient due to an excessive use of the pumps in the cooling system. However, because of the structure of the system, the dynamic behavior includes transport delays and nonlinearities, which complicates the design of more advanced control laws. This entails that the models used for control design must describe the important dynamics of the system sufficiently accurate, but also has a form that fits the control design method.

One approach for dealing with the problem of control design for nonlinear systems is by use of linear parameter varying (LPV) control theory (Toth, 2010). LPV systems are characterized by being dependent on an unknown, but measurable time-varying parameter that describes the variations in the plant dynamics. When designing control for the LPV system, the time-varying parameter is used for scheduling the control laws according to how the system dynamics changes. This makes LPV control applicable to a wide range of systems, including a large class of nonlinear systems that can be converted to an LPV form. With the combination of theory from optimal and robust control it is possible to guarantee stability, optimal performance and robustness of an LPV model in the entire field of operation. This is contrary to former gain scheduling approaches where a global nonlinear control design is obtained from interpolating local linear controllers, and where guarantees of performance and robustness cannot be made in general (Shamma and Athans, 1991), (Apkarian and Adams, 1998). Some results on the use of LPV control theory for systems with time-varying delays have been presented in (Zope, Mohammadpour, Grigoriadis, and Franchek, 2010), (Tan, Grigoriadis, and Wu, 2003), (Wu and Grigoriadis, 2001) and is part of the motivation for this work. However, the use of LPV control theory requires that the system model has an LPV representation which can be difficult to obtain (Jung and Glover, 2003).

The objective in this paper is to rewrite the nonlinear model from (Hansen, Stoustrup and Bendtsen, 2011) into the form of an LPV model that includes the flow dependent transport delays, and represents important dynamics sufficiently accurate. We only consider the thermodynamic part of the model, while appropriate control is assumed to be designed for the hydraulics such that the flows in the system can be considered as free input variables.

Related work is presented in (Jung and Glover, 2003) where a third order nonlinear model of the airpath of a turbocharged diesel engine is converted to an LPV model. However, delays are not a part of the nonlinear model considered (Jung and Glover, 2003), and the resulting LPV model is of the quasi-LPV type i.e, where scheduling variables depends on the system dynamics, which is somewhat different from what we seek here. The main contribution of this paper lies in the inclusion of transport delays when converting the nonlinear model to an LPV representation, and in the corresponding choice of scheduling parameters for adequately describing the transport delays as well as the nonlinear dynamics in the resulting LPV model.

The remaining paper is structured as follows: In Section 2 we make a brief presentation of the nonlinear model considered in this paper. In Section 3 we bring the model into an LPV form and in Section 4 we compare the performance of the LPV model with the original nonlinear model. Finally, concluding remarks are presented in Section 5.

We make use of the following fairly standard notation: $\mathbb{R}$ denotes the set of real numbers while $\mathbb{R}_+$ denotes the set of non-negative real numbers. $\mathbb{R}^{n\times m}$ is the set of real $n \times m$ matrices and $C^1(\mathcal{M}, \mathcal{N})$ is the set of continuous functions mapping from $\mathcal{M}$ to $\mathcal{N}$ with first order continuous derivatives.

2. NONLINEAR MODEL

The cooling system consists of three circuits; a sea water (SW) circuit, a low temperature (LT) circuit and a high temperature (HT) circuit. In this work the HT circuit is not of interest, and is therefore left out in the following. A simplified layout of the system considered in this work is illustrated in Figure 1.

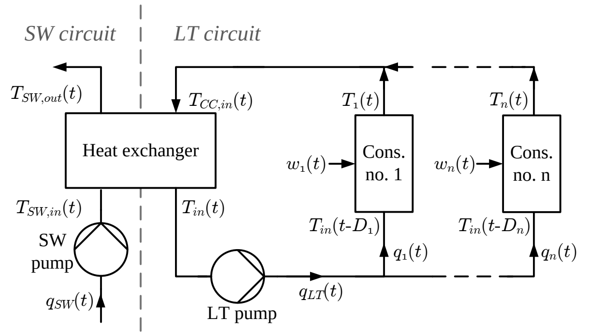

Figure 1: Simplified layout of the cooling system considered. The sea water (SW) circuit is to the left, while the low temperature (LT) circuit containing all the consumers is to the right.

The SW circuit pumps sea water through the cold side of the heat exchanger for lowering the temperature of the coolant in the LT circuit. The LT circuit contains all the main engine auxiliary components in a parallel configuration, and the supplied cooling is controlled through the flow rates in the system, $q_{SW}(t)$ and $q_{LT}(t)$.

The nonlinear thermodynamic model consists of two parts; one to describe the temperature change in the coolant out of each consumer in the LT circuit, and one to describe temperature change of the coolant out of the LT side of the heat exchanger.

The dynamics for the consumers $i = 1, \ldots, n$, with $q = [q_1,\ q_2, \ldots,\ q_n]^T$ is described by:

$$\dot{T}_i(t) = \frac{1}{V_i}\left[q_i(t)(T_{in}(t - D_i(q)) - T_i(t)) + \frac{w_i(t)}{\rho c_p} \right] , \tag{1}$$

where $q_i(t)$ is the volumetric flow rate through the consumer, V_i is the internal volume of the consumer, $T_i(t)$ is the outlet temperature of the consumer and $T_{in}(t)$ is the outlet temperature of the heat exchanger (into the LT circuit). Also, $w_i(t)$ is the heat transfer from the consumer to the coolant, ρ is the density of the coolant and c_p is the specific heat of the coolant.

We here consider the case where the flows $q_1(t), q_2(t), \ldots, q_n(t)$ are not independents, but satisfy the relation:

$$\begin{aligned} q_1(t) &= c_1 q_{LT}(t) \\ q_2(t) &= c_2 q_{LT}(t) \\ &\vdots \\ q_n(t) &= c_n q_{LT}(t) \ , \end{aligned}$$

where $\{c_i\}_{i=1}^n$ are positive constants, subject to: $\sum_{i=1}^{n} c_i = 1$.

For the dynamics of $T_{in}(t)$ we have that:

$$\begin{aligned} \dot{T}_{in}(t) = \frac{1}{V_{CC}} \Bigg[& q_{LT}(t)(T_{CC,in}(t) - T_{in}(t)) \\ & + q_{SW}(t)\frac{\rho_{sw} c_{p,sw}}{\rho c_p} T_{SW,in}(t) \\ & - q_{SW}(t)\frac{\rho_{sw} c_{p,sw}}{\rho c_p} T_{SW,out}(t) \Bigg] \ , \end{aligned} \tag{2}$$

where $c_{p,sw}$ is the specific heat of sea water, ρ_{sw} is the density of sea water, and $T_{CC,in}(t)$ is the temperature of the coolant into the LT side of the heat exchanger. Also, $T_{SW,in}(t)$ and $T_{SW,out}(t)$ are the temperatures of the sea water in and out of the SW side of the heat exchanger. The transport delays are described by the relation:

$$D_i(q) = \sum_{j=1}^{i} \left(a_{m,j} \sum_{k=j}^{n} \frac{1}{q_k} \right) + \frac{a_{c,i}}{q_i} \ , \tag{3}$$

where $a_{m,i}$ and $a_{c,i}$ are system specific positive constants.

It is assumed that the temperatures $T_{CC,in}(t)$, $T_{SW,in}(t)$ and $T_{SW,out}(t)$ are measurable while the heat transfers $w_1(t), \ldots, w_n(t)$ are unknown but belongs to the set:

$$\mathcal{W} := \{ w \in C(\mathbb{R}, \mathbb{R}); 0 < \underline{W} \le w(t) \le \overline{W} < \infty \} \ . \tag{4}$$

i.e., the heat transfer from each consumer is continuous, positive and bounded from below by $\underline{W}$ while bounded from above by $\overline{W}$. Also, we assume that delays $D_1, \ldots, D_n$ belongs to the set:

$$\begin{aligned} \mathcal{D} := \{ & D \in C(\mathbb{R}, \mathbb{R}); 0 \le D(q) \le \overline{D} < \infty \ , \\ & \dot{D}(q) < 1 \ \forall t \in \mathbb{R}_+ \} \ , \end{aligned} \tag{5}$$

which ensures that $t - D_i(q)$ is monotonically increasing for all D_i. The requirement that the first order derivative of the delays must be less than one is a necessary requirement, but obviously causes restrictions to how fast the input is allowed to change due to the relation between the inputs and the delays. In other words this means that the flow rates in the system cannot be allowed to decrease arbitrarily fast. Also, since it is required that the delays are positive and bounded from above by $\overline{D}$, the flow rates $q_1(t), \ldots, q_n(t)$ must be non-zero and positive, which is considered to be the case for all relevant operating conditions.

3. CONSTRUCTION OF LPV MODEL

We seek a representation of the input-affine time delay system given by (1) and (2) on the LPV form of (Wu, 2001):

$$\begin{aligned}\dot{x}(t) =& A(p(t))x(t) + \sum_{i=1}^{k} A_{Di}(p(t))x(t - D_i(p(t))) \\ &+ B_1(p(t))w(t) + B_2(p(t))u(t)\end{aligned} \tag{6}$$

where $x(t) \in \mathbb{R}^{n_x}$ is the state vector, $w(t) \in \mathbb{R}^{n_w}$, is the disturbance vector and $u(t) \in \mathbb{R}^{n_u}$ is the input vector. The initial condition for the delay system in (6) is given by:

$$x(\theta) = \phi(\theta) \ , \quad \theta \in \left[-\overline{D}, 0\right] \ . \tag{7}$$

The time-varying parameter, $p(t)$, belongs to the set of allowable parameter trajectories defined as:

$$\begin{aligned}\mathcal{P} :=& \{p \in \mathcal{C}(\mathbb{R}, \mathbb{R}^m); p(t) \subset \mathbb{R}^m, |\dot{\rho}_j(t)| \leq v_j, \\ & j = 1, 2, \ldots, m, \ \forall t \in \mathbb{R}_+\} \ ,\end{aligned} \tag{8}$$

where $\{v\}_{j=1}^{m}$ are positive constants, which means that the parameters have bounded trajectories, and bounded variation rate.

Choosing scheduling variables is not a trivial matter as there are several factors that come into play. It is obviously desired to describe the important dynamics of the system adequately by the choice of parameters. However, it is also essential to keep the number of parameters as low as possible, as a high number of parameters complicate the control design for the system (Jung and Glover, 2003).

In this particular case, a reasonable choice for a scheduling variable is the temperature difference $(T_{SW,in}(t) - T_{SW,out}(t))$ which is measurable and satisfies the requirements for bounded trajectories and bounded variation rates as given by (8). However, in order to describe the dynamics of $T_i(t)$ on the linear form (6), as well as to preserve the flow dependency of the delays, we need an additional parameter. We therefore write $q_{LT}(t)$ as:

$$q_{LT}(t) = \tilde{q}_{LT}(t) + \hat{q}_{LT}(t) \ , \tag{9}$$

where $\tilde{q}_{LT}(t)$ represents the time varying operating point of the flow, while $\hat{q}_{LT}(t)$ is a small perturbation from this operating point.

Choosing $\tilde{q}_{LT}(t)$ as a scheduling variable along with $(T_{SW,in}(t) - T_{SW,out}(t))$, we get that:

$$\begin{aligned}p(t) &= \begin{pmatrix} p_1(t) \\ p_2(t) \end{pmatrix} \\ &= \begin{pmatrix} \tilde{q}_{LT}(t) \\ (T_{SW,in}(t) - T_{SW,out}(t)) \end{pmatrix} \ .\end{aligned} \tag{10}$$

This brings (1) and (2) to the form:

$$\begin{aligned}\dot{T}_i(t) =& \frac{1}{V_i}\Big[c_i p_1(t)(T_{in}(t - D_i(p_1(t))) - T_i(t)) \\ &+ c_i\hat{q}_{LT}(t))(T_{in}(t - D_i(p_1(t))) - T_i(t)) \\ &+ \frac{w_i(t)}{\rho c_p}\Big]\end{aligned} \tag{11}$$

$$\begin{aligned}\dot{T}_{in}(t) =& \frac{1}{V_{CC}}\Big[p_1(t)(T_{CC,in}(t) - T_{in}(t)) \\ &+ \hat{q}_{LT}(t))(T_{CC,in}(t) - T_{in}(t)) \\ &+ q_{SW}(t)\frac{\rho_{sw}c_{p,sw}}{\rho c_p}p_2(t)\Big] \ .\end{aligned} \tag{12}$$

We define the state, disturbance and input vectors, $x(t), w(t), u(t)$ from (6) as:

$$\begin{aligned}x(t) &= \begin{pmatrix} T_1(t) \\ T_2(t) \\ \vdots \\ T_n(t) \\ T_{in}(t) \end{pmatrix} \ w(t) = \begin{pmatrix} w_1(t) \\ w_2(t) \\ \vdots \\ w_n(t) \\ T_{CC,in}(t) \end{pmatrix} \\ u(t) &= \begin{pmatrix} \hat{q}_{LT}(t) \\ q_{SW}(t) \end{pmatrix} \ .\end{aligned} \tag{13}$$

It is clear that (11) and (12) cannot be brought directly to the form of (6) without simplifications or introducing additional scheduling variables. Since it is desired to keep the number of scheduling variables low, we make the following approximation for (11):

$$\hat{q}_{LT}(t)(T_{in}(t - D_i(p_1(t))) - T_i(t)) \approx \hat{q}_{LT}(t)(\bar{T}_{in} - \bar{T}_i)$$

where are $\bar{T}_{in}$ and $\bar{T}_i$ are constant set point values for $T_{in}(t)$ and $T_i(t)$, respectively. This approximation can be justified by the fact that the purpose of designing control laws for the system is to keep the temperatures at or close to predefined set points. This means that with properly designed control laws, the temperatures $T_{in}(t)$ and $T_i(t)$ should be close to $\bar{T}_{in}$ and $\bar{T}_i$ at all times, making the approximation small.

For (12) we make the approximation:

$$(p_1(t) + \hat{q}_{LT}(t)) \approx p_1(t) \ .$$

The argument here is that it is not desired to use $\hat{q}_{LT}(t)$ as an control input for $T_{in}(t)$, and since it only constitutes a small perturbation from $p_1(t)$ it is reasonable to discard it in this context, as it otherwise appears multiplicative with the disturbance $T_{CC,in}(t)$.

This results in approximated models given by:

$$\begin{aligned}\dot{T}_i(t) \approx &\frac{1}{V_i}\Big[c_i p_1(t)(T_{in}(t - D_i(p_1(t))) - T_i(t)) \\ &+ c_i \hat{q}_{LT}(t))(\bar{T}_{in} - \bar{T}_i) + \frac{w_i(t)}{\rho c_p}\Big]\end{aligned} \tag{14}$$

$$\begin{aligned}\dot{T}_{in}(t) \approx &\frac{1}{V_{CC}}\Big[p_1(t)(T_{CC,in}(t) - T_{in}(t)) \\ &+ q_{SW}(t)\frac{\rho_{sw} c_{p,sw}}{\rho c_p} p_2(t)\Big] \ .\end{aligned} \tag{15}$$

The system given by (14) and (15) can now be written in the form of (6). With the choice of input, state and disturbance vectors as given by (13) we get that $A(p(t))$ can be written as:

$$A(p(t)) = \begin{bmatrix} \frac{-c_1}{V_1}p_1(t) & 0 & \cdots & 0 \\ 0 & \ddots & & \vdots \\ \vdots & & \frac{-c_n}{V_n}p_1(t) & 0 \\ 0 & \cdots & 0 & \frac{-1}{V_{CC}}p_1(t) \end{bmatrix} \tag{16}$$

For matrices $A_{Di}(p(t))$ we have that:

$$A_{Di}(p(t)) = \begin{bmatrix} 0 & \cdots & 0 & \delta_{i,1}\frac{c_1}{V_1}p_1(t) \\ \vdots & \ddots & & \vdots \\ 0 & \cdots & 0 & \delta_{i,n}\frac{c_n}{V_n}p_1(t) \\ 0 & \cdots & & 0 \end{bmatrix} , \tag{17}$$

for $i = 1, \dots, n$ and where δ is defined as:

$$\delta_{i,j} = \begin{cases} 1 & \text{for } i = j \\ 0 & \text{for } i \neq j \end{cases}$$

Furthermore, for $B_1(p(t))$ and $B_2(p(t))$ we have that:

$$B_1(p(t)) = \begin{bmatrix} \frac{1}{V_1 c_p \rho} & 0 & \cdots & 0 \\ 0 & \ddots & & \vdots \\ \vdots & & \frac{1}{V_n c_p \rho} & 0 \\ 0 & \cdots & 0 & \frac{1}{V_{CC}}p_1(t) \end{bmatrix} \tag{18}$$

$$B_2(p(t)) = \begin{bmatrix} \frac{c_1(\bar{T}_{in} - \bar{T}_1)}{V_1} & 0 \\ \vdots & 0 \\ \frac{c_n(\bar{T}_{in} - \bar{T}_n)}{V_n} & 0 \\ 0 & \frac{\rho_{sw} c_{p,sw}}{\rho c_p}p_2(t) \end{bmatrix} . \tag{19}$$

Equations (16)-(19) constitutes the generic LPV model for the cooling system, and with the definitions of scheduling variables in (10) we have that delays are written as:

$$D_i(p(t)) = \sum_{j=1}^{i}\left(a_{m,j}\sum_{k=j}^{n}\frac{1}{c_k p_1(t)}\right) + \frac{a_{c,i}}{c_i p_1(t)} \ . \tag{20}$$

To make the structure of the LPV model clear, as well as to illustrate how the LPV model compares to the original nonlinear model, we construct a fictitious simulation example in the following section.

4. SIMULATION STUDIES

We consider a simulation example for a system with two consumers i.e., where $n = 2$. According to (16)-(19) we have that:

$$\begin{aligned}\dot{x}(t) = &\begin{bmatrix} \frac{-c_1}{V_1}p_1(t) & 0 & 0 \\ 0 & \frac{-c_2}{V_2}p_1(t) & 0 \\ 0 & 0 & \frac{-1}{V_{CC}}p_1(t) \end{bmatrix} x(t) \\ &+ \begin{bmatrix} 0 & 0 & \frac{c_1}{V_1}p_1(t) \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} x(t - D_1(p(t))) \\ &+ \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{c_2}{V_2}p_1(t) \\ 0 & 0 & 0 \end{bmatrix} x(t - D_2(p(t))) \\ &+ \begin{bmatrix} \frac{1}{V_1 c_p \rho} & 0 & 0 \\ 0 & \frac{1}{V_2 c_p \rho} & 0 \\ 0 & 0 & \frac{1}{V_{CC}}p_1(t) \end{bmatrix} w(t) \\ &+ \begin{bmatrix} \frac{c_1(\bar{T}_{in} - \bar{T}_1)}{V_1} & 0 \\ \frac{c_2(\bar{T}_{in} - \bar{T}_2)}{V_2} & 0 \\ 0 & \frac{\rho_{sw} c_{p,sw}}{\rho c_p}p_2(t) \end{bmatrix} u(t) \ .\end{aligned} \tag{21}$$

Accordingly, delays $D_1(p(t))$ and $D_2(p(t))$ are given by:

$$\begin{aligned} D_1(p(t)) &= \frac{a_{m,1}}{p_1(t)} + \frac{a_{c,1}}{c_1 p_1(t)} \\ D_2(p(t)) &= \frac{a_{m,1}}{p_1(t)} + \frac{a_{m,2}}{c_2 p_1(t)} + \frac{a_{c,2}}{c_2 p_1(t)} \ . \end{aligned} \tag{22}$$

Thermodynamic parameters are shown in Table 1 while system parameters are illustrated in Table 2. Be aware that only the V_1 and V_2 parameters have been estimated from an actual cooling system, while other system specific parameters have been chosen for this example. The reason for not having more parameters for the actual system is simply the lack of available measurement data for parameter estimation.

Table 1: Thermodynamic parameters.

c_p	$c_{p,sw}$	ρ	ρ_{sw}
4181	3993	1000	1025

Table 2: System parameters for simulation examples.

V_{cc}	V_1	V_2	$a_{m,1}$	$a_{m,2}$
20	13.5	13.5	30	10
$a_{c,1}$	$a_{m,2}$	c_1	c_2	
10	10	0.51	0.49	

The LPV model represented by (21) and the corresponding nonlinear model, which we will not state here, are subjected to the same input and disturbances as well as changes in scheduling variables. The model outputs are then compared to illustrate how well the LPV model approximates the nonlinear model. The simulation scenario is constructed such that the system is in steady state with the chosen initial conditions. The division of the input into a time varying set point and a perturbation from the set point as given by (9), is implemented using a simple first order discrete low pass filter with a cut off frequency of 0.002 rad/s. Initial conditions for the simulation are illustrated in Table 3 and the responses for both the LPV and nonlinear model are shown in Figure 2. Figure 3 shows the input signals, $\hat{q}_{LT}(t)$, $q_{LT}(t)$ and $q_{SW}(t)$, while Figure 4 illustrates the disturbances in terms of $w_1(t)$, $w_2(t)$ and $T_{CC,in}(t)$. Finally, Figure 5 shows the scheduling variables, $p_1(t)$ and $p_2(t)$, where $p_1(t)$ is the low pass filtered input, $q_{LT}(t)$.

Table 3: Initial conditions for the simulation example.

$T_{sw,in}(0)$	$T_1(0)$	$q_{LT}(0)$	$T_{in}(0)$	$w_1(0)$	$w_2(0)$
24	45	0.21	36	4×10^6	6×10^6
$T_{sw,out}(0)$	$T_2(0)$	$q_{SW}(0)$	$x(\theta)$ for $\theta \in [-\overline{D}, 0]$		
40	50	0.59	$[45\ 50\ 36]^T$		

The purpose of the simulation example is not to illustrate a real world scenario, but rather to excite the models in a way that shows how well the LPV model approximates the original nonlinear model. It is expected that the model outputs will differ only when the approximated part of the LPV model is excited. As can be seen from Figure 2, deviations between the LPV model and the nonlinear model occurs in the transitions of the input $q_{LT}(t)$, which is expected since all approximation in the LPV model has to do with $q_{LT}(t)$. Despite the deviations, the LPV model captures all important dynamics and is considered to be sufficiently accurate for control design.

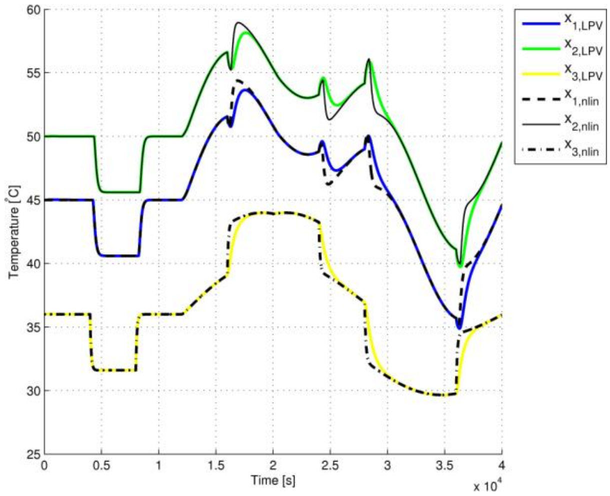

Figure 2: Comparison between LPV and nonlinear model outputs. Index 'LPV' denotes LPV model output, while 'nlin' denotes nonlinear model output.

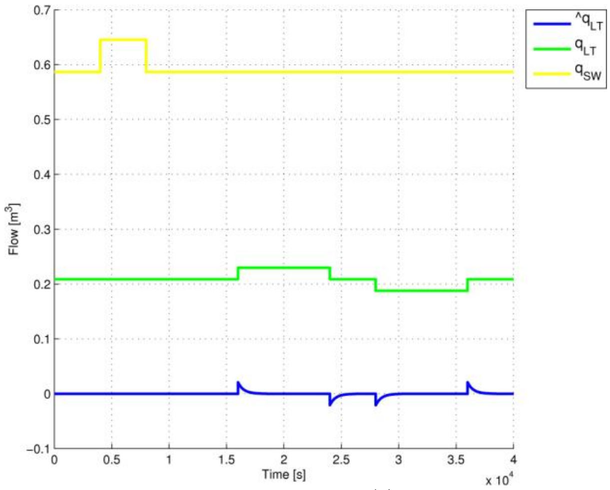

Figure 3: Plot of input signal $\hat{q}_{LT}(t)$ for the LPV model and $q_{LT}(t)$ for the nonlinear model. The input $q_{SW}(t)$ is the same for both models.

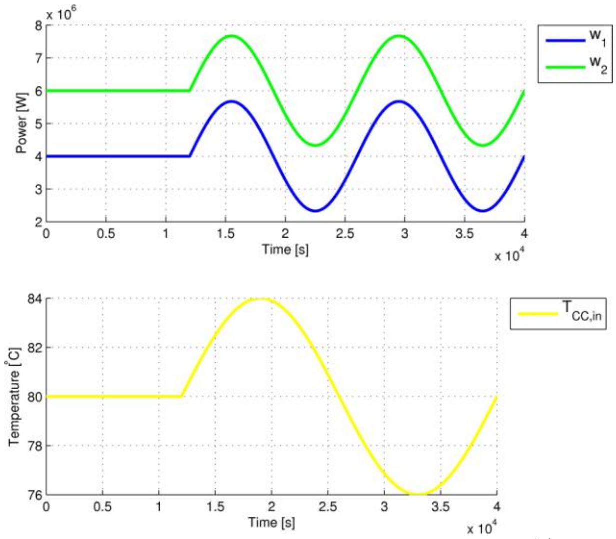

Figure 4: Top plot illustrates disturbances $w_1(t)$ and $w_2(t)$, while the bottom plot shows the disturbance $T_{CC,in}(t)$.

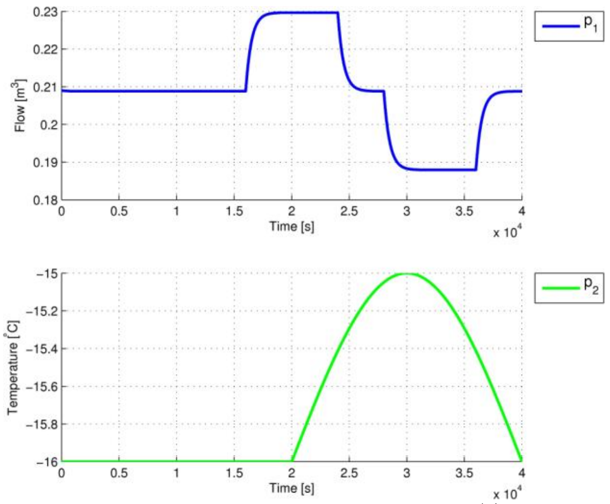

Figure 5: Top plot illustrates parameter $p_1(t)$ which is the low pass filtered input $q_{LT}(t)$, while the bottom plot shows the parameter $p_2(t)$ which is the temperature difference $(T_{SW,in}(t) - T_{SW,out}(t))$.

5. CONCLUDING REMARKS

We have presented the conversion of a nonlinear model to an LPV model for a marine cooling system with transport delays. The choice of scheduling variables for the LPV model was based on an attempt to keep the number of scheduling variables as low as possible, while still capturing the important nonlinear dynamics of the system and preserving the flow dependency of the delays. To illustrate the performance of the LPV model compared to the original nonlinear model, a simulation example was constructed. The simulation showed that the LPV model output only differed from the original nonlinear model when the input $q_{LT}(t)$ was excited, which was expected since all approximations in the LPV model was related to this input. The simulations indicate that the LPV model is sufficiently accurate for control design, and future work involves design of energy optimizing control laws that ensures robustness with the presence of disturbances and transport delays.

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EFFICIENCY OF TRIPLE LEFT-TURN LANES AT SIGNALIZED INTERSECTIONS

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ABSTRACT

Left-turn maneuvers can cause major delays to other traffic, and require specific analysis, design consideration, and traffic control to avoid operational and safety problems. As traffic congestion and travel demands continue to grow, alternatives such as triple left-turn lanes need to be considered. When installing a triple left-turn lane at an intersection, vehicles make their left turn movement from three separate left turn lanes. The purpose of this paper was to estimate any improvement in the efficiency of signalized intersections due to the addition of the triple left-turn lane compared to a dual left-turn lane under different scenarios using micro-simulation. A linear regression model was created to help practitioners to estimate the percentage of delay reduction expected when adding a triple left-turn. This information will be useful to improve the decision-making process of using triple left-turn lanes as an alternative solution to the traffic congestion problem.

Keywords: traffic simulation, left turn lanes, signalized intersections

1. INTRODUCTION

Signalized intersections represent the most critical elements of an arterial street. When traffic volumes increase on major intersecting arterials, left turning vehicles increase. The left-turn maneuver is a very complex driving challenge at high volume intersections and can have a major impact on the intersection traffic operations. Drivers turning left must find a gap in opposing traffic and check for pedestrians, bicycles, and other traffic in the intersection under a dynamic of changing traffic patterns.

Dual left-turn lanes are considered an alternative where land-use constraints and construction costs prevent a grade-separated interchange, especially where severe left-turn operational problems exist. As a general rule, dual left-turn lanes are considered in locations with left-turn demands of 300 vehicles per hour (vph) or more (Ackeret, 1994).

2. PREVIOUS WORK

2.1. Dual Left-Turn Lanes and Triple Left-Turn Lanes

Operational studies related to double left-turn lanes have focused on their efficiency in terms of saturation flow rate. Capelle and Pinnell (1961) found that the capacity of the inside and outside lane of the double left-turn movement are only 88% and 95% respectively of the capacity of the through lane.

Nicholas (1989) compared the dual and single left-turn lanes at signalized intersections as far as overall operating efficiency using the Highway Capacity software (HCS). It was found that the using the dual left-turn lane, the overall vehicular throughput was raised by 17.5%. Nicholas recommended using dual left-turn lanes at intersections with high left turning volumes and opposing traffic.

As traffic congestion and travel demands continue to grow on the street systems, the triple left-turn lane alternative was introduced. The main advantage of triple left-turns is their ability to handle large volumes. Also, they can reduce the left-turn queue length. It also helps where intersections are closely spaced. Shorter queue lengths will lower the probability for left-turn traffic to spill back onto the upstream intersection. Properly applied, triple left-turn lane can decrease total intersection delay by providing more green time for other movements through the intersection and increasing overall capacity.

There is a limited number of studies with regard to both operational characteristics and geometric design of triple left-turn lanes. However, the triple left-turn lane concept has been receiving design acceptance in the United States. In 1994, Ackeret proposed criteria for the geometric design of triple left-turn lanes at signalized intersections based on design experience gained in Las Vegas, Nevada. Ackeret has suggested that there are three general types of triple left-turn lane configurations: exclusive all lanes shadowed, exclusive outside trap lane, and permissive outside lane optional. Ackeret found that triple left-turn lanes have the ability to increase an intersection capacity to handle a large left-turn volume of left turn maneuvers (600 vph or more) and reduce delays and intersection queues. Reduction in upstream driveway conflicts by reducing queue lengths and resulting on vehicle storage lane lengths for left-turn lane. He also found that triple left-turn lanes have the ability to reduce the green time given to the left-turn movement so that it may be assigned to other intersection movements thus reducing overall intersection delay and improves the intersection level of service. Ackeret concluded that additional research is necessary and further studies are strongly required to address safety concerns by comparing crashes between double and triple left-turn lane installations.

Shen (2001) presented a study that aims to determine the minimum merging section lengths for triple left-turn lanes with downstream lane reductions. Simulation models were successfully developed to estimate the effects of different merging section lengths on average vehicle delay under various traffic and control scenarios. The average delay experienced by vehicles, traveling on the downstream roadway, were modeled through curve fitting as a function of merging section length, left-turn green time, left-turn heavy vehicle percentage and downstream free-flow speed. A look-up table for determining the minimum merging section lengths was developed based on a set of linear relationships that showed the minimum merging section length to:

- increase linearly with the left-turn green phase length
- increase at a decreasing rate with percentage of heavy vehicles
- increase at a decreasing rate with downstream free-flow speed

Although the simulation models produced results that gave very logical relationships among all of the variables considered, further studies were recommended to attempt to validate the simulated results with field data when they can be collected.

There is a limited literature discussing triple left-turn lanes. A better understanding of the efficiency and capacity of triple left-turn lanes at signalized intersections is needed to improve the decision-making process of using triple left-turn lanes as an alternative solution to the traffic congestion problem.

2.2. Simulation

Traffic simulation is a great tool to assess traffic operations along intersections and roadway segments. There are several microscopic models commercially available including CORSIM, AIMSIM, Paramics, SimTraffic, and VISSIM. Microscopic simulation of traffic has become a valuable aid in assessing the system performance of traffic flows and networks. Microscopic simulation tools allow for detailed analysis of traffic systems and have great potential for analyzing alternative strategies. They implicitly account for the stochastic nature of the transportation system and can provide both temporal and spatial information down to the individual vehicle level.

Modeling and simulation of this research was carried unsing PTV's VISSIM, a behavior based micro-simulation software. VISSIM (2011) is a stochastic microscopic, time step and behavior based simulation model developed to analyze the full range of functionally classified roadways and public transportation operations. VISSIM can model integrated roadway networks found in a typical corridor as well as various modes consisting of general purpose traffic, buses, light rail, heavy rail, trucks, pedestrians, and bicyclists. The model contains a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements (lane changing). The model was developed at the University of Karlsruhe, Germany during the early 1970s. Commercial distribution of VISSIM began in 1993 by PTV Transworld AG, who continues to distribute and maintain VISSIM until today. VISSIM can be applied as a useful tool in a variety of transportation problem settings. Modeling of intersections in VISSIM requires the detailed coding of links, connectors, priority rules, speed zones and gap acceptance (VISSIM 2011).

3. METHODOLOGY

3.1. Geometric Design of the Analyzed Intersection

The analyzed intersection was a four-leg intersection. Each of the four approaches had the same number of lanes: two through lanes, dual left-turn lanes, and one right turn lane. The methodology of the analysis was to add an imaginary third left turn lane to one of the approaches and study the delay for different scenarios using the micro-simulation software VISSIM. The eastbound approach for the studied intersection was used for the analysis. The approach was selected since it has the highest left-turn volume , the highest delay for the existing condition (dual left-turn), and the receiving section for the left turn movement is a three-lane section. This last reason was important because in this case there was no need to design a merging lane with downstream lane reduction in order to have three receiving lanes for the three left turn lanes. All left turn movements at the intersection are protected-only.

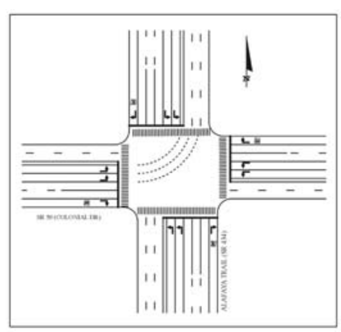

Figure 1: Geometric Configuration of the Studied Intersection

3.2. Calibration Process

The VISSIM model was calibrated using real data obtained for the studied intersection from the maintaining agency and using the HCS software. HCS is well-known software in the field of analysis of signalized intersections. HCS calculates the delays for signalized intersections using the methodology described in the Highway Capacity Manual. An assumption was made that the delay computed using the HCS software is the true value of delay.

Traffic volumes on each link, turning movement counts on each approach, geometric features, and signal timing were used to create the model. The first step in the calibration process was to use the peak hour volume data to create the model in the VISSIM software. These turning movement volumes in addition to geometric configuration and signal timing information, were entered into the VISSIM software. Delay was then computed for each approach. The same data was entered in the HCS software and delay was calculated for each approach. A comparison was done between the two outputs from HCS and VISSIM for all approaches. The absolute percentage error was calculated for each approach. The absolute percentage error for an approach is defined as the difference between the delay from HCS and the simulated delay divided by the delay from HCS multiplying by 100%.

The goal was to achieve an of error of five percent or less. To achieve this goal, VISSIM variables needed to be adjusted. The main VISSIM variables are divided into three main categories. The first category is related to the vehicle types and classes. This category includes the desired speed distribution, and vehicle types. These variables affect the roadway capacity and achievable travel speeds. The desired speed will be achieved by the driver if not hindered by other vehicles. Higher speed vehicles will check for a possibility of passing. The speed distribution used was in the range of 40 MPH to 60 MPH based on a spot speed study conducted at the intersection. According to the turning movement counts at the intersection, percentage of trucks in the traffic stream was negligible. Based on this information, the vehicle-type variable in the VISSIM software was set to. Mileage distribution for all cars was set to the range of zero miles to 200,000 miles.

The second category is the driving behavior. Driving behavior is composed of two main factors. The first factor is the general driver factor. This factor includes the average standstill distance, which defines the average desired distance between stopped cars and also between cars and stop lines (signal heads, priority rules, etc.). It also includes the maximum deceleration, which is the fastest any vehicle can slow down. The second factor is the lane change behavior. This includes the waiting time before diffusion which is the maximum amount of time a vehicle can wait at the emergency stop position waiting for a gap to change lanes in order to stay on its route (VISSIM 2001). An emergency stop is when a car cannot change lanes while moving, so, it has to stop to find a gap to change lanes. Vehicles will be deleted from the network one reaching this time. Default values for VISSIM software were used for these variables during the calibration process.

The third category is related to the simulation parameter, which is mainly the random seed parameter. The random seed parameter is generated using this parameter. The simulation runs will result identical results if they have the same input files and same random seeds numbers. By using a different random seed number, a stochastic variation of input flows occurs and therefore the results of the simulation runs will also change. Eighteen iterations were completed with eighteen different random seed numbers until an error percentage of less than five percent or less was achieved for all approaches. The other sets of data were then entered into the model and the delay was calculated from the VISSIM model and from the HCS software.

The second step was to compare the data obtained from the model against the data from the HCS software. According to Kelton (2000), there are two approaches to statistically compare the outputs from the real-world system with the simulation outputs. These two approaches are the visual inspection approach, and the statistical approach. The visual inspection approach was conducted by comparing the outputs from the HCS and simulation output data. Assuming that X_i is the delay obtained from the HCS software and Y_i is the corresponding delay obtained from the simulation model, a plot of X_i and Y_i is created such that the horizontal axis denotes each data set and the vertical axis denotes the delay obtained from HCS and simulated model. The user can then eyeball the difference to see if there is a major difference between the different values of X_i and Y_i. The visual inspection of the data showed that there were no major differences between the simulated delay and the HCS delay. A sample data set comparison is shown in Figure 2.

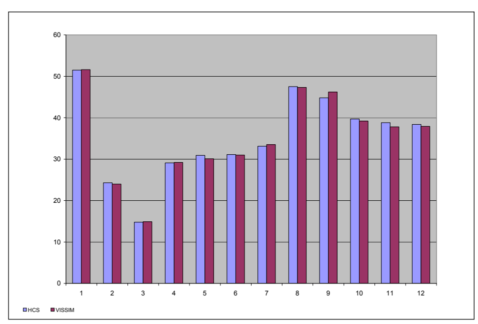

Figure 2: HCS Delay vs. VISSIM

A paired t-test was performed to determine if there is a difference between the means of the simulation results and the HCS results. The statistical analysis of the errors was performed using SPSS software (Version 19). The results of the test indicated, that at the 95% confidence level, the mean difference between the simulated results and the HCS results included zero, which indicated that the difference between the two values is statistically insignificant.

3.3. Analysis

The methodology of the analysis was to use the calibrated model to add an imaginary third left turn lane to one of the approaches and study the delay for different scenarios using the simulation software (VISSIM). The eastbound approach was used for the analysis. This approach had the highest left-turn volume, the highest delay for the existing condition (dual left-turn), and the receiving section for the left turn movement is a three-lane section. This last reason was important due to the need for a third receiving lane for the three left turn lanes.

The first part of the analysis was to estimate any improvement in the efficiency of intersection due to the addition of triple left-turn lane under different scenarios. The analysis was conducted by comparing two models; one for the existing conditions (Case 1 – Dual Left-Turn Lanes) and one by adding a third left turn lane to one of the eastbound approach (Case 2 – Triple Left-Turn Lanes). Hypothetical values were used in the study to create different scenarios. There were three parameters identified for this research: the approach left turn volume (increasing the existing left turn volume by 1% at a time until reaching a 20% increase), the left turn green time (decreasing and increasing the left turn green time by one second at a time until reaching a range of -40% to +40%), and the length of the left turn lane (decreasing and increasing the length of the left turn lane by one car at a time until reaching a range of -55% to +55%). The total number of scenarios developed was one hundred twenty two (122) scenarios.

Based on the micro-simulation results, it was concluded that the decrease in delay ranged from 13 percent to 84 percent by using the triple left-turn lanes in place of dual left-turn lanes for the study case. The results of the analysis indicated that the installation of triple left-turn lanes is favorable in intersections containing high volumes of left-turning traffic, limited pocket length and/or constraints on increasing the green time. Figure 3 shows the percentage of delay reduced by adding a triple left-turn lane for the studied scenarios.

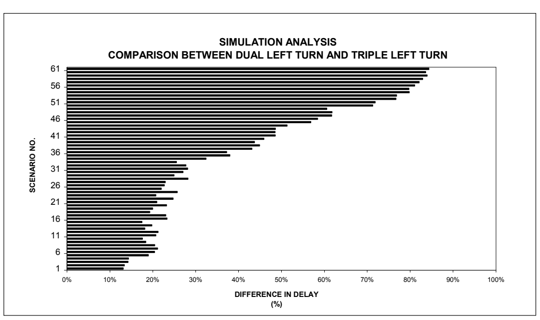

Figure 3: Percentage of Delay Reduced by Adding a Triple Left-Turn Lane

Based on the analysis, adding a triple left-turn lane will reduce the delay at the intersection but considering the high cost of right of way acquisition and construction, a benefit cost analysis should be conducted for each case to determine if adding a triple left-turn lane is the best alternative to consider. A linear regression model was created to estimate the percentage of delay reduction expected when adding a triple left-turn lane for their particular case. This percentage will be useful to improve the decision-making process of using triple left-turn lanes as an alternative solution to the traffic congestion problem.

The independent variables selected for including in the model were the left turn volume, the left turn green time, and the length of the left turn lane. The delay reduction forecasting model was therefore developed using the following convention:

- The response variable is:
  1. Delay Reduction Percentage; DRP
- The independent variable are:
  1. Left turn volume; LTV
  2. Left turn green time; LTGT
  3. Length of left turn lane; LLTL

The multiple linear regression model developed was checked for multicolinearity. All the statistical analyses were conducted using the SPSS software (Version 19) and according to standard Statistical Textbooks. The delay reduction forecasting model had the following form:

DRP= 1.544 + 0.001 LTV – 0.038 LLGT – 0.002 LLTL

Output from the SPSS software used to develop the model reported an R^2 of 0.729 and an R^2 (adj) of 0.715. An analysis of variance for the model indicated that the model estimated by the regression procedure is significant at an α - Level of 0.05, indicating that at least one coefficient is different from zero. Each variable in the model was tested for significance. Analyzing the residuals plots generated by the statistical software, a histogram of residuals shows a pattern consistent with a normal distribution. Based on the results obtained from the statistical analysis, the model should have good predictive ability to estimate the of delay reduction expected. To further test the forecasting model, a validation study must be conducted using another set of data.

4. CONCLUSIONS AND RECOMMENDATIONS

This paper developed a delay reduction percentage model to calculate the reduction in delay expected when adding a triple left turn lane at an intersection using three variables. The predictors used in the model included:

- Left turn volume
- Left turn green time
- Length of left turn lane

A statistical examination concluded that the model was capable of explaining 73% of the variability in the delay reduction percentage. The model developed in this research can be used to help practitioners to estimate the percentage of reduction in delay when adding a triple left turn lane to an approach. Further research is needed to incorporate additional variables and to validate the model using other sets of data.

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Performance Comparison between Immediate and Nonimmediate Passenger Guidance in Group Control for a Multi-Car Elevator System

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ABSTRACT

A multi-car elevator system is such an elevator system that more than one car is installed in every elevator shaft. In this study we consider a call allocation problem in group control for a multi-car elevator system with nonimmediate passenger guidance. In nonimmediate passenger guidance the car allocated to a passenger is indicated to him/her just before the car arrives at the floor where he/she is waiting. On the other hand, in immediate passenger guidance the car is indicated immediately after a call is registered at an elevator hall. We will propose a simple call allocation algorithm by a local search for nonimmediate passenger guidance and compare its transportation capability with that of immediate passenger guidance by computer simulation.

Keywords: multi-car elevator system, nonimmediate passenger guidance, call allocation, local search

1. INTRODUCTION

Along with the increase of high-rise buildings, multi-car elevator systems have been attracting considerable attention (ThyssenKrupp Elevator 2005, Onat, et al. 2011, Valdivielso and Miyamoto 2011). A multi-car elevator system is such an elevator system that more than one car is installed in every elevator shaft (hoistway). Figure 1 shows a typical multi-car elevator system. In our previous studies (Tanaka and Watanabe 2009, 2010) we proposed an optimization-based collision avoidance algorithm for a realistic multi-car elevator system where floor stop time of a car cannot be known in advance by the system. It was shown by computer simulation that a simple call (passenger) allocation algorithm together with the proposed collision avoidance algorithm can improve the transportation capability of the system much compared to an ordinary single-car elevator system. In these studies immediate passenger guidance was assumed: The car that a passenger should board is indicated to him/her immediately after he/she pushes a button at an elevator hall and registers his/her destination floor. It is true that this is a user-friendly interface, but disadvantageous from the viewpoint of improving transportation capability because call allocation should be fixed early and hence its freedom is restricted. On the other hand, in nonimmediate passenger guidance the car is not indicated to a passenger until his/her car arrives at the floor. Compared to immediate passenger guidance, better transportation capability can be expected at the expense of user-friendliness.

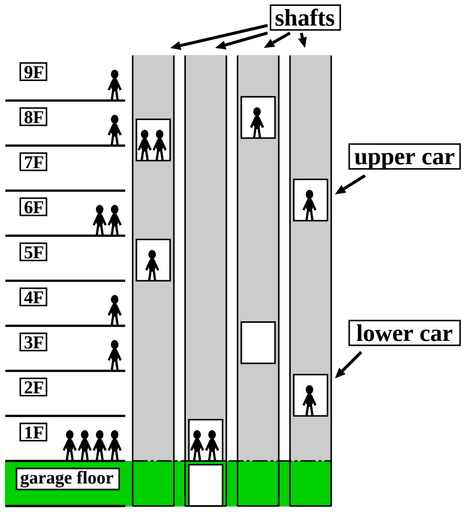


Fig. 1: Multi-Car Elevator System

The purpose of this study is to propose a simple call allocation algorithm for a multi-car elevator system with nonimmediate passenger guidance. Then, its transportation capability will be compared with that of a system with immediate passenger guidance by computer simulation.

2. SYSTEM CONFIGURATION

In this section we will describe the multi-car elevator system treated in this study.

Let us consider that an M-story building (the highest floor is the M-th floor) where a multi-car elevator system with two cars in every elevator shaft is installed. The entrance is the 1st floor and there is a garage floor under it where the lower car escapes to when the upper car is going to stop at the 1st floor (see Fig. 1). The hall call registration is destination-based. That is, a passenger who comes to an elevator hall at some floor registers his/her destination floor directly by pushing a button if it is not registered yet (Fig. 2(a)). The reason why such a destination hall call registration system is adopted in multi-car elevator systems is that the lower cars cannot go up to the highest (M-th) floor and hence destination floors of passengers are necessary for call allocation.

The shaft indicator panel and the destination-based

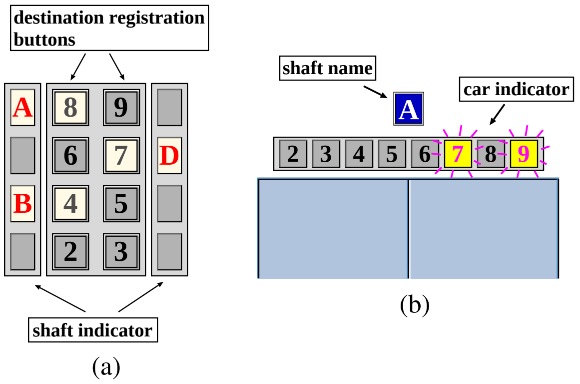


Fig. 2: (a) Destination Registration Buttons and Shaft Indicator, (b) Destination-Based Car Indicator

car indicator panel are used to guide passengers to the cars that they should board. The former is installed aside the destination registration buttons and the latter is above the door at each shaft (Fig. 2). In immediate passenger guidance (Tanaka and Watanabe 2009, 2010), the shaft indicator panel displays the shaft where he/she should wait for his/her car immediately after his/her destination floor is registered. The car indicator panel at that shaft displays the passenger's destination floor to urge him/her to board his/her car when the car stops at the floor (before the door opens). On the other hand, in the nonimmediate passenger guidance considered in this study, the shaft and the destination floor are displayed at the same time when the passenger's car stops at the floor.

The group control system for this multi-car elevator system is composed of a group controller and shaft controllers as shown in Fig 3. The group controller allocates calls to cars and generates car travel schedules by the selective-collective operation (Strakosch 1998), i.e. the ordinary elevator car operation, without considering collisions. Then, the shaft controllers control individual cars by modifying the travel schedules passed from the group controller so that collisions never occur. This study treats the call allocation algorithm in the group controller.

3. OPTIMIZATION-BASED COLLISION AVOIDANCE – AN OVERVIEW

Here, we will give a brief summary of the optimization-based collision avoidance for the shaft controllers proposed in our previous studies (Tanaka and Watanabe 2009, 2010).

Since passengers are assumed to push buttons at elevator halls only when their destination floors are not registered yet, the number of passengers corresponding to one call is unknown. Moreover, passenger boarding/leaving time varies in practice. It follows that the system cannot know in advance how long a car should stop at a floor. Therefore, in the proposed collision avoidance algorithm collisions are considered only until cars reach floors to be visited next, and the cars are assumed to stay there infinitely long. The collision avoidance algorithm is applied again when one of the cars finishes unloading passengers and becomes ready to start, This is repeated until all the passengers are served. To be

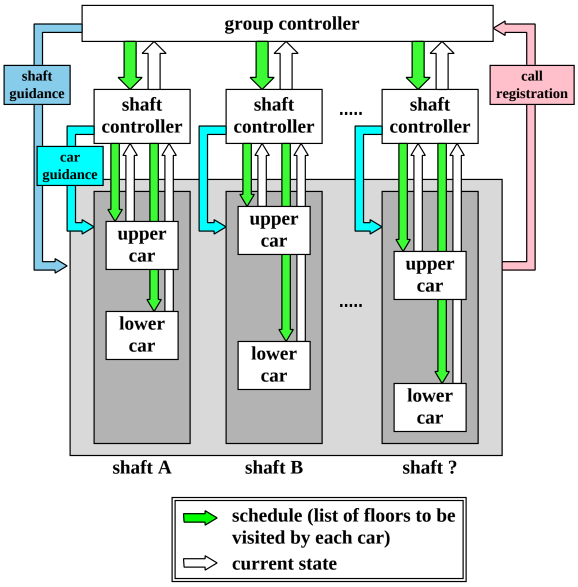


Fig. 3: Group Control System for Multi-Car Elevator

more precise, the collision avoidance algorithm is triggered when

(a) a new call is assigned to one of the cars in the shaft,

(b) a traveling car arrives at a floor,

(c) a car closes the door and becomes ready to start.

To determine floors to be visited next by cars, all feasible combinations are enumerated so that objective functions are minimized. In our first study (Tanaka and Watanabe 2009) an objective function to suppress reversal is adopted as the primary objective function, where reversal is such an undesirable car operation that onboard passengers travel in the opposite direction of their destination floors. However, in computer simulation reversal occurred frequently especially when passenger traffic is heavy. Moreover, a shaft could enter a livelock state and no call was served at all, although it was ensured that deadlock never occurs. Therefore, we improved the collision avoidance algorithm in the subsequent study (Tanaka and Watanabe 2010) so that reversal never occurs. For this purpose, suppressing reversal is regarded as a constraint instead of an objective function. It is also ensured that the system can always escape from a livelock state by switching the objective function when livelock is detected.

4. CALL ALLOCATION ALGORITHM FOR NONIMMEDIATE PASSENGER GUIDANCE

In this section we will first describe the call allocation algorithm in our previous studies for immediate passenger guidance. Then, we will propose a simple algorithm for nonimmediate passenger guidance.

In the case of immediate passenger guidance, a call is allocated to a car of some shaft immediately after it is registered at an elevator hall. Therefore, the optimal (in the sense that some objective function is minimized) allocation of the call can be easily obtained by enumerating all the possible allocations because the number of allocations that should be considered is at most the number of cars in the system. In our previous studies, which car

Table 1: Car Allocation by Zoning

direction	call type: origin floor	call type: destination floor	allocation
up	—	lower half	lower car
	—	upper half	upper car
down	lower half	—	lower car
	upper half	—	upper car

(upper or lower) should be used in a shaft is determined by zoning (Strakosch 1998) (see Table 1) and only the shaft is determined by such an enumerative approach.

On the other hand, in nonimmediate passenger guidance, we allocate a new call tentatively to a car of some shaft by the same method as that for immediate passenger guidance. Then, this allocation is repeatedly modified at every instant when the state of the shaft changes. These timings are the same as those when the optimization-based collision avoidance is triggered (see Section 3.). It is obvious that a simple enumerative approach is too time-consuming and hence intractable in this case, because allocations of several calls should be optimized at every time instant of the modification. To overcome this, a local search is employed to obtain a near-optimal allocation. It only searches for shaft allocation, and car allocation in the selected shaft is always determined by zoning as in the algorithm for immediate passenger guidance. The neighborhood in this local search is a combination of insertion and interchange. That is, the neighborhood of the current allocation (solution) is defined by all the solutions obtained by moving one call from the allocated car to another or by interchanging two calls allocated to different cars.

5. CALCULATION OF OBJECTIVE VALUE

To perform the local search in the preceding section, it is necessary to evaluate each allocation of calls. The optimization-based collision avoidance also requires to evaluate each combination of next visited floors. These evaluations are based on the passenger waiting time or service time. Here, the waiting time of a passenger is the time from when he/she appears at an elevator hall until when he/she boards a car. On the other hand, the service time of a passenger is the time from when he/she appears at an elevator hall until when he/she leaves a car at his/her destination floor. It is natural to use these for the evaluation of elevator operation because to transfer passengers as soon as possible is the primary purpose of elevator systems. However, their exact values are unknown from the elevator control system and hence should be estimated by some method. One reason of it is that the number of passengers that correspond to one call is unknown. Another reason is that car travels in the future are unknown even if no call is registered in the future because the collision avoidance algorithm only determines next visited floors and car travels after arriving there are not fixed at the current moment. It is true that car travel schedules after arriving the next visited floors are given by the group controller, but they are subject to modifications if collisions occur.

To calculate the passenger waiting/service time, it is assumed that only one passenger corresponds to a call and car travels after arriving next visited floors are estimated by a simple collision avoidance rule, as in our previous study (Tanaka and Watanabe 2009). There are two types of collisions: a collision when the cars of the shaft travel in the same directions, or, that when the cars travel in the approaching directions. In the former case, the rule makes one of the cars wait at some floor so that it does not catch up with the other. In the latter case, the rule makes one of the cars wait or evacuate.

Several types of objective functions in terms of the passenger waiting time and service time are examined in computer simulation.

Table 2: System Specifications

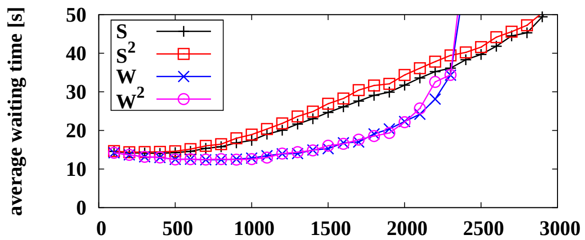
number of floors	30
number of shafts	5
interfloor distance	4.33m
passenger boarding/leaving time	1.2s/person
passenger response time	2.0s
door opening time	1.8s
door closing time	2.4s
maximal speed	6m/s
maximal acceleration	$1.1 \mathrm{m/s^2}$
jerk	$2.0 \mathrm{m/s^3}$
car capacity	20 persons

6. COMPUTER SIMULATION

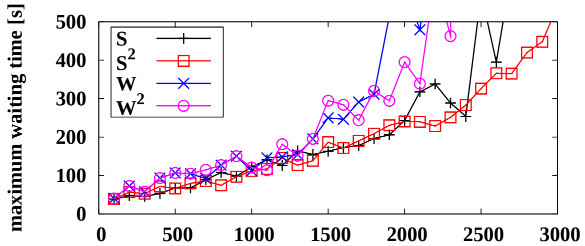
In this section the transportation capability is compared by computer simulation between immediate and nonimmediate passenger guidance. The specifications of the system follow our previous studies (Tanaka and Watanabe 2009, 2010), which are summarized in Table 2.

Data sets of passengers are generated as follows. Passenger arrival times at elevator halls are generated from the uniform distribution $[0, 7200)$ (in seconds). Their origin and destination floors are randomly generated to simulate two types of passenger traffics, uppeak and downpeak traffics, and the ratios among
(1) the number of passengers from the 1st floor,
(2) the number of passengers to the 1st floor,
(3) the number of upward passengers that travel between floors other than the 1st floor,
(4) the number of downward passengers that travel between floors other than the 1st floor,
are set to (1):(2):(3):(4)=19:1:1:1 and 1:19:1:1, respectively. For each setting of the passenger arrival rate (the number of passengers per one hour), and the type of passenger traffic, 10 data sets are generated. To examine stationary performance, the average and maximum waiting/service times of passengers whose arrival times are in the interval $[1800, 5400)$ are evaluated.

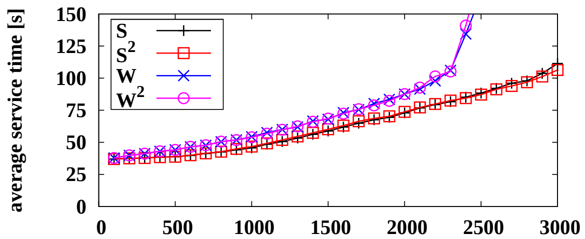
First, the objective function for the collision avoidance and the call allocation is examined. The results in uppeak traffic are shown in Figs. 4 and 5, and those in downpeak traffic are shown in Figs. 6 and 7. In these figures, the average or the maximum waiting/service time



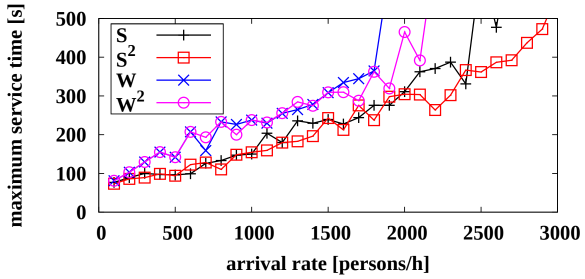
(a) average waiting time



(b) maximum waiting time

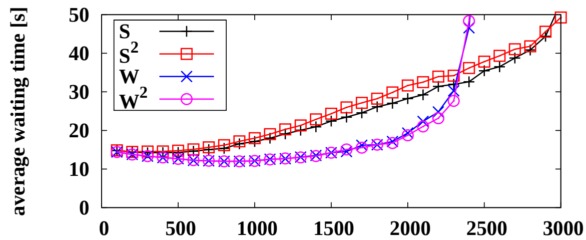


(c) average service time

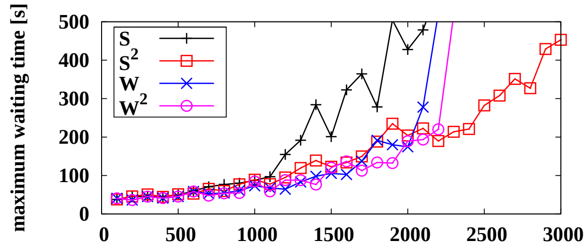


(d) maximum service time

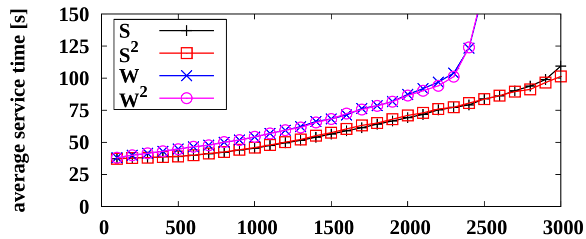
Fig. 4: Comparison of Objective Functions for Immediate Guidance (Uppeak Traffic)



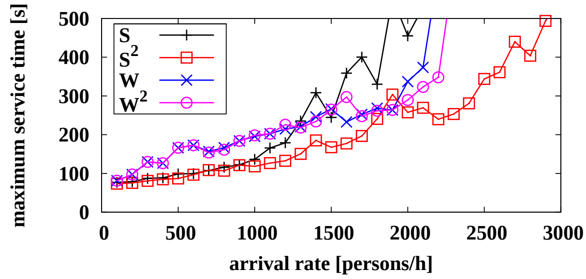
(a) average waiting time



(b) maximum waiting time



(a) average service time



(b) maximum service time

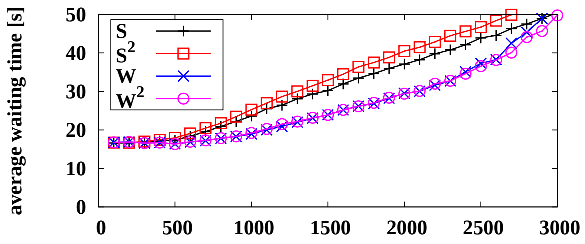
Fig. 5: Comparison of Objective Functions for Nonimmediate Guidance (Uppeak Traffic)

over 10 instances is depicted against the passenger arrival rate. Each line corresponds to a setting of the objective function: S and S^2 denote the sum and the square sum of service times, respectively, and W and W^2 the sum and the square sum of waiting times, respectively. We can see from Figs. 4 and 6 that the objective functions based on weighting times (W and W^2) work well for suppressing the average waiting time in light uppeak traffic and downpeak traffic, when immediate passenger guidance is adopted. However, the average waiting time diverges in heavy uppeak traffic (more than about 2200 persons/h). Moreover, the average and maximum service times of W and W^2 are worse than those of S and S^2.

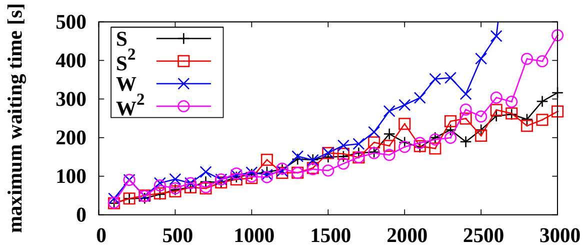
These results are natural because only waiting times are considered in W or W^2. Unlike single-car elevator systems, it is possible that passengers should stay long in cars until they reach their destination floors due to collision avoidance. However, the objective functions W and W^2 do not take such a situation into account. Thus it seems more appropriate to adopt S or S^2 as the objective function.

With regard to the performances of S and S^2 for immediate passenger guidance, the average waiting/service time of S^2 is worse than that of S while the reverse is true for the maximum. However, the differences are small.

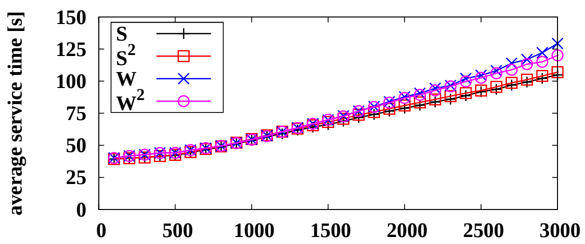
Similar results are observed for nonimmediate passenger guidance in Figs. 5 and 7, but the differences between S and S^2 are larger: The maximum waiting/service time of S is much worse than that of S^2 especially in uppeak traffic. Hence the best objective function among the four is S^2 for nonimmediate passenger guidance. The reason why S deteriorates the maximum waiting/service time would be that a specific call may



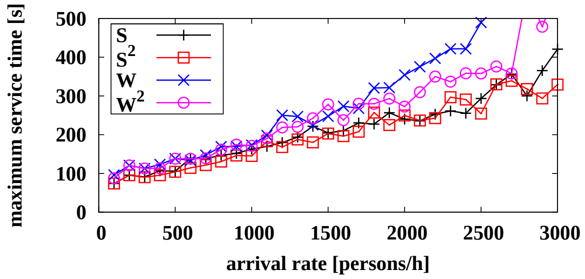
(a) average waiting time



(b) maximum waiting time

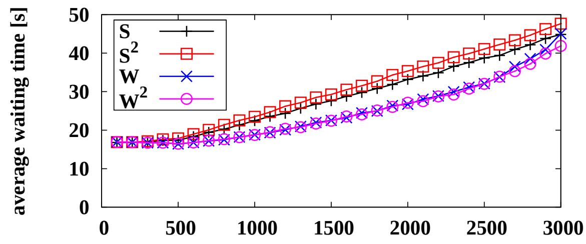


(c) average service time

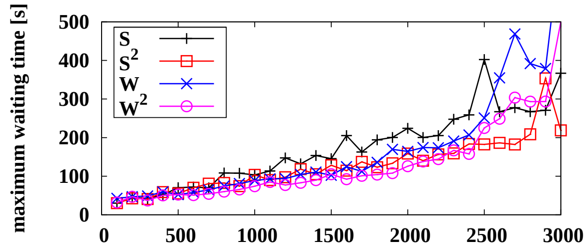


(d) maximum service time

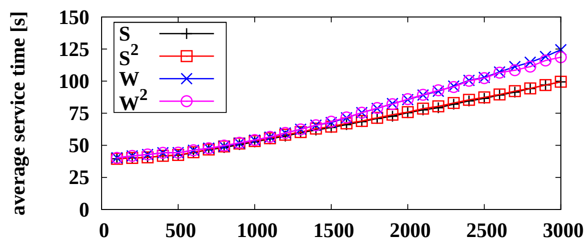
Fig. 6: Comparison of Objective Functions for Immediate Guidance (Downpeak Traffic)



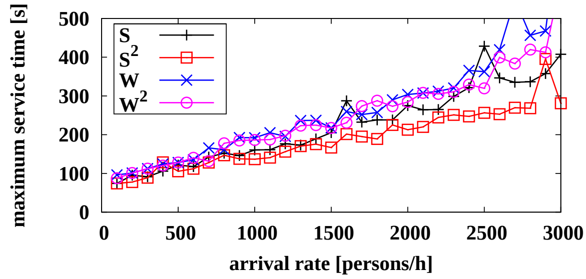
(a) average waiting time



(b) maximum waiting time



(a) average service time



(b) maximum service time

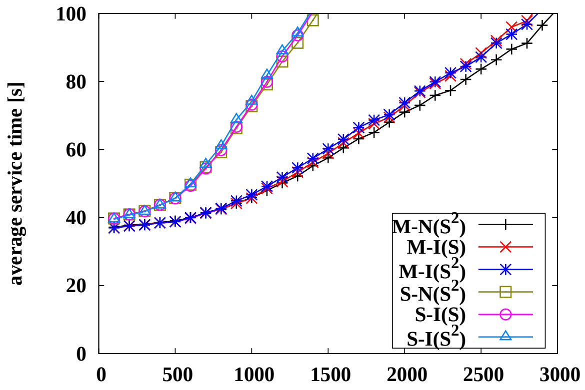
Fig. 7: Comparison of Objective Functions for Nonimmediate Guidance (Downpeak Traffic)

be delayed again and again by reallocating it from one car to another. Since service times of calls (passengers) equally contribute to S, a call may be delayed to improve service times of other calls when it leads to the improvement of the total service time. On the other hand, this is less likely to happen for S^2 because the square sum will increase if a call with a large waiting/service time is delayed.

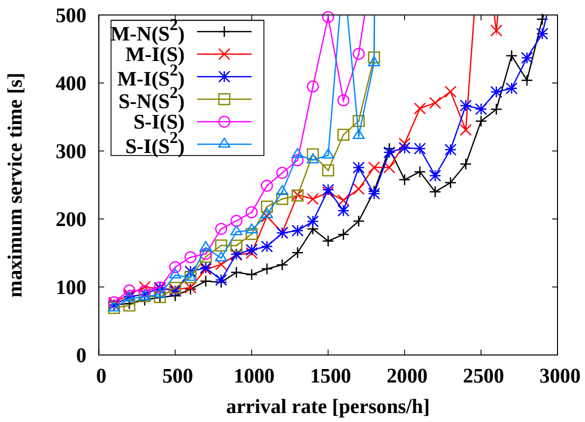
Next, the transportation capability is compared between immediate and nonimmediate passenger guidance. The average and maximum service times are shown in Figs. 8 and 9. In these figures, "M–" and "S–" denote the multi-car system and the single-car system (with five shafts), respectively, and "N" and "I" after them denote nonimmediate passenger guidance and immediate passenger guidance, respectively. The objective function used is given in parentheses. From these figures, we can verify that nonimmediate passenger guidance can decrease both the average and maximum service times compared to immediate passenger guidance. We can also see that the improvement is not significant for the single-car elevator system. In other words, reallocation of calls in the single-car elevator system does not affect much on the transportation capability at least when the proposed allocation method is employed.

7. CONCLUSION

In this study we proposed a simple call allocation algorithm for multi-car elevator systems with nonimmediate passenger guidance. Then, computer simulation was conducted to examine the most appropriate objective function and to show the effectiveness of the proposed method. As a result, it was verified that nonimmediate passenger guidance can improve the transportation

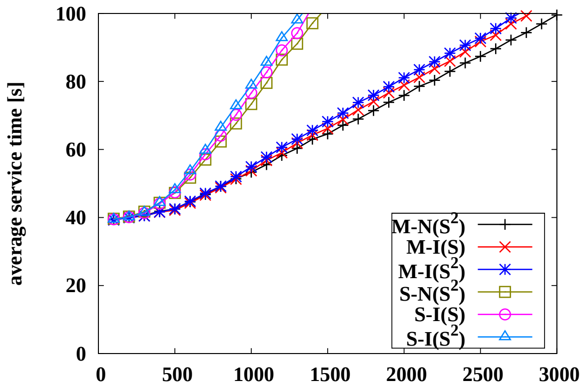


(a) average service time

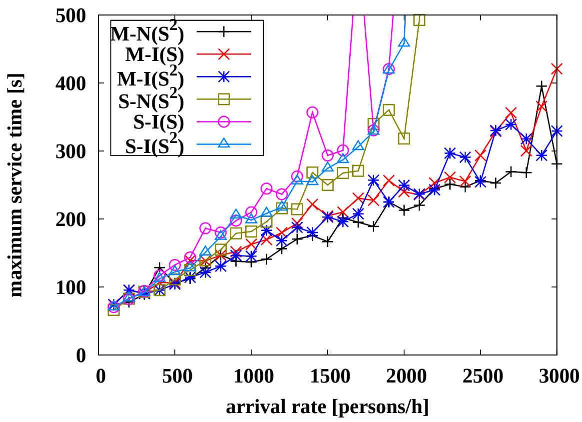


(b) maximum service time

Fig. 8: Comparison between Immediate and Nonimmediate Passenger Guidance (Uppeak Traffic)



(a) average service time



(b) maximum service time

Fig. 9: Comparison between Immediate and Nonimmediate Passenger Guidance (Downpeak Traffic)

capability compared to immediate passenger guidance. However, more intelligent algorithms would be able to improve the transportation capability further. Therefore, it is worthwhile to investigate it in the future study. It will also be necessary to treat systems with more than two cars.

ACKNOWLEDGEMENT

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SIMSHUNT – A FAST SIMULATION TOOL FOR CAPACITY ANALYSIS OF SHUNTING YARDS

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ABSTRACT
For capacity analysis of shunting yards a tool for fast and solid evaluation of changes in car flow characteristics and rail infrastructure is needed. Current available simulation tools do not allow a strategic network wide view, due to their highly detailed data requirements. This paper introduces SimShunt, whose goal is to develop a new simulation tool for shunting yards that is fairly easy to handle and possible to use for different yards with short set up times. A combined simulation and optimization approach is used.

Keywords: shunting, simulation, optimization

1. INTRODUCTION

Freight transportation is seen as an eco-friendly and in many cases efficient part of a supply chain. The planning of its infrastructure is possible through computer based simulation tools and can be put on a fundamentally and mathematically sound basis with such methods. As companies tend to use single wagons for transporting their goods, these wagons have to be part of different trains until they reach their final destinations. Shunting yards are needed to reassign the wagons for this type of transport. Different types of shunting yards exist, where complex actions of shunting can be performed. Commercial software tools for analyzing shunting yards are available (Adamko and Klima 2008), but they only allow a very detailed simulation, coming along with fairly long set up times. This results in long processing times for practical applications. Mid- and long term decisions are made on forecasts, which are cyclically updated. Therefore, long set up times tend to generate results based on obsolete data.

A strategic network wide view is not possible with the available tools. Nevertheless, an aggregated consideration is a much more important and relevant question for railway infrastructure projects. Higher potential is seen in an optimization of the whole transport system for single wagons, for which a strategic view of the whole network is needed. Currently, there is no known tool that allows the planning of shunting yards on an allocated, but relevant level.

2. PROBLEM DESCRIPTION

With SimShunt we develop a new simulation approach for shunting yards. The developing partner is the Austrian Federal Railways (ÖBB) who currently uses a simulation tool called NEMO. It is focused on the arcs of the rail network and therefore does not allow capacity analysis of shunting yards. Furthermore, the software tool RailSys allows simulation of planned and delayed rail schedules, which is also in use at ÖBB. It is possible to automatically reschedule trains with it to compare and validate decisions that are made in reality. Kettner, Sewcyk and Eickmann (2003) describe RailSys in combination with NEMO and the required data for the model. Depending on the size of a case different set up times are needed, but in any case several months of work are required. Slovakia based Simcon developed a software tool called VILLON for simulating logistic nodes, like plants, ports, railway stations, shunting yards and others. Its usage requires sufficient data set up (see e.g. Kavicka et al. 1999, Adamko and Klima 2008).

The analysis of shunting yards gains more and more focus in scientific literature. Kroon, Lentink and Schrijver (2008) developed a model for track allocation. Riezebos and van Wezel (2009) present a new method that was developed for the shunting yard Zwolle (Netherlands). Prioritized and blocked tracks are possible for certain trains in their survey, respectively. He, Song and Chaudhry (2003) developed a mathematical model for shunting to minimize times of train throughput and delays. Dahlhaus et al. (2003) present a mathematical model for reallocation of wagons during shunting and point out relevant parameters for the shunting problem. Dessouky et al. (2006) introduced a branch-and-bound based method, which optimizes the track dispatching, whereas the focus of Lübbecke and Zimmerman (2003) is set on optimizing sequence planning and dispatching of locomotives.

The above mentioned methods and models result either in a very specific problem of parts of a shunting yard or in very detailed requirements for a simulation. This results in the fact that a strategic network wide view is not possible with these tools, but the developing partner ÖBB requires a view of shunting problems on an aggregated level.

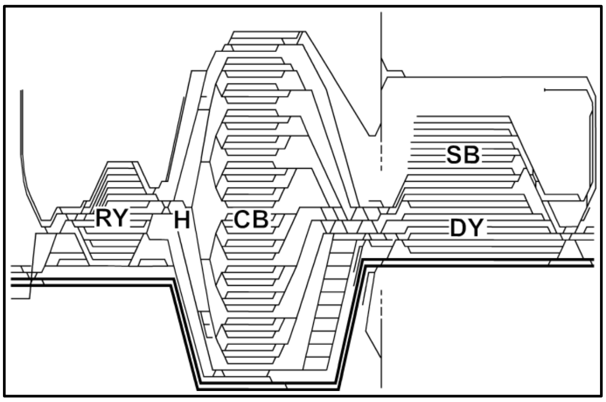

Figure 1: Shunting yard with receiving yard (RY), hump (H), classification bowl (CB), sorting bowl (SB), and departure yard (DY).

The shunting yard that is used for this case consists of different parts, where each of them has a certain number of tracks. They are called receiving yard, hump, classification bowl, sorting bowl and departure yard. A schematic diagram of the used yard layout is displayed in Figure 1.

An optimization of the carriage of single wagons seems to show great potential, but therefore a strategic network wide view including its nodes is necessary. This strategic view is used as a basis to be able to design an operative infrastructure development. The goal of this research is to develop a new simulation approach that is capable to perform capacity analysis of shunting yards with as few input parameter as possible. They should be fairly simple to determine and available for various yards. This would result in short processing times for the simulation. Additionally, various strategies ranging from current best practice to optimization based ones are developed and used for scenario analysis.

3. METHODS

The software tool SimShunt, which is used as a proper tool for capacity analysis of shunting yards, is designed as a hybrid model. It combines elements of discrete event simulation with mathematical optimization. For calculation of effects of different changes in dimensioning infrastructure and resource allocation a generic simulation model is developed. With its help, impacts on various configurations, dimensioning and scenarios can be calculated. The tool is designed with different modules (Figure 2) that contain the following:

- Shunting yard configuration,
- Simulation,
- Optimization and
- Report generator.

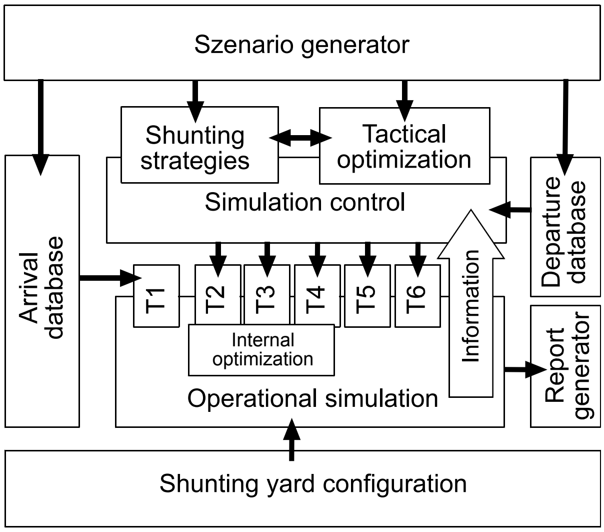

Figure 2: Simulation model design.

The model is designed as a synchronous simulation. Thereby a detailed schedule of movements is not needed. Trains are inserted according to the arrival database by execution of the arrival task (T1). Further different tasks (i.e. T2-T6) exist to simulate defined actions of the whole manipulation process until train departure. Their sequential execution is initialised by the simulation control logic according to different strategies and tactical optimization methods. On the operational simulation level simplified rules like dynamic route reservation are necessary to fulfil requirements on task sequence, conflict free dispatching and avoiding deadlocks, which is a serious problem in synchronous railway simulation caused by real time dispatching (Pachl 2007). Information has to be provided in order to ensure that simulation control has consistent data available.

3.1. Shunting yard configuration

First the tool is initialized with shunting yard relevant data that contain yard layout (tracks, signals) and available resources (shunting engines). This is done within the shunting yard configuration package. The generation of necessary incoming and outgoing trains for the simulation is done from arrival and departure database that consists of real data from the considered shunting yard. Out of this it is possible to generate various scenarios to run cases with different amounts of incoming and outgoing trains and their characteristics by data modification. These scenarios are used to find the capacity limitations of such a yard according to defined conditions.

3.2. Simulation

A discrete event simulation model is developed, using the Java based simulation software AnyLogic. The model is designed on a modular basis to ensure a fast implementation not only for various shunting yards, but also for in- and outgoing train flows. All movements on a yard can be simulated, displayed and followed through a graphical animation. The direction of incoming trains to the yard varies, because it is possible to enter the yard from different incoming tracks. The routing of trains, shunting engines and wagons through the yard is possible from a start to an end signal. Its path is calculated automatically through a k-shortest paths algorithm (see Riezebos and van Wezel 2009; Yen 1971), whose weighted graph consists of signals as nodes and specified connected track sections between the signals as arcs. Note, that a signal can be placed at any position on a track, not necessarily at start- and endpoint of it, to ensure correct track capacities and shunting movements as well as meeting safety restrictions on an accurate level. The use of k-shortest paths allows various alternatives for the routing in case one route is used by other resources or blocked for safety reasons. The simulation model is validated for test cases with real data. Validation can be performed by comparing the collected existing shunting performance indicators with the obtained ones of the rebuilt scenarios of the simulation's report generator.

3.3. Optimization

Optimization based methods – both exact and heuristic ones – need to be integrated to provide rules for shunting yard relevant decisions and are embedded within the simulation. These are decisions for track allocation of the receiving yard and the classification bowl. The former is relevant since the yard that is used in this paper has two parallel hump tracks, which are not directly connected to all receiving yard tracks. When using more than one shunting engine in the receiving yard these tracks are used alternately. Therefore, the track allocation of the receiving yard has influence on the humping sequence. Track allocation is also important for the classification bowl, since the tracks have different capacity restrictions and it influences the complexity of needed shunting movements during the sorting process and the assembling of outgoing trains. Intelligent track allocation can help improving efficiency of the sorting process in the sorting bowl. Various strategies for decision support are implemented and used for predefined scenarios. Therefore, mixed integer programming models can be developed to describe the relevant decision problems (see e.g. He, Song and Chaudhry, 2003). Depending on the size of the problem to be solved, either the model itself is used for determining solutions or a heuristic procedure is developed. Also the currently used heuristic methods are implemented for comparison and used to quantify the impact of potential improvements.

3.4. Report generator and animation

An animated view is generated to get a visual insight of the simulation. Reports with the relevant input parameters and output results can be generated. Benchmarks to validate the yard's capacity are calculated. The most relevant ones are the percentage of wagons of incoming trains reaching the defined outgoing train and of delayed departures. As the hump is a major bottleneck of the shunting process, its utilisation is determined as the major performance indicator. The software tool SimShunt allows to test the impact on changes of traffic volume and characteristic on yard performance as well as to show the efficiency of different strategies and optimisation techniques.

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DECISION SUPPORT IN A SERVICE FIRM

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ABSTRACT
The goal of this study is to produce a decision support simulation model with discrete event logic applied to a health spa service. The simulation is an extremely useful tool for predicting the constant changes that take place in a highly dynamic context such as that of services. In particular, this study develops a simulation model can be used to build a structure that helps predict delay and to produce a logical and rational management of queues and therefore to reduce the inefficiencies of the service.
The model was tested in a medium-sized Italian health spa (Telese thermal baths).

Keywords: discrete event simulation, service system, resource management, decision support system.

1. INTRODUCTION

The thermal spa studied is a service company, that is, an operating system consisting of a combination of infrastructure, facilities, equipment, systems and personnel that collectively deliver a service to the customer.

Operational efficiency has a direct impact on customer satisfaction and also on the financial performance of the company.

In particular, this paper is aimed at the study of issues related to the carrying out of thermal treatments, with the aim of streamlining the health spa service system, focusing attention on the main customer of the spa.

The slow expansion of capacity (limited by physical dimensions that cannot always be further extended) has increasingly complicated the ability of the health spa to maintain satisfactory customer service.

The management has essentially two main objectives: customer satisfaction and cost effectiveness. On the one hand, it must seek to contain the queues, which increase the cost of customer inconvenience; on the other hand, it must consider the limited capacity available.

As a result the task of management, following a capacity planning analysis, is to adopt systems to optimize resource utilization and maximize customer satisfaction. Determining the optimal combination of resources, processes and technologies that will produce a satisfactory service for the customer is a complex problem.

Using analytical methods, customer waiting times in queues cannot be readily predicted with accuracy. The best way to take account of all the variables is undoubtedly a simulation that offers important benefits such as flexible modeling and immediacy of understanding through animations.

In the field, it was realized that a very detailed analysis of the existing process is required for understanding of the times and methods, highlighting in particular the organizational and procedural inefficiencies that affect the quality of the service, causing delays with potentially negative impacts on customer relations and therefore on the market performance of the company. We have therefore tried to offer an ad hoc methodology to limit these delays and the related costs.

2. SERVICE SYSTEM

Every production system uses resources to convert input factors to desired output factors. These transformation processes are carried out in different fields, and what differentiates them is the nature of the output. The service is "the intangible output of the production process"; its characteristics are not to be identified with the physicality and materiality that characterize the output of industrial production (tangible output). The service can therefore be defined as an exchange of activities between a subject who expresses needs, wants and aspirations and another subject who responds to these. It is therefore essential to valorize the service, as a tool to solve problems and respond to the specific needs of the customers.

Another aspect to be underlined is the lack of storage, a feature that makes the production process difficult to standardize and to schedule. This consequently means that production capacity must be immediately available to produce a service as required, preferably located at the point where the customer requests the service. Another feature of a system that provides services, is the significantly higher volatility of demand relative to manufacturing systems. This happens primarily due to lack of storage, which does not allow reserves to be accumulated during slack periods for use during periods of peak demand, making it difficult to maintain a steady level of output. Secondly, this level of variability is also caused by the "personalized" nature of the service – the delivery process is addressed to different customers who often have different needs.

Within the service sector, quality can only be observed from the perspective of customers. The service is generated in response to their needs, wants and aspirations. The performance is of high quality if the customer can enjoy the results. The organization must therefore plan the service not just according to its own needs (its problems, constraints, internal costs, and difficulties), but also to address those of the customer.

2.1. Constraints and objectives in service models

Supply differentiation is the fundamental tool to capture customer preferences. The operational features and the constraints on differentiation in service models are more varied and often more difficult to specify than those used in manufacturing.

One constraint consists of the time window related to the demand or supply of the service. There are capacity constraints related to the physical dimensions of the structures that deliver the service within the limits of the available space. Then there are constraints relating to the availability of physical resources (such as facilities and equipment) and human resources (staff). The basic problem is to optimize resource management so that wastage is reduced.

The primary goal of all manufacturing systems is to minimize production costs associated with a given level of quality, that is, the provision of a high quality product to the customer within the time limit. In service models too, one of the objectives is the minimization of the costs of service delivery. Other main objectives may be different, such as minimization of the average time of service delivery, minimization of the average customer wait time, minimization of the average distance covered by the customer in the service system, or minimization of the average number of staff required.

One of the most representative parameters of service quality is constituted by time. Just as in manufacturing companies, time is an important parameter because it is necessary that the product ordered by the customer is delivered within the time limit. In service companies, customer waiting times for service delivery must be below a tolerance limit.

A satisfactory service for the customer is therefore a service that minimizes its own inefficiencies, such as queues and customer waiting times for service delivery.

2.2. Queuing theory

Queuing theory aims to develop models for the study of waiting lines that may form in the presence of demand for a service. When the demand for a service and/or the capacity to provide that service are subject to uncertainty, this can result in temporary situations where the service provider is unable to meet customer demand immediately.

The arrival of customers is usually random and each customer requires a service with a delivery duration that also varies in each case. If a new customer arrives and the service is exhausted, he/she enters a waiting line until the facility becomes available. In the service sector, since queues are formed of people rather than tangible goods (as may be the case in manufacturing), the problem of congestion results in various hardships and inconveniences.

Queuing theory analyzes waiting lines by modeling the behavior and process of the arrival of a customer (service demand), and the modalities and process of delivery (service supply). As in any situation where supply exists in respect of a demand, it seeks to find a balance between conflicting needs:

- customers want to receive the service as soon as possible;
- the service manager must design the service system so as to maximize the level of customer satisfaction and at the same time to minimize the costs incurred in service delivery, primarily infrastructural costs and staff costs.

By means of a model (descriptive or simulative), queuing theory studies the queuing system and seeks the optimal level of resources at the minimum total cost (sum of the costs of waiting in queues and of resources), so as to balance the above objectives. In most cases, as already mentioned, the demand for the service and the duration of the delivery of the service are variable, so system sizing and effective coordination among its constituent parts are of key importance. Queuing theory is an excellent tool for planning and managing a service system for this purpose. The sizing of a service system, whether simple or complex, is determined on the basis of certain fundamental parameters, such as the average length of queues, average number of users in the system, and average customer waiting time.

Simple system types can be analyzed analytically, but when the system becomes complex, as when multiple queues are present in the system and the service involves different operations, then analytical study becomes very difficult and the only solution to estimate system performance is the use of simulation models.

The elements that define a complete service system, and therefore the phenomenon of waiting lines are:

- customer population;
- customers arrival process;
- number of servers;
- service process;
- service capacity;
- queue discipline.

The customer population is the set of potential customers arriving in the service system and leaving it after being served. The main characteristic of the population is its size, which represents the total number of different potential customers requiring a service. The behavior of customers is important: they may be patient and willing to wait (for a long time) or they may be impatient and leave after a while. For example, in call centers, customers will hang up if they have to wait too long before an operator is available, and they possibly try again after a while.

The arrival process describes the way in which customers request the service. It is defined in terms of interarrival times, i.e. the time interval between two successive arrivals. This process may be deterministic, but in general it is described by a random variable. Usually we assume that the interarrival times are independent and have a common distribution. In many practical situations, customers arrive according to a Poisson stream (i.e. exponential interarrival times). Customers may arrive one at a time, or in batches. An example of batch arrivals is the customs office at a border where travel documents of bus passengers must be checked.

The service process, on the other hand, describes the way in which each server delivers the service. It is defined in terms of service time, that is, the time required by a server to provide the service. As with the arrival process, the service process may be deterministic, but in most cases it is described by a random variable.

It is essential to define the number of servers in the service system at the time of the analysis. If there is more than one server, it is also essential to distinguish whether these work in series, if the service requires several operations to performed, or whether they work in parallel, if the service requires a single operation. Service capacity is the maximum number of users that can be present simultaneously in the system, including both customers in queues and those who are using the service. Customers, who arrive after that this capacity is saturated, are rejected.

Queue discipline describes the way in which customers are "selected" from the queue to be served, more specifically, the rule that a server uses to choose the next customer from the queue when the service of the current customer is complete. Commonly used queue disciplines are:

FIFO (“first-in first-out”): the customers are served in order of arrival;

LIFO (“last-in first-out”): the last customer to arrive is served first;

SIRO (“service in random order”): customers are served in random order;

Service based on classes with different priority, where customers with the highest priority are served first.

The costs are usually split between variable costs, which are a function of at least one of the quantities characterizing the dynamics of the system, and fixed costs, which are independent of the observed dynamics and which are generally a function solely of the physical structure of the system. In a queue there will always be present at least the variable costs associated with customer waiting time and fixed costs related to the number of servers available. The different actors involved in the system obviously consider these costs with different emphasis. Customers consider the reduction of waiting times in queues to be essential, while the manager of the service system is probably interested in achieving the maximum utilization of resources while seeking to satisfy customer needs.

3. A SIMULATION APPROACH TO THE ANALYSIS AND CRITICAL ASSESSMENT OF A PROCESS

The term simulation refers to a wide range of methods and applications that allow reproduction of the behavior of a real system, building a model with the purpose of reflecting the behavior of a physical system so that it can be studied from different perspectives and points of view.

Simulation is a very powerful tool that is widely used in the study of systems. It is typically applied in the following areas:

- design and analysis of a manufacturing process;
- design and analysis of a service process (call-centers, fast food, hospitals, banks, post offices, thermal spas, etc.);
- establishment of ordering and inventory strategies;
- design and operational implementation of transportation systems (highways, airports, ports);
- analysis of financial and/or economic systems; etc.
- Two different types of model exist:
- physical models, where there is a scale model of the system (a plastic model, flight simulator, etc.);
- abstract or logical models, where a number of assumptions are made, with all the consequent approximations regarding the structure and quantities, to reflect as far as possible the functioning of the real system. A logic model is usually represented through a program that permits queries to be made regarding its behavior and consequently that of the physical system.

After developing the model, we must interact with it, in order to analyze its behavior, and therefore (with some approximations) that of the physical system. If the model is simple enough, it is possible to solve it with a numerical / statistical / analytical approach: integral equations, linear programming, queuing theory, etc. Most systems that are modeled are rather complex and structured and so it is not possible to identify the mathematical laws that govern the system. In such cases, it is more effective use a simulation approach. In any case, the simulation is affected by uncontrollable input variables (random) which propagate in the model until they reach the exit.

3.1. Steps to perform a simulation

A simulation consists of ten steps. The first step is to formulate the problem and to plan the study. Generally, the project manager proposes a problem and, in a series of meetings in the presence of simulation analysts and experts, the following points are discussed:

general objectives of the study;
specific questions that the study should answer;
system configurations to be modelled;
software to be used;
schedule of activities of the study.

The second step consists in data collection, where information is gathered regarding operating procedures, the system layout, the data input system. The data should be made available in electronic format and organized in an appropriate database. The data should be traceable to a particular probability distribution, so that they can be included in the simulation model.

The third step is the definition, construction and representation of the conceptual model using graphical languages (such as flow charts, Idef0, Petri nets, etc.). After having defined and constructed the conceptual model, it is expressed in a programming language (Fortran, C, Matlab, etc..), or in simulation software (Arena, AutoMod, Extend, ProModel, Witness). The direct use of programming languages has the advantage of fairly low costs that lead to a fast and efficient simulation. Simulation software, on the other hand, is fast and easy to use, thus reducing programming time.

The fifth step is to create simulation tests in order to provide the data necessary for the next step. This is the validation of the simulation, in which performance measures of the real system are compared with those provided in output by the simulation model.

The seventh step is the design of experiments so as to construct an experimental plan that minimizes the number of runs for each simulation and maximizes information on critical aspects of the problem. This is followed by the carrying out of the simulations themselves, and the analysis of output data with comparison of alternative system configurations. The tenth and final step is the documentation, presentation and interpretation of results.

3.2. Discrete Event Simulation

A simulation involves the chronological representation of system states over the observation period (simulation run length), identifying those elements within the system with independent life (entities), having particular characteristics (attributes) and interacting according to particular laws when carrying out activities. The entities use the resources to carry out the activities, and the execution of one or more activities generally corresponds to a change of system state, and therefore, to the occurrence of an event.

In continuous state models, the dynamics of the system state depends on time and for this reason they are denoted as time-driven systems. In the case of discrete state systems, however, the state changes instantaneously at particular moments of time in which certain conditions associated with events are verified. Conceptually, an event can be considered as:

- a particular action (such as receiving a telephone message, the shutdown of an engine);
- the spontaneous occurrence of a condition (failure of an engine, voltage drop on a particular device);
- the occurrence of certain conditions (the number of packages in a storehouse reaches a predetermined quantity).

Assuming that a time signal (clock) is available to measure the time, there are two possible ways to generate events:

- in all multiple instants of the period of the clock there is an event e. If neither event takes place in a particular instant, we add the null event ε to the set of possible events ∑ that cause the transitions of the state of a system;
- the events occur in instants of time that are not known in advance and do not necessarily coincide with the multiples of the clock period.

In the first case, the state of the system is evaluated at each clock signal. The state may change depending on the generation of an event e or of the null event ε. There are, therefore, transitions of state synchronized with the clock signal, and the dynamics of the state of the system remains time-driven. In the second case, however, the state of the system changes at instants of time that are not known in advance, whenever an event is generated and, and transitions of state are driven by the succession of events. These systems are denoted as event-driven systems.

Summarizing we have identified two classes of dynamical systems:

- continuous state systems and time-driven systems (linear or nonlinear, time-varying or not, continuous time or discrete time);
- discrete state systems and event-driven systems (the systems of this class are called discrete event systems DES).

In the majority of problems for which a simulation approach is adopted it is necessary to manage the queues within the system. For these problems, a discrete event simulation is appropriate. In a discrete event simulation, which may be based on both continuous and discrete states, the state variables only change at discrete events (special instants), which are determined in turn by activities and delays, and not continuously (such as the volume of a gas or the level of a liquid). The basic objects of the system model are entities and resources. The former are elements of the system to be considered individually, information on the state of which is maintained during the simulation (such as passengers who arrive at the check-in waiting to be served, or patients who arrive at a hospital reception). Resources are those goods required by the entities in the course of activities and are usually elements of the system that need to be modeled individually, but which are usually available in limited quantities. It is obvious, therefore, that the entities needing a resource are blocked if that resource is not available.

An event is the instant of time when there is a significant change in the system, typically corresponding to the start or end of an activity. For example, in a queue, a possible event is the moment when the server stops serving one customer and becomes available to serve the next customer. The activity in this case is to serve the customer.

To make the simulation it is necessary to build the model, for which the following steps are required:

- identify the classes of entities;
- identify the activities that take place in the system;
- identify the relations between entities and activities.

4. HEALTH SPA SERVICE

The health spa service is complex and highly structured, characterized by various activities such as the bottling of water, traditional thermal treatments, and health and fitness services, including cosmetic activities. The connection between the thermal spas and wellness, in those destinations where it has been established, has attracted more young customers in their thirties and forties, compared to the over-fifties who characterize demand for traditional thermal treatments.

The strategic importance of the thermal spas and treatments as a specific component of tourism, was progressively established in France, Hungary and the Czech Republic in the first place and also in Slovenia, Bulgaria and Austria. In particular, with the liberalization of market, Eastern European countries have accelerated investment, offering a competitive supply system, in terms of quality and price, thanks to the collaboration of international hotel chains. Italy is the European country that has the largest number of thermal spas, thanks to its particular geological structure, rich in volcanic phenomena. 380 companies are active across a very diversified area. The regions with the highest number of thermal spas are Campania (114) and Veneto (110), followed by Emilia-Romagna (24), Tuscany (22), Lazio (18) and Lombardy (16).

4.1. Thermal activity at Telese thermal spa

The thermal spa of Telese, in the province of Benevento, has an ancient tradition of sulphurous waters, famous their numerous therapeutic applications. The thermal activity is mainly performed in the central departments of the thermal spa and partly in the decentralized departments of the associated hotel complex. In particular, thermal treatments are carried out in the central departments of the thermal spa from May to November, and in the decentralized department of the hotel for the rest of the year. The period of high flow and thus the most critical period is the month of September. The therapies performed include mud baths, warm baths, hydromassages, vaginal douches, inhalations, pulmonary ventilations, entotympanic and politzer insufflations, and massages. There are separate departments for each type of treatment and each type of client, whether private individuals or belonging to a group that has an agreement with the company. In the study we have focused only on the non-booking departments, in which there is highest criticality in terms of long queues and high waiting times in queues. The departments that are non-booking are the inhalation department, massage department, and warm bath and hydromassage department. The thermal treatments can be obtained either on prescription of the family doctor or privately. The main difference between the two types of access is that those accessing the thermal baths on the prescription of the doctor must pay only a proportion of fee, and they may be exempt altogether. With private access, the customer must pay the entire tariff determined by the company. Every citizen has the right to take a single course of treatment per year for a period of 12 days, from the Monday to the Saturday of the following week.

The company has agreements with municipalities, and also has a special agreement for lodging in the associated hotel with some organizations and national institutes.

The opening times of the departments are, in principle, from Monday to Saturday morning from 8.00 to 12.30 and from Monday to Friday afternoon from 15.30 to 17.15. During the months of high flow the company prefers to open the departments in the morning at 7.00 and in the afternoon at 14.30.

4.2. Text Paragraphs

The treatments take place in the departments of the health spa, located inside the thermal park. It has two separate entrances, a central one for groups that have an agreement with the company, and a side entrance for private customers. There are therefore two separate control stations at the entrance.

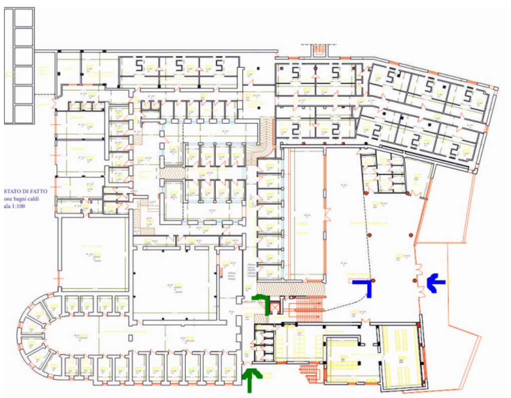

Figure 1: two separate entrances with two separate control stations for groups and private customers

We have focused only on non-reservation departments: the inhalation department, massage department, and warm bath and hydromassage department. On the lower floor is the inhalation department dedicated to the groups, on the upper floor is the inhalation department dedicated to private customers. Both have 27 aerosol appliances, 27 inhalation appliances, and 10 appliances for nasal showers and there are 3 operators in each.

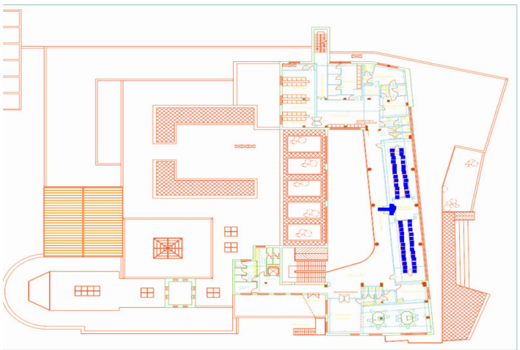

Figure 2: upstairs the inhalation department dedicated to the private customers

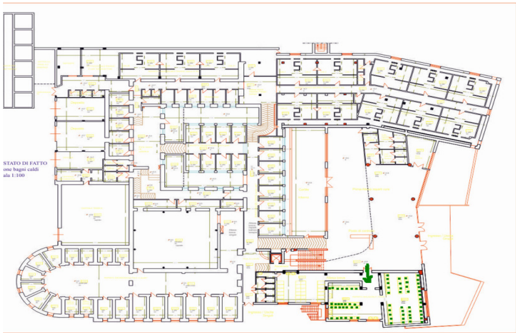

Figure 3: Lower floor inhalation department dedicated to groups

The massage department consists of 5 massage cabins used out of a potential availability of 8 cabins, with 5 operators. There is a single department for the two types of customer and it is located downstairs.

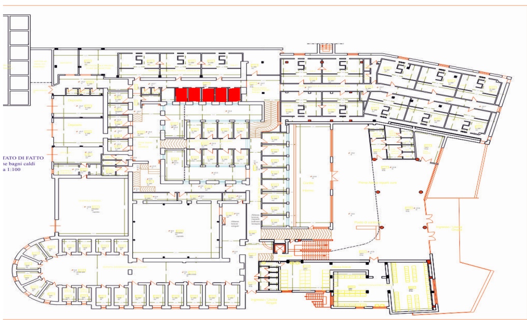

Figure 4: Massage department

There are distinct warm bath and hydromassage departments for private customers and groups. For groups there are "yellow cabins" and "green cabins" consisting of 16 warm bath/hydromassage cabins. For private customers there is an area called "horseshoe", consisting of 9 warm bath/hydromassage cabins and 7 cabins that are warm bath only. A hydromassage cabin is also suitable for a warm bath, but a warm bath cabin is not suitable for hydromassage. In addition, if one of the two departments, for example that of private customers, is busy and the other department has availability, then a private customer may access the groups department, and vice versa. For this department there are 3 operators.

5. DATA ANALYSIS

The delays occur at the entrance to the departments. The less time that the customer spends in the system, the greater his or her satisfaction. The time that the customer spends undergoing therapies in the different departments varies according to the period when the customer undertakes the treatment and then according to customer flow and the type of care. Customer wait times can last hours, and the most critical months in this case are those of September and October. A large collection of data can be used to build a simulation that helps predict these times. The goal of this study is to identify delays and create scenarios that will improve efficiency.

The simulation allows the observation of criticalities that can arise in the management of real flow, according to key factors such as the volume of traffic of customers, the type of customers (whether private or members of groups), and the type of care. Obviously, the simulation is the final stage of a project lasting several months.

Building the model is equivalent to following virtually the path made by customers to undertake treatments, studying the issues and highlighting all the possible alternatives. A visit at the spa was necessary to understand, in general terms, the approach of customers, and to gather all the information necessary for the work to proceed. The frequency with which customers arrive is a key variable of our study process, considering that the period of highest flow is the month of September when there are the greatest criticalities. After careful examination of the flow of customers, thanks not only to on-site visits, but also to a list of the thermal treatments compiled and archived each month, detailing entrances in each department, it emerged that the traffic peaks of customers during the months when they undertake treatments (i.e. from May to November) occur in September. September is a critical period, in which there can be waiting times of one or two hours for delivery of the service. We focus on the most critical month, and in particular the simulation was made for the day of September 24, the day of highest average customer flow during September. From a company archive database, we have been able to extract the time at which each person entered the various departments of the health spa, because as each customer enters a thermal department, he/she must pass a magnetic card and the entrance time is registered in the database. In this way it was possible to introduce a schedule of arrivals into the simulation model, using the quarter hour as the base unit of time.

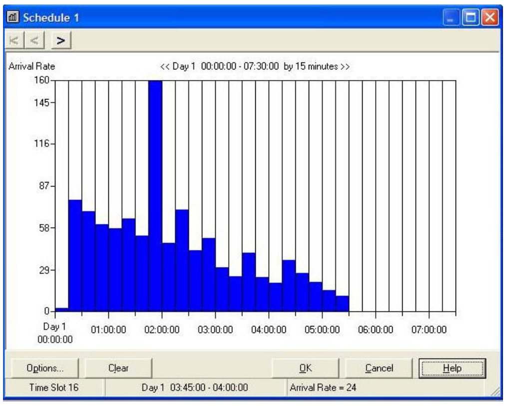

Figure 6: Arrival flow schedule

The goal of on-site sampling was to obtain service times for each type of treatment, arrival times and customer wait times. This on-site sampling was carried out for two week, in a different department each day. From these data the probability distribution of service times was obtained for each type of treatment, represented by a triangular distribution.

6. LOGICAL MODEL

The simulation model is the implementation in simulation software (Arena, in this case) of a previously-developed logical model. In general for complex service systems it is necessary to adopt the perspective of a modular system, developing the model through several sub-models.

First it is necessary to distinguish two categories of customers, customers belonging to groups that have an agreement with the company, and private customers. There are in fact two different entrances for the two types of customers. At this point we must make a further distinction by type of treatment. Both private customers and groups are sent to different departments depending on the therapy that has been assigned:

- for inhalation treatments, customers go to the inhalation department, groups on the lower floor, private customers on the upper floor;
- for warm bath or hydromassage treatments, customers go to the respective department. There are in fact two departments, one for private customers and one for groups, but if one of them is busy and the other is available, a private customer can access in the group department and vice versa;
- for massage treatment, customers go to the massage department, which is identical for both types of customers.

Each department is represented as a sub-model. We will briefly consider just one of these, the massage department. For massage treatment, customers go to the massage department, which has 5 cabins with 5 operators. As discussed above, there are two different entrances to the departments, one for groups and one for private customers. If the massage cabins are all busy, the customer remains in the queue, and the queue is formed at the control station where customer must pass the magnetic card, rather than within the massage department. There are therefore two queues, one for each type of customer. The logic of the queue in this case is for the longest queue to be dealt with first, so the condition of progress in the queue for a private customer, for example, is that one of the five cabins is free and that the private queue is longer than the group queue. At this point a distinction must be made between full massage and partial massage, which differ by the duration of treatment, about twenty minutes for the full massage and ten minutes for the partial massage. These times are not standard, but variable according to the operator and patient. The process times are defined in the block allocations, estimated through on-site sampling. Once the treatment is complete, the customer leaves the department.

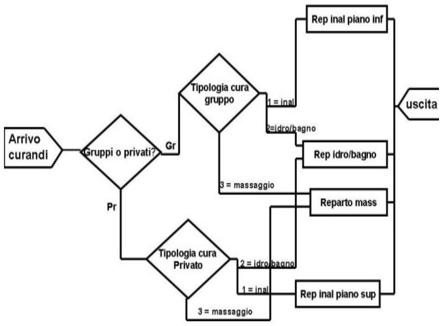

Figure 7: Overview of the logical model of the system

7. SIMULATION MODEL IN ARENA SOFTAWARE

Although the Rockwell Arena software is very powerful, it is also very easy to use. The real system is simulated through the use of blocks, linked together to form a model that reflects the real situation. For more immediate visibility, the model is developed in different modules, which represent the different steps followed by the customer in undergoing treatments.

As mentioned, the entry flow of customers is traced back to a probability distribution derived from information taken from the corporate database on the day which was chosen for simulation. The model is developed in the most general way possible, as is logical for a model that must adhere to reality.

Having extensively discussed the model from the logical point of view, we will now limit ourselves to highlighting only some salient features in order to avoid unnecessary repetition.

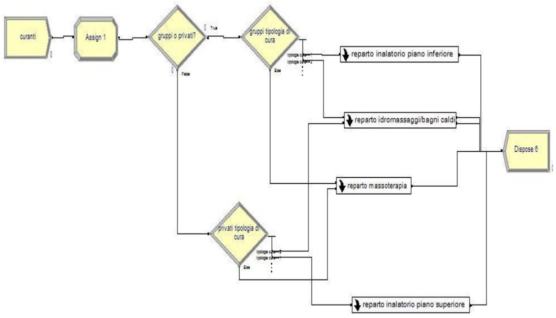

Figure 8: Graphical representation of the simulation model in Arena

Each process, aerosol, inhalation, nasal shower, hydromassage, or massage, has been represented as SEIZE - DELAY - RELEASE. In general, each process module has the ability to perform four different actions: DELAY, SEIZE, SEIZE - DELAY - RELEASE and DELAY - RELEASE. The DELAY action causes a delay of the entity without the need for a resource, the SEIZE action does not release the resource from the entity. In our case, there is an action that requires an entity to be processed and afterwards sets the entity free; SEIZE - DELAY - RELEASE is therefore the most appropriate action. By representing the processes in this way, the queues are managed autonomously by the process blocks according to a FIFO logic without having to introduce a HOLD block, a type of block specifically for the management of the queues. The service times of each process have been represented with a triangular distribution around the average. The values are those recorded during on-site sampling. In the case of the massage department and warm bath and hydromassage department, for the management of the queues we had to introduce HOLD blocks in which an expression of progress of the queue is inserted.

To define the number of runs for any simulation we need to make some statistical considerations. In fact, each simulation provides as output the average value of the variable calculated during the simulation together with the half-width of the confidence interval with which that variable was estimated. Each confidence interval is accompanied by the relative level of significance which is a measure of risk of error in estimating the value of a statistical variable. The range of values between the lower and upper limit depends on the level of probability selected and the sample size. So, although we cannot say if the real value of the variable is contained within the confidence interval estimated, the narrow confidence intervals indicate that the estimate obtained with the sample is an accurate estimate of the variable. All design decisions should be taken based on statistically significant results, which are obtained by increasing the number of runs in order to obtain an acceptable confidence interval with a significance level of 95%, provided by default by ARENA. Therefore, indicating with n_0 a minimum number of runs (at least 10) we have:

$$n = n_0 * \left(h_0 / h\right)^2$$

where h_0 is the half-width of the confidence interval corresponding to the number of replications n_0 (Half-width/Average) and h is 0.05.

We then proceed with the first simulation with ten replications. From the graph we can see that the greatest queues occur in the inhalation department.

Making the necessary calculations, we concluded that in this case we should make 260 replications for each simulation to have a significant estimate for all parameters.

Output

Output	Average	Half Width	Minimum Average	Maximum Average
C_T	13417.37	1.617,63	10637.82	17073.78
costo disservizio	8179.37	1.617,63	5399.82	11835.78
COSTO_INFR	4089.00	0,00	4089.00	4089.00
Tempo_attesa_mass_gr	0.4769	0,09	0.2783	0.6896
Tempo_attesa_mass_pr	0.5490	0,14	0.2616	0.8455
Tempo_attesa_medio_aerosol	1.0076	0,08	0.7096	1.1090
Tempo_attesa_medio_aerosolpr	0.3623	0,05	0.2111	0.4914
Tempo_attesa_medio_bagnocaldo_pr	0.01596383	0,02	0.00	0.06653352
Tempo_attesa_medio_docciana sale	0.02304063	0,00	0.01769247	0.02917486
Tempo_attesa_medio_docciana salepr	0.02198476	0,00	0.01719767	0.02644154
Tempo_attesa_medio_idromassaggio_gruppi	0.2649	0,03	0.1775	0.3180
Tempo_attesa_medio_idromassaggiopr	0.1540	0,03	0.07444875	0.2330
Tempo_attesa_medio_inalazione	0.03902494	0,00	0.03043131	0.05007024
Tempo_attesa_medio_inalazionepr	0.05096267	0,01	0.03459430	0.07347233
tepo_attesa_medio_bagnocaldogr	0.04095608	0,04	0.00	0.1855

Figure 9: Waiting times with 10 replications

7.1. Optimization with Optquest for Arena

The ultimate goal of any mathematical model is not solely to estimate the costs, but to optimize them according to some criteria. Optimization involves defining an appropriate objective function and the related criterion; in fact we must decide if the objective is to minimize or maximize. In our model, the parameter that we want to optimize is the "Total Cost". The value of the objective function will change according to the range of inputs, or combinations of resources. Our interest is to calculate the value of the function for different inputs belonging to a defined domain, and to determine with which input values produce the minimum of the objective function. The total cost function, in this case, is a total daily cost for the simulated day, which can be seen as the sum of three contributions:

- costs of infrastructure resources (aerosol device, inhalation, hydromassage, nasal douche, warm baths, massage cabins);
- cost of human resources (number of operators for each department);
- cost of customer waiting time in different queues.

The cost of infrastructure resources is measured as the product of the unit cost of each available resource and the number of each, all multiplied by a weighting factor. The cost of human resources is measured as the sum of products of the number of operators for each department and the daily unit cost of each operator, again multiplied by a weighting factor. The third rate, that is the cost of inefficiency, has been quantified in order to give weighting to average waiting times in queues that exceed a tolerance limit set to 20 minutes. In particular, the greater the difference between average waiting time in queues, and the maximum tolerated waiting time, the higher the cost of inconvenience of the customers. The three weighting factors are different in order to produce rates with the same order of magnitude, giving slightly more weight to the inconvenience of customers waiting in queue, according to the requirements of the company.

Considering also structural constraints and the budget of costs in a year reported to the day, OptQuest for Arena provides as the best solution (after 1000 simulations, each of them with the optimal number of replications as previously calculated i.e. 260): the addition of 14 new aerosol devices for groups and 4 for private customers, 11 new inhaler devices for groups and 2 for private customers, one more nasal douche for both groups and private customers, one more massage cabin, the removal of 4 warm baths, and the addition of one operator in each department.

With this new resource configuration there is a substantial reduction in the total cost by 45% and in particular, an 11% increase of resource costs corresponds to the significant reduction of about 76% in the cost of inefficiency.

Consequently, because the cost of inefficiency is quantified so as to give weighting to average waiting time in queue for customers exceeding a tolerance limit of 20 minutes, with the new sub-optimal configuration calculated by Optquest according to the variables, constraints and objectives provided as requested by the company, we have significantly reduced the waiting times and therefore obtained a higher quality of service

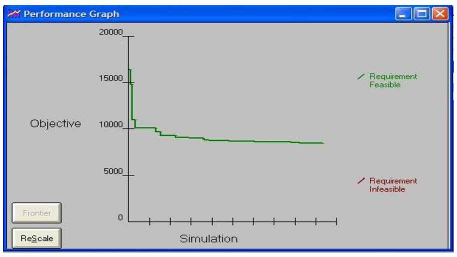

Figure 10: Performance graph

8. CONCLUSIONS

The optimal combination of resources allows minimization of the inefficiencies of service in terms of reducing queues and customer waiting times. The new configuration has lowered the cost of inefficiency in relation to the fact that the average waiting time in queues, and similarly the average number of customers in the queue are greatly reduced. Therefore we can see the importance of the simulation model, which produce considerable benefits both for the company, which can thus use the space available in a more rational way, and for customers due to the reduction of waiting times and therefore the probability that they may not be satisfied by the service. These advantages are not just in terms of space but also in terms of costs.

We believe that the model presented in this project can dynamically assist managers in their vital role, developing the optimal solution for the particular context. Although the results are satisfactory, in the future the optimization could be improved through scheduling of the available resources, so that some resources do not remain active for the entire period of the simulation, but open and close in response to queues. We can also imagine the scheduling of arrivals, creating a kind of call center system so as not to accumulate too many arrivals in one day, and consequently to reduce queues. The main advantage of using a software simulation is the ability to explore different scenarios or new methods without incurring the cost of experiments in the real system. After validating the model, changes can be made and the effects of these can be observed directly on the computer. On the other hand, the model needs to be kept up to date because the company operates in a highly dynamic context and is still evolving, so the operational scenario in a few years could be significantly different from the current one. The simulation model was developed in a very flexible way, allowing input data to be easily changed and adapted to the particular situation of reference. In this way it is possible to enter alternative configurations, change the process times in relation to the acquisition of new technologies, etc. For these reasons, the importance of organizing the system in sub-models is clear.

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D²CTS: A DYNAMIC AND DISTRIBUTED CONTAINER TERMINAL SIMULATOR

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ABSTRACT
The CALAS project (Carrier Laser Tracking System) consists in a laser measure system able to localize precisely straddle carriers within a container terminal. The information given by such a tool makes an optimization possible. As members of the LITIS, our participation in this project concerns the conception and the development of a simulation platform able to reproduce both structure and dynamics of a container terminal. The software must be able to simulate dynamic events occurring during a container terminal day of work. Therefore, we proposed D²CTS, a Dynamic and Distributed Container Terminal Simulator. We will discuss in this paper the modelling process and the possibilities of such a simulator.

Keywords: container terminal, modelling, simulation, dynamics.

1. CONTEXT

With the development of trade activities which have continually increased, container has become the first mode of packaging for exchanging goods. Container terminals have been created all around the world in order to facilitate the transfer between ships and trucks or trains. The performance of these transfers has to be considered to reduce the waiting cost of the container terminal customers.

Le Havre’s harbour is the biggest harbour of France in container traffic. It is located at the North West cost of France, beside the Channel, sea door between the Atlantic and the North Sea. To keep competitive, the harbour has to provide a high quality of service and unceasingly develop new technologies and processes.

To compute optimized solutions for problems such as berth allocation, vehicle routing, mission scheduling or container positioning, the location of entities present within the terminal must be known. GPS systems were traditionally used to locate the vehicles but this technology is not accurate enough regarding the terminal configuration. In fact, the distance between two lanes can be less than the precision of GPS. So more accurate technology have been developed such as differential GPS (DGPS) or laser systems which are much more accurate.

CALAS project (acronym for Carrier Laser Tracking System) concerns a laser localization system created by Laser Data Technology Terminal (LDTT). This project takes place in Le Havre's harbour in France and regroups multiple partners such as industrial companies (*Ateliers de Normandie*, EADS Astrium, Electronic Equipment and D2A), research laboratories (LMAH, LITIS) and universities (University of Le Havre, INSA of Rouen). LDTT's technology is composed by a set of laser data access points spread all over the terminal and laser sensors able to send data such as location, current task, direction, etc. to the optimization system in real time.

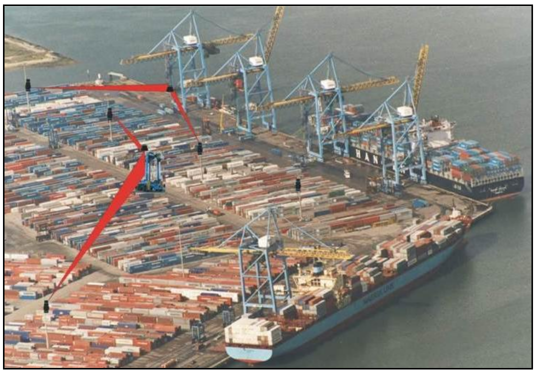

Figure 1: Laser Heads located on the *Terminal de Normandie*, Le Havre, France (source: http://www.ldtt-fr.com/).

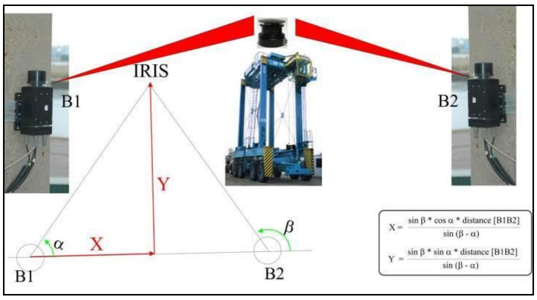

Figure 2: LDTT’s laser localization system (source: http://www.ldtt.fr.com).

D²CTS (Dynamic and Distributed Container Terminal Simulator) is our contribution to this project. It models a container terminal and all the interactions occurring in this complex system. Our purpose was to represent the terminal both in its structure and its dynamics. D²CTS aims at being coupled to the laser data system and at running optimization algorithms dealing with the data sent by the sensors and finally at sending the results to the entities through the communication system.

2. MODEL

As usual with complex systems modelling, the level of precision of the model must be considered carefully. Indeed, a useless level of detail will degrade the performance (Heidemann et al. 2001) and, on the other hand, a lack of detail will generate inaccurate data (Cavin et al. 2002).

We chose to use discrete time to be able to control the level of details in the time dimension. Moreover, to be able to model such a large scaled simulation, we used a parallel and distributed simulation architecture (Fujimoto 2000).

2.1. Container terminal organization

A container terminal is generally divided in three parts. First, the quay side where ships are loaded or unloaded. On the opposite, the land side concerns both trucks and trains. And finally in between these two areas the stocking area (yard) is used to stock temporary containers within the terminal. Each zone is composed by one or several blocks. Each block is formed by a set of lanes. And each lane is composed by a set of slots.

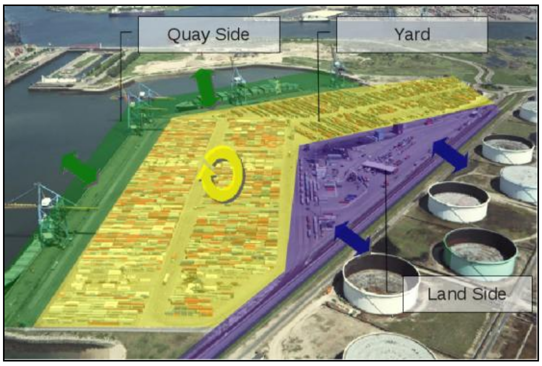

Figure 3: The three container terminal areas.

The trucks area has been modelled by lanes of only one slot able to stack only one container high if and only if a truck is parked at this location. The train areas have also been modelled by lanes of slots of one container high but those lanes can be discontinuous to let other vehicles going through. A container can be stack on a lane of this area only if a train is there too. In the yard area, a slot is generally able to contain a stack of three containers high according to the handling trucks characteristics.

2.2. Container terminal vehicles

As described in (Steenken, Voss, and Stahlbock 2004), vehicles found within a container terminal can be divided in two categories. The first one concerns the customers' vehicles such as trucks, trains or ships. The second one concerns container handling vehicles.

The vertical handling facilities are all the cranes such as quay cranes (or gantry cranes) or stocking cranes. These structures are respectively used to load or unload ships and to stock a container in the yard.

Figure 4: Quay cranes used at Le Havre's harbour (source: http://www.t-n.fr).

On the other hand, the horizontal handling category regroups vehicles able to move a container from a place to another one into the container terminal.

Some of them are passive, that is they cannot load or unload a container by their own means, they generally need a crane. Among these vehicles, the automated guided vehicles (AGV) are able to drive within the terminal thanks to an electric wire network.

On the contrary, the active handling trucks are able to lift a container by themselves. These vehicles are straddle carriers, forklift trucks or reach stackers. Forklift trucks are generally used to handle empty containers whereas reach stackers which can take a container by the side, are used to load containers on a train. Straddle carriers can lift a container from above and are very useful to move containers in the yard by driving over the lanes. They are also used to load or unload trucks or trains. Some of them are able to dynamically adapt the spreader size to any container dimensions while some of them require to be set up in the depot.

Figure 5: straddle carrier, forklift truck and a reach stacker used in the *Terminal de Normandie* (source: http://www.t-n.fr).

2.3. Container terminal road network

The blocks of the terminal are linked by a network of roads and crossroads. We can model it by a directed graph in which the nodes are the crossroads and the edges are both the roads and the lanes.

The two types of edges are handled differently, because two straddle carriers cannot cross when they are on the same lane. That is why lanes are modelled as First-In-First-Out edges (Orda and Rom 1990). Moreover, the capacity of a lane is usually limited to one vehicle at a time. So other vehicles will have to wait for the lane to be freed before using it. This characteristic has a consequent impact on the routing performance and has to be considered by the routing algorithms (Lesauvage, Balev and Guinand, 2011).

2.4. Straddle carrier activities

For the moment, this simulator focuses on the straddle carrier activities. As described above, these vehicles are autonomous and are widely used for this reason. A straddle carrier moves containers within the terminal. Those moves are called missions. We distinguish four kinds of missions:

- Incoming container missions;
- Outgoing container missions;
- Transhipment missions;
- Staying container missions.

The first category concerns trucks, trains and ships unloading. Straddle carriers drive to the pick-up locations and unload the vehicles, and then lift the container, drive to the yard to stock it. Concerning ships, they are unloaded by quay cranes which stack the containers on the quay. Then, straddle carriers come to pick-up the containers. The second category concerns trucks, trains and ships loading. In this case, straddle carriers start by picking-up a container from the yard and then drive to the delivery location (trucks areas, trains area or ship areas) to deliver it to their recipient. The third category of missions concerns the move of a container from a ship to another one. Finally, the last kind of missions concerns internal yard optimization process. Indeed, in some cases, it can be useful to reorganize a part of the stock area in order to reduce further delivery times or to free strategic container slots for next unloading missions.

Two time windows are affected to every mission. One concerns the pickup phase, the other one is related to the delivery. These time windows are used to fix an appointment between straddle carriers and hypothetical customer vehicles (trucks, trains or ships) concerned by the missions. Straddle carriers have to reach the pickup or delivery location within the given time window and so does the customers vehicles. If a straddle carrier comes too early, it will have to wait. On the contrary, if it comes too late, the customer vehicle will have to wait. As a consequence, a time window overrun implies a cost for the terminal because, if a customer has to wait excessively, it may require late fees from the container terminal exploitation company. However, in the case of yard optimization missions, the time windows can be overrun because it has no direct effect on the customers. So, according to the mission kind, time windows can be hard or soft. For incoming missions, the pickup time window is hard and the delivery time window is soft. For the outgoing container missions, the pickup time window is soft but the delivery time window is hard. For transhipment missions, both time windows are hard, and for yard optimization missions both time windows are soft. Those time windows characteristics have to be taken into account in the mission scheduling process (Balev, Guinand, Lesauvage and Olivier 2009).

2.5. Terminal de Normandie

The LDTT's laser system has been first implanted within the *Terminal de Normandie* (Normandy Terminal) in Le Havre. This is the reason why we have first modelled this terminal.

Figure 6: *Terminal de Normandie*, Harbour of Le Havre, France (source: http://www.t-n.fr).

It is delimited at north by the quay of Asia (North West) and the quay of Osaka (North East), and at South by the truck and train areas. This terminal is made up of 1170 crossroads, 170 roads, 531 lanes and 3499 containers slots. The yard contains 12 stocking areas and there are 3 train lanes and 3 truck areas. This terminal has been created in 1990 in order to contain the flow of container exchanges which has grown at a sustained rate. It is able to deal with the biggest container ships.

It uses five quay cranes and a fleet of about twenty straddle carriers. There is no stocking crane in this terminal. So the traffic regulation within the terminal is essential to ensure a sufficient quality of service for the customers. Moreover, if a straddle carrier comes too early at a truck or train location, it will have to wait for the truck or the train to pickup or deliver the container. The vehicles depot is located at the centre of the terminal to reduce the travelling costs to the containers locations. In this container terminal, the straddle carriers do not have to pass by the depot after every mission, but in order to avoid traffic jam, if a straddle carrier has no mission to accomplish, then it will go back to the depot.

In order to model this terminal, a detailed computerized plan has been created based on another rough plan supplied by our partners. The xml description file of the *Terminal de Normandie* resulting from this work contains around 2500 lines just to describe its structure and the road network.

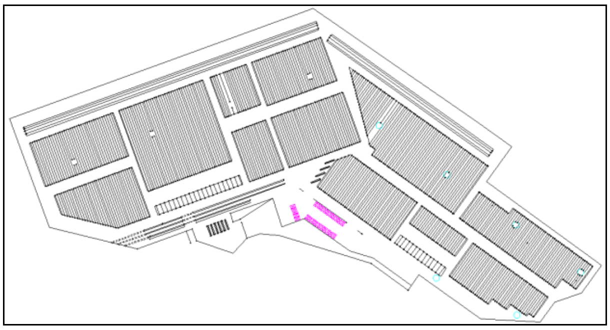

Figure 7: Detailed computerized plan of the *Terminal de Normandie*.

2.6. Dynamics modelling

Time modelling is essential in D²CTS because we aim at studying the dynamics impact on the system behaviour. We chose to use discrete time in order to be able to model events related to the dynamics. Therefore, discrete time allows setting up the time step depending on the desired level of precision and of performance.

As a matter of fact, a container terminal is a complex system made up of a large number of entities interacting with each other's and changing the state of the terminal at every moment. This system is also open, and external flows come in and out, making it to change. These flows concern trucks, trains and ship arrival/departure. Moreover dynamic events can occur within the container terminal such as handling vehicles or cranes failure, mission arrival into the system, mission cancelling, container lost, and every events generated by the human behaviour such as the failure to adhere to the mission schedule or the routing paths. The events are modelled by a start time stamp, a system knowledge time stamp and a description. When the simulation time reaches the time of a start time stamp, the event is triggered.

3. IMPLEMENTATION OF THE MODEL

3.1. What does D²CTS do?

D²CTS is able to model a container terminal and its dynamics. So it is able to perform some tests about:

- the terminal architecture;
- the terminal communication architecture;
- the vehicles routing;
- the vehicles fleet size;
- the mission scheduling;
- the containers location;
- the containers traffic absorption capacity.

Indeed, the program allows changing the configuration of the terminal itself. We can for instance decide to add a depot or to remove a stocking area and measure the consequences on the terminal evolution. It is also possible to add roads in the network or to remove some of them to test the impact of such modifications on the traffic within the terminal.

Moreover, several routing algorithms can be used. The Floyd-Warshall's and Dijkstra's algorithms (Floyd 1962, Dijkstra 1971) have already been implemented. Furthermore, we developed a routing algorithm based on the Dijkstra's algorithm, taking waiting time and FIFO arcs into account.

D²CTS can also be useful to perform some tests on the size of the straddle carriers' fleet. Indeed, a straddle carrier is very expensive and such an outlay has to be considered carefully. So, D²CTS can run two simulations: a first one without adding the new straddle carrier, and a second one with the new vehicle. Then, the both results can be compared to help the decision makers to reduce the risk factor related to such an investment.

In the same way, several mission scheduling policies or containers location strategies can be tested thanks to the simulator.

3.2. Technology and generic programming

D²CTS is written in Java which ensures a large flexibility in coding and executing the program. The distribution process uses the Java RMI technology and all the data are described by XML files. It concerns the terminal structure and road network, the vehicles characteristics, the containers location, the dynamic events and the program distribution.

The graphical user interface uses the GraphStream API (Dutot, Guinand, Olivier and Pigné 2007) which is an open-source library developed within the University of Le Havre and able to model and draw dynamic graphs. On the other hand, EADS Astrium, our partner within the CALAS project has developed a 3D graphical user interface able to simulate the driving of the straddle carriers. It uses data sent by D²CTS through a database to reproduce the container terminal structure and components. The actions realized within their program are also reproduced within D²CTS thanks to the database interconnection.

The program architecture is based on a modular paradigm. It means that the simulator contains a kernel connected or not to other parts. This approach has the benefits to ensure a high flexibility for developing new modules and for adapting the simulator to the users' expectations. Thus, it is possible to run D²CTS without graphical user interface or, for instance, to perform some tests with different routing algorithms.

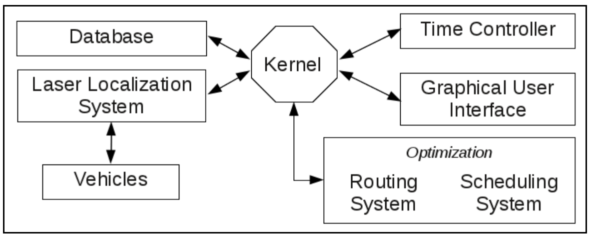

Figure 8: D²CTS architecture.

The available modules are:

- the kernel;
- the time controller;
- the 2D graphical user interface;
- the laser localization system;
- the vehicles routing algorithms;
- the missions scheduling algorithms;
- the automated vehicles component.

Figure 9: Time controller GUI snapshot.

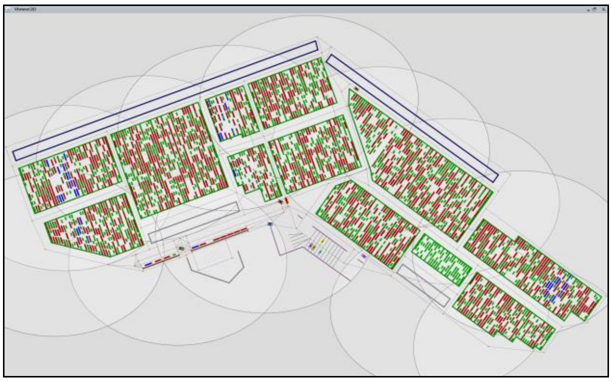
Figure 10: D²CTS 2D GUI snapshot of a simulation using the *Terminal de Normandie*.

Data (@localhost)

Missions | Reservations | Slots | Laser System | Straddle Carriers | Containers

ID	CONTAINER	PICKUP_TW	TARGET	DELIVERY_TW	VEHICLE	STATUS
load_truck...	XDBU 848468 5	[00:01:20.54 - 00:03:20.54]	D-15/21-0	[00:03:51.00 - 00:05:17.00]	cav7	Achieved
stockMissi...	EKFU 493901 8	[00:03:27.00 - 00:05:16.10]	K-4/25-4	[00:05:28.38 - 00:07:17.48]	cav6	Achieved
stockMissi...	HZAU 092517 6	[00:03:34.00 - 00:04:40.69]	J-1/41-4	[00:04:58.50 - 00:06:05.19]	cav9	Achieved
unload_tr...	ICZU 335387 4	[00:03:41.49 - 00:05:32.23]	H-11/35-7	[00:04:28.47 - 00:06:42.71]	cav6	Delivery
stockMissi...	SFOU 789718 5	[00:05:02.00 - 00:07:21.19]	A-29/40-3	[00:08:08.56 - 00:10:27.74]	cav5	Delivery
load_truck...	OTXU 954041 8	[00:06:05.27 - 00:08:33.27]	L-8/13-0	[00:09:42.00 - 00:11:04.00]	cav1	Delivery
stockMissi...	QBPU 682638 9	[00:06:58.00 - 00:08:24.59]	N-38/42-0	[00:09:07.19 - 00:10:33.77]	cav5	Waiting
unload_tr...	KRHU 379452 8	[00:07:21.00 - 00:09:12.00]	A-21/40-4	[00:10:18.11 - 00:12:06.11]	cav3	Pickup
stockMissi...	RSAU 166615 4	[00:07:36.00 - 00:09:24.58]	G-1/34-0	[00:09:41.36 - 00:11:29.94]	cav9	Pickup
load_truck...	PRQU 711226 1	[00:07:38.55 - 00:09:52.55]	D-16/21-0	[00:10:25.00 - 00:12:49.00]	cav2	Pickup
stockMissi...	TXOU 076984 5	[00:11:05.00 - 00:12:13.63]	I-23/73-1	[00:12:39.60 - 00:13:48.23]	cav8	Waiting
unload_tr...	GWRU 040141 9	[00:15:56.10 - 00:23:54.14]	H-33/35-2	[00:17:07.33 - 00:25:40.99]	cav5	Waiting
stockMissi...	AMOU 643982 2	[00:17:10.00 - 00:18:31.95]	J-21/41-6	[00:18:57.44 - 00:20:19.39]	cav7	Waiting
load_truck...	FBPU 935053 1	[00:18:55.70 - 00:21:17.70]	L-12/13-0	[00:21:36.00 - 00:23:52.00]	cav10	Waiting
unload_tr...	IRDU 854993 8	[00:23:26.16 - 00:35:09.24]	A-14/40-0	[00:24:34.24 - 00:36:51.35]	cav4	Waiting
stockMissi...	BRLU 191269 1	[00:29:40.00 - 00:31:35.76]	I-10/73-2	[00:31:15.57 - 00:33:11.33]	cav4	Waiting
stockMissi...	YWYU 080821 6	[00:33:11.00 - 00:35:22.91]	C-8/41-10	[00:35:14.88 - 00:37:26.79]	cav6	Waiting
unload_tr...	XJMU 036825 1	[00:59:31.21 - 01:29:16.82]	C-15/41-6	[01:00:19.56 - 01:30:29.34]	cav1	Waiting
unload_tr...	LXGU 150609 0	[01:20:05.97 - 02:00:08.96]	K-2/25-5	[01:21:18.44 - 02:01:57.67]	cav8	Waiting
unload_tr...	BYHU 274353 4	[01:20:17.76 - 02:00:26.65]	J-23/41-5	[01:21:15.26 - 02:01:52.90]	cav10	Waiting
load_truck...	KSVU 052989 1	[01:24:26.49 - 01:25:38.49]	L-9/13-0	[01:26:05.00 - 01:26:45.00]	cav4	Waiting
unload_tr...	QRUU 201002 1	[01:31:02.22 - 02:16:33.33]	M-53/62-1	[01:32:51.26 - 02:19:16.89]	cav7	Waiting
unload_tr...	VIEU 969933 1	[01:31:15.00 - 01:31:56.00]	M-57/62-3	[01:33:40.90 - 01:34:10.90]	cav10	Waiting
reload_tra...	CRVU 910096 7	[02:02:41.72 - 03:04:02.59]	train3_4/4-3	[02:03:30.80 - 03:05:16.20]	cav3	Waiting

Figure 11: Snapshot of the missions tab of the D²CTS data view.

These modules can be executed on several and heterogeneous computers. The distribution process uses Java RMI technology which implies a serialization of the remote objects. But the data sent through the network can be weighty; this is the reason why the distribution configuration must be handled carefully. A bad configuration implies high communication times and the performance might drop.

3.3. Configuration

D²CTS uses XML files to describe its configuration. The files concern the network and the distribution configuration, the terminal description (stock and exchange areas, road network, vehicles depot, containers location...), the laser localization system description (laser heads location and range), and the vehicles description, location, and behaviour. Those files are then parsed by the simulator which creates corresponding objects according to the description.

3.4. Vehicles handling

In the simulator, a straddle carrier can be either autonomous or man-driven.

In the first case, the straddle carrier behaviour is handled by the software which checks objectives at each step of time. If the objective is not reached, then a direction is computed and the straddle carrier makes a move towards it. Else, a new objective is computed.

In the second case, the straddle carrier is driven by a user through the EADS Astrium 3D interface. So, the simulator supplies a mission workload, the routing paths to these locations, and just checks the new location of the straddle carrier trying to detect if the vehicle is following its given path. If an error is detected the path has to be recomputed. Moreover, if an event occurs concerning the road network or mission scheduling, new routing solutions are computed and sent to the concerned vehicles.

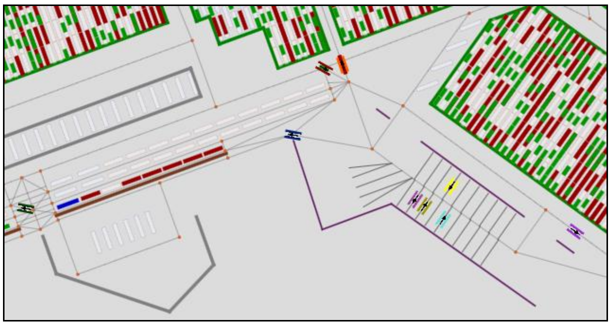
Figure 12: Straddle carriers 2D implementation in the simulator.

A straddle carrier can also generate some events such as failures or the impossibility to pick-up or to deliver a container at a given location. These events occur when the state of the terminal in the data structure does not fit with the reality. It may happen if a straddle carrier driver chose a mission and decide to change but without advising the system. So, the system becomes corrupted and the errors can be detected much later. D²CTS aim at detecting incoherencies between a supposed behaviour of a straddle carrier and its real actions. If such incoherencies are detected, the system tries to repair them if it is possible. Otherwise, a communication between the straddle carrier driver and the control operator is required to take decisions and acting on either the straddle carrier activity or the system knowledge of the terminal state.

3.5. Test data generation

Another module has been developed within D²CTS in order to generate realistic data. It concerns the starting state of a terminal and events generation.

The container generator is used to create containers and to locate them within a given terminal. The algorithm makes sure that the container can physically be placed at the computed location. The corresponding XML file is then generated.

The mission generator role is to provide missions events within a given period of time and according to an initial state of a terminal. It generates ships, trucks and trains arrival and departure. The algorithm makes sure that the vehicles location will be free at the arrival time. Next, it computes which containers have to be loaded or unloaded. Finally, the time windows for both pickup and delivery operations are calculated by taking into account the travel time between those locations. A time margin is next added to let a relative tolerance to fit with reality constraints. The events are finally written in a XML file which can be added for further simulations.

4. CONCLUSION AND PERSPECTIVES

D²CTS is a container terminal simulator able to reproduce dynamic events and to perform tests concerning optimization matters such as the terminal architecture, the vehicles routing or the mission scheduling. It is fully adaptable thanks to a XML data description structure and distribution configuration.

The calibration of D²CTS will consist in representing the state of the terminal at the very beginning of a working day. Then, the validation will consist in running the simulation taking into account the real events occurring in the working day at the container terminal and finally by comparing the state of the real terminal and of the simulated one at the end of the day.

We are currently developing routing algorithms taking into account the graph properties of a container terminal road network. We are also creating mission scheduling policies based on meta-heuristics. Those problems are defined as NP-hard (Bish, Leong, Li, Ng and Simchi-Levi 2001) and only a simulation approach could propose an integrated solution for all the concerned subsystems (Soriguera, Espinet and Robuste 2006). The next step of our work will consist in measuring the performance of these algorithms thanks to D²CTS.

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SIMCONT – THEORY AND PRACTICE IN SIMULATION OF BINNENLAND CONTAINER TERMINALS

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ABSTRACT
In this paper we show the SimConT approach in símulation of Binnenland Container Terminals (BCT). SimConT was used during the last years in several projects on capacity evaluation of BCT. During these works we collected some experiences on how to carry out simulation studies for BCT. Especially, main important steps are data collection of infrastructure, train related and load carrier data. Secondly, the detailed operation of the yard and finally during the analysis phase to adapt the study steps to the marginal productivity rate of the BCT. We will provide a guideline for conducting the simulation studies and connect it to the theoretical architecture of the SimConT simulation model(s). The guidelines also focus on how scenarios for the up following simulation runs are constructed in order to reach the marginal rates of the yard. During the works we were also able to identify relevant key data and indicators reflecting the BCT's performance. These indicators may be used for comparing the performance of different sites.

Keywords: Binnenland Container Terminal, rail-rail and rail-truck terminal, simulation study approach

1. INTRODUCTION
Inland container terminals hold a crucial role in modern supply chains, as they are the essential transshipment points for containerized freight between transport modes by land and sea, and function as feeder terminals for open sea terminals. Given the increasing importance of inland terminals and increasing flows of goods, rail transport must be strengthened as favoured mode of transport. Over the last years a simulation tool called SimConT was developed which is tailored to the special characteristics and requirements of inland container terminals. The tool allows for strategic and tactical simulation of terminal infrastructure and operations. By means of simulation, decision makers are actively supported in planning processes, while minimizing the risk of bad investments and stranded costs when planning and (re)building terminal infrastructure and enlarge terminal capacity.

BCT mark the peripheral nodes in efficient freight transport. They distribute and collect containers and other intermodal load carriers like swap bodies and 'liftable' semi trailers. BCT receive and ship containers from sea terminals, another BCT or from local industries. In BCT Intermodal Transportation Units (ITE) usually represent a mix of the above mentioned load carriers. We can observe that in the recent past the portion of liftable trailers was steadily increasing. This is an effect of increasing intra European freight transport modus shift from road to rail.

All over Europe there are approx. 800 BCT of different sizes and networks roles operating in the intermodal transportation network. An ongoing change in European transport infrastructure also leads to requirements to adapt BCT to new tasks.

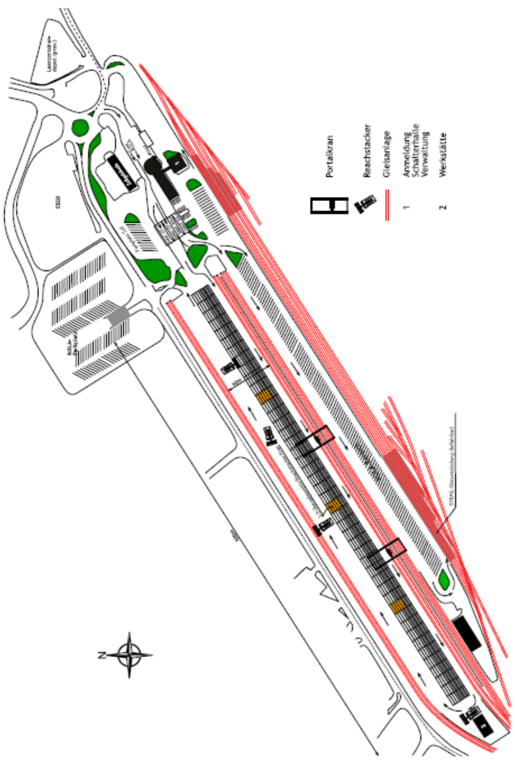

Figure 1: BCT Layout

One key element in the operation of these BCT is the organization of ITE – exchange. We denote this as operation strategies (Benna and Gronalt, 2008) for

BCTs. The second element which contributes to the performance of BCT is infrastructure: rail yard tracks, cranes, stacker for single or multi terminal environment and terminal infrastructure network for movement of stackers, trucks, terminal tractors and storage capacity and portion of dedicated storage areas of the BCT. In **Figure 1** a typical BCT Layout is shown.

Further, we have to consider the arrival pattern of trains and trucks, the ITE-mix on trains and the relation between import and export ITE as order systems of the BCT. Figure 2 shows how these elements are used as a standard input for SimConT Simulation module in order to analyze BCT performance.

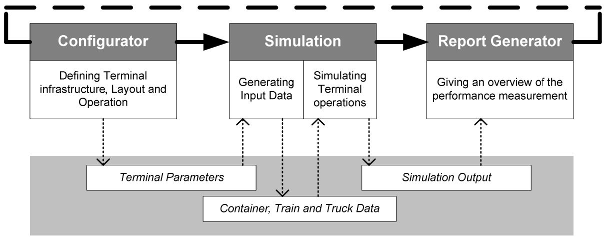

Figure 2: SimConT modules dependencies

2. METHODS AND TOOLS FOR ANALYZING BCT

Several authors propose analytical approaches, mainly MILP models for selecting various design options for rail-rail and rail-road terminals. Boysen et al. (2010) propose a dynamic programming approach, to determine yard areas for gantry cranes for balancing workload in order to improve the operation of the cranes. Wiese et al. (2011) describe different technologies in container terminal operation and their impact on the terminal layout. For a layout which is typical for the use of automated rail-mounted gantry cranes they propose a procedure to calculate promising storage yard configurations.

Simulation as an evaluation method has also been studied intensively. Studies can be grouped into two categories. The first category concentrates on a certain subarea (see Yang et al. 2004), while the second category models the whole container terminal (see Gambardella et al. 1966; Lee et al. 2003; Parola and Sciomachen 2004). This last category is rather comparable with our approach (Benna and Gronalt 2008). But due to the fact that nearly all relevant papers are devoted to open-sea Terminals, activities around the ship berthing, loading and unloading play a predominant role in the studies and are reflected in the process of goal setting, which is less suitable for our purpose. In fact, in BCTs activities and goals are rather centered on container shipment by railway. To summarize our literature review, it should be mentioned that only few research is done on the special nature of binnenland container terminals.

3. SIMCONT – ELEMENTS

We have both developed a simulation system (SimConT) and a procedure how to stepwise evaluate the capacity of a particular BCT. The approaches are interdependent and we will now first present the SimConT elements and further show how we are using them on a detailed simulation case study. SimConT is both a concept and a simulation tool completely coded with Java Classes and supplemented by AnyLogic statecharts functions.

3.1. Terminal Configuration

The terminal configuration prepares the detailed layout of the terminal, the gates, parking areas inside and outside the terminal, loading and storage areas and all the distance and time related data. This is completed by opening and operating hours of the terminal.

For the terminal equipment it is necessary to define its operations modes and ranges. For this an assignment of tracks and storage areas has to be defined and detailed operation plan for each of the various equipment is applied.

The terminal is dominated by the train schedule and the flow attributes of the ITEs. The daily arrival distribution of trains, their lengths and ITE-mix must be defined clearly and flexible for further adjustments. Also the operation mode (floating or fixed) for the trains generally and/or in particular effects the terminal capacity and must be provided as a system's input. Figure 3 shows the activity diagram of exporting containers with trucks.

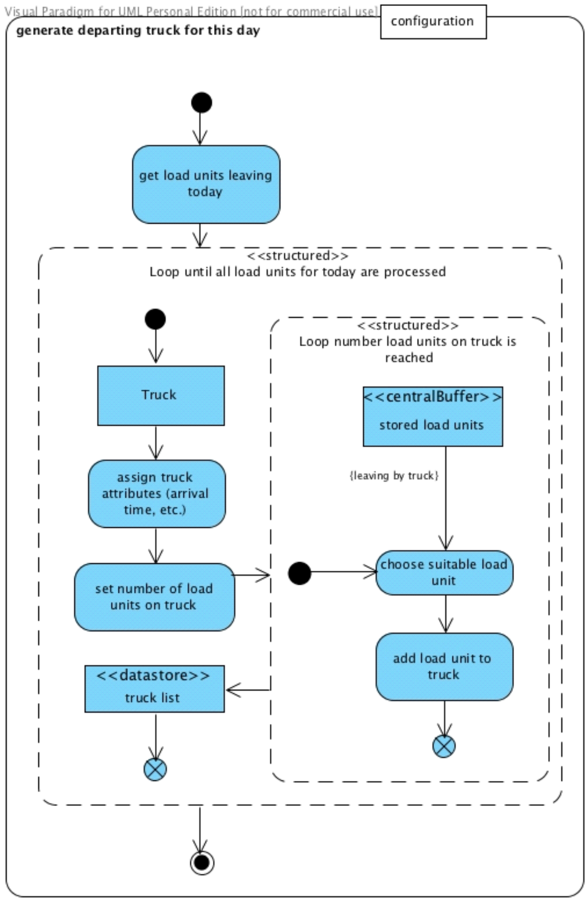

Figure 3: Modelling of daily truck arrival

For particular ITEs the in- and outflow in the system, planned storage time, dedicated storage areas, stacking attributes and required handling equipment must be defined.

The above presented data and dependencies are stored and provided in a database outside the simulation. It used as a generic input for the simulation and is application driven adapted. For example, it is necessary to work with a variable portion of non stackable trailers in BCT due to an increase of intra-european freight traffic.

Figure 4 shows some selected configuration parameter the corresponding simulation logic and attributes.

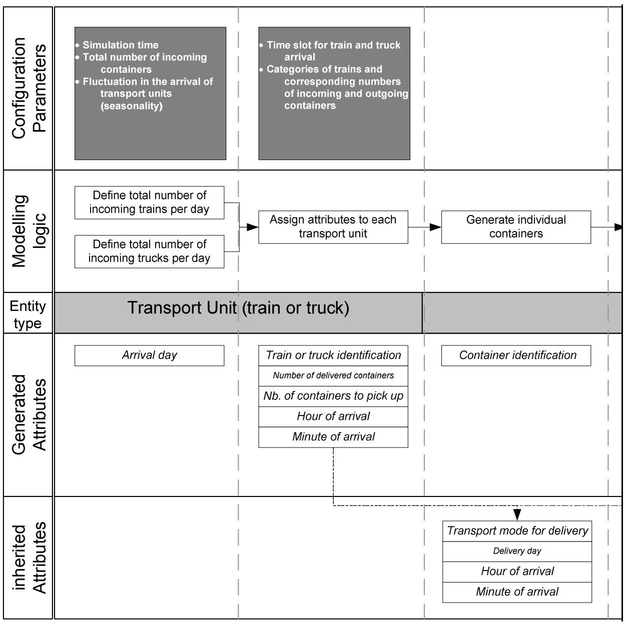

Figure 4: Configuration parameter and attributes of simulation entities

3.2. Simulation model

The simulation model for conducting various experiments is coded with Any Logic, where the main control processes are implemented in state chart logic. As depicted in

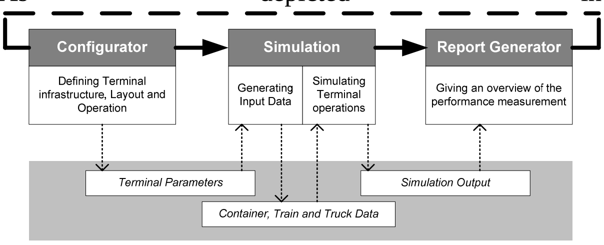

Figure 2 the first phase of the simulation is generating input data for the simulation model. This iteration makes the simulation application specific. According to the terminal configuration database the main elements of the simulation logic can be divided in

- Flow control,
- Handover control,
- Track control,
- Equipment control and
- Storage control.

Figure 5 provides the storage control state chart. It selects the next possible storage spot for the specific ITE at hand. Clearly, the simulation model provides spots classes for controlling the storage areas.

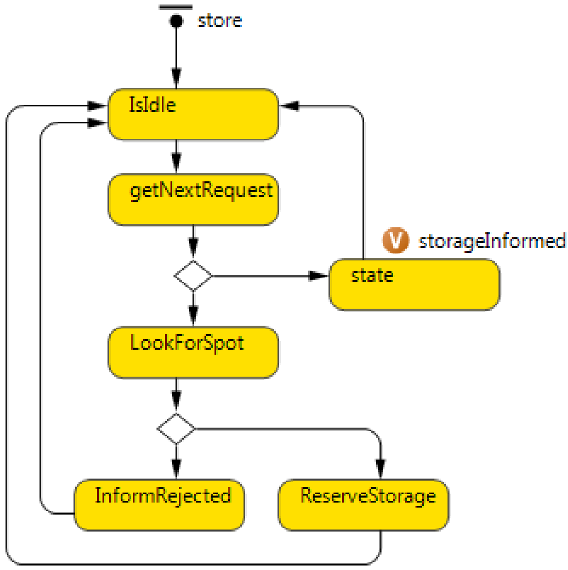

Figure 5: Storage state chart

In the following figure we show the state chart for the equipment class. It displays the state transitions of cranes in the terminal. The supporting evaluation functions like pickTime(), dropTime(), chooseNext() which are responsible for the efficient movement of the cranes are not shown here.

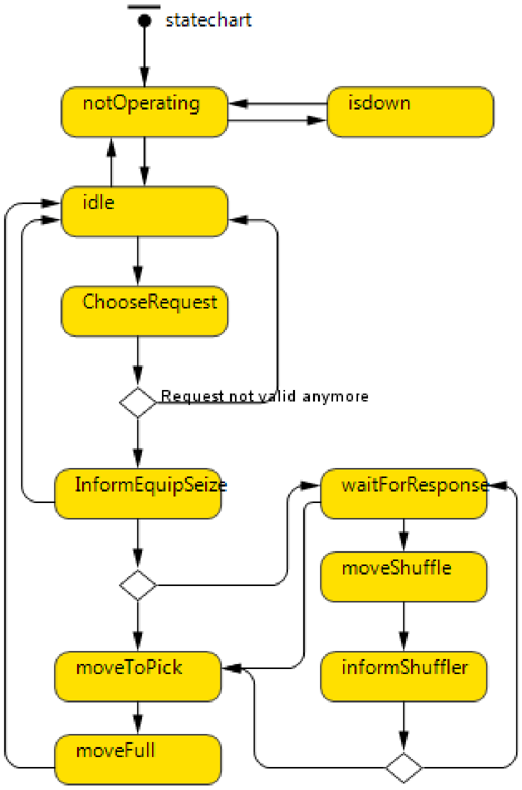

Figure 6: Crane state chart

We have validated our approach during the conceptual phase with three different BCTs. One further essential element is the simulation output generation which is presented in the next section.

3.3. Simulation Report

The simulation report puts together the simulation expertise with the BCT process knowledge to extract the most relevant performance figures. For SimConT we decided on the following concept on report generation.

Basic Indicators describe the BCT in general. Regarding the terminal infrastructure we focus on the following data:

- storage capacity of loaded containers, empty container, trailers and swap bodies,
- total storage capacity,
- number and length of tracks,
- number of cranes per terminal unit,
- number of stackers,
- number of gates and
- number of container handover places.

For the infrastructure related indicators usually utilization measures are evaluated in the reports. These can be defined both static and over the time. Especially for the cranes the portion of service lifts are reported.

In addition the terminal operation and container flow are also considered in the standard report. Basic set of indicators contain the number of import and export container per time unit and the portion of train and truck deliveries. According to these data, flow time indicators for containers, trucks and trains are reported. The set of basis indicators may be extended according to the specific requirements of the application. For example for new terminals the truck queue in front of the gates are important to estimate the traffic jams caused by the terminal.

4. SIMULATION STUDIES

Simulation experiments are used to evaluate system's performance over time. Beside statistical issues like simulation run length, warm-up periods and number of replication and others it is further essential to consider specific terminal requirements. These may be related to the role of the terminal in the freight network (gateway, feeder, hinterland, industry supply) or the portion of empty container for exchange with industry or development possibilities of the terminal like additional terminal units. According to the role of the terminal we found different procedures on how to improve terminal's performance.

In the first step of the simulation study we use the generic SimConT models as shown in Figure 2 in order to simulate a Basis Scenario. Before we conduct the simulation experiments we apply the configuration steps in order to generate the data for terminal infrastructure, layout and operations strategies. For these it is especially important to build reliable train schedules. The data generated were validated with terminal operator and it also assists in defining the goals and varying parameters to guide the simulation experiments. For these the standard reports are extended to fit the simulation application. Usually we use order data for one month as model input and generate the simulation data for the simulation period (e.g. one year).

The second step usually consists of the first simulation experiments for a new or existing terminal to calibrate the simulation to application specific restrictions. The simulation results (report) are analyzed for critical or near critical performance values. If the model is calibrated we can now define future simulation scenarios. Some elements which may be used to define scenarios are listed below:

- train length,
- arrival frequency of trains,
- relation of direct exchange containers,
- dedicated storage for containers/swap bodies/trailers,
- number of terminal tractors and
- portion of liftable trailers.

This iteration - definition of scenario parameters and simulation - is run again and again until the performance shows stable results and no further infrastructure options should be considered. In the last section we will now present the results of a real life case. We show the results with modified data.

5. CASE STUDY – TERMINAL A

The starting point for this was the renewal of the BCT network in Austria (see Gronalt et al 2010). For this, a performance analysis of existing and new terminals is required. We discuss now the procedure to support the infrastructure investment decisions for a specific industry supply terminal. The terminal handles a large amount of empty containers.

The current configuration of the terminal was used as a baseline and compared to two improved terminal layouts. By doing this we defined some scenarios with increased transshipment volumes in order to figure out the marginal capacity of the terminal. The key figures of the starting configuration and the simulated layout variants are summarized in Table 1.

Table 1: Key terminal figures

	Current Layout	Layout 1	Layout 2
storage capacity loaded container (TEU)	570	479	1277
storage capacity empty container (TEU)	1450	2773	3582
total storage capacity (TEU)	2020	3252	4858
number of tracks	6	4	4
track length	1310	2000	2240
cranes	1	2	2
stacker	2	2	2
truck parking area	9	15	20
gates	1	2	2

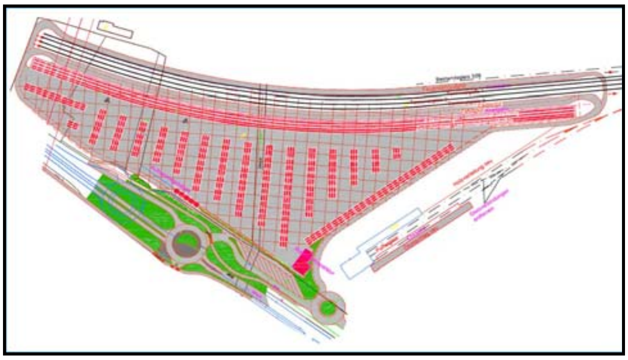

Figure 7 displays the layout and storage blocks for terminal layout 2. Handover spots are located near the tracks for direct rail-truck transshipment. The number of transshipment points is restricted and also the number of trucks inside the terminals was controlled in order to prevent jams in the terminal.

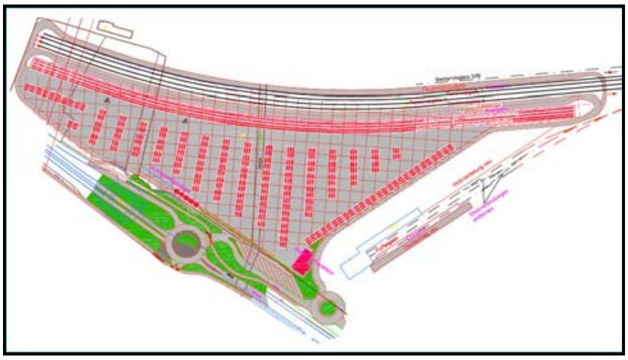

Figure 7: Case study - Terminal Layout 2

For terminal layout 2 an increase in transshipment volume was simulated in order to determine the marginal capacity of this layout. The volume increase was modeled by a higher train arrival rate and by the number of container per train. The consolidated figures are given in **Table 2**.

Table 2: Increasing transshipment volumes

Scenario 2	increase arrival rate	+ increase volume	increase
2.1	*(+ 5%)*	*(+ 16%)*	**21%**
2.2	*(+ 10%)*	*(+ 18%)*	**28%**
2.3	*(+ 15%)*	*(+ 20%)*	**35%**
2.4	*(+ 20%)*	*(+ 22%)*	**42%**
2.5	*(+ 25%)*	*(+ 24%)*	**49%**

For each scenario a simulation was made with a run period of one year for smoothing seasonal fluctuations in the results. The simulation runs were replicated 20 times to eliminate stochastic disturbances.

Figure 8 shows the crane utilization rates for these different volume increase scenarios. It can be seen that for the current volume which is at the limit of the existing terminal's capacity, the new layout will be able to handle these volume very easily. But a 42% increase or above leads to near critical crane average utilization of about 70%. We also can notice that we may have some opportunities to raise the capacity if we can change train schedules. Further improvements are possible by new crane movement strategies.

6. CONCLUSIONS

In this paper we provided our point of view in conducting simulation studies with the generic BCT simulation tool SimConT. We can conclude that this approach is very suitable for analyzing the performance of binnenland container terminals.

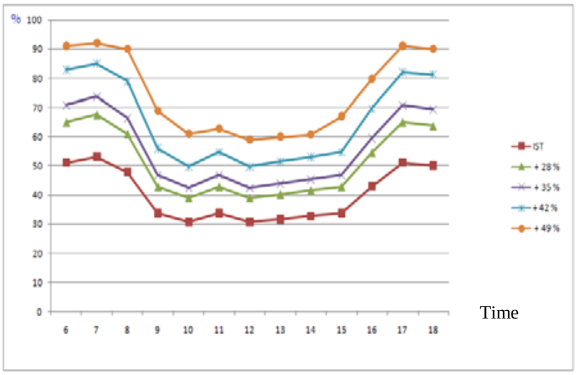

Figure 8: daily development of crane utilization and volume increase scenarios

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IMPACTS OF VENDOR MANAGED INVENTORY ON BUSINESS PROCESSES - DEMONSTRATION AND PROCESS REFERENCE MODELING

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ABSTRACT

In order to improve their inventory management a growing number of *SME*'s plan to implement *Vendor Managed Inventory (VMI)* with supply chain partners. This means, they have to coordinate their business processes with their partners. The impact of *VMI* on business processes is frequently underestimated and hence the implementation of *VMI* fails. However, the use of process reference models for implementing *VMI* can lead to successful implementation as they offer best practice processes, which support the adoption of processes to a supply chain concept. An example for that is *LogWIN-P*, which has a high level of detail and is easily adaptable to processes of companies of different sizes and industries. The *LogWIN-P* model was extended to provide support for *VMI* implementation. This model thus describes the *VMI* process and shows the impacts of *VMI* on company's business processes and points out the required process-modifications.

Keywords: Vendor Managed Inventory, Business Process, Process Reference Model, Supply Chain Concept

1. INTRODUCTION

Due to globalization companies are doing business with partners all over the world to meet the needs of the end-user. Consequently, the companies develop closer cross-organizational relationships with their suppliers and customers and realize collaborative supply chain concepts like *Vendor Managed Inventory (VMI)*.

For the supplier *VMI* can reduce demand uncertainties for the production planning and improve forecasting. For the customer it ensures the availability of goods in the warehouse and reduced inventory and costs. Consequently, *VMI* improves the performance of the supply chain (Fisher 1997, Whipple and Russell 2007, Bernstein, Chen, and Federgruen 2006, Werner 2008, Schulte 2009).

However, the adoption rate of *VMI* is not as high as these associated benefits may lead us to expect, as a longitudinal study by the *Upper Austria University of Applied Sciences* in *Steyr* and the *Upper Austrian Chamber of Commerce* with 168 small, medium and large companies of the sectors trade and commerce, industry, information and consulting and transportation, showed (Humpl and Starkl 2009).

The study revealed that nearly half of the companies consider supply chain concepts (*VMI, Cross Docking, Just-in-Time*) as well as warehouse and identification technologies (*WMS, RFID, Barcode*) as important or very important for their business. However, only one fifth of the surveyed companies plan, optimize, coordinate and implement processes with their suppliers. Especially small and medium enterprises (*SME*) do not or only rarely coordinate and cooperate with partners. *SMEs* have to close this gap by developing knowledge about these concepts and evaluating their potential benefits.

It is especially difficult for small and medium enterprises to estimate the potential of *VMI*. They do not know which business processes are affected by *VMI* and how to integrate this concept into their business reasonably and successfully (Niranjan, Wagner, and Thakur-Weigodl 2011).

To support the implementation of *VMI* a best practice process model is needed, which helps companies to estimate the effects on their current processes, shows the required process-modifications and points out the differences to the conventional processes without *VMI*.

Therefore, an enhanced process reference model concerning *VM*I was developed which is based on the existing standard reference model *LogWIN-P* (Ortner, Rothböck, Stüger, Unterbrunner, and Wallner 2005) and is called extended-*LogWIN-P_VMI*. Hence *LogWIN-P_VMI* offers a good foundation and support for implementing *VMI* and shows the advantages of redesigning business operations.

The remainder of this paper is structured as follows: In chapter 2 we discuss related work by describing different versions of *VM*I and the use of process reference models. In chapter 3 we introduce the research methodology that includes a literature study and an empirical part. In Chapter 4 we describe the impacts of *VMI* on business processes and the differences to the product and information flow of a traditional individual order. Finally, we draw conclusions and point out our plans for future work.

2. RELATED WORK

Since in this paper we introduce a process reference model that shows the differences of traditional processes to *VMI*, this section presents *VMI* (2.1) and provides an overview of existing process reference models (2.2).

2.1. Vendor Managed Inventory (VMI)

VMI is a *Supply Chain Management* concept that is part of *Efficient Replenishment*, which aims at replenishing the goods continuously. *Efficient Replenishment* belongs to *Efficient Consumer Response (ECR)*, which focuses on collaboration of supply chain partners to satisfy customer needs (Arnold, Kuhn, and Furmans 2008, Hieber 2002). *VMI* assumes that the vendor takes over the responsibility for directly and independently replenishing the inventory of its customers without waiting for replenishment orders (Wannenwetsch 2010, Mentzer 2001).

Beside *VMI* the three cooperation concepts *Buyer Managed Inventory (BMI), Co-Managed Inventory (CMI)* and *Supplier Managed Inventory (SMI)* also belong to *Efficient Replenishment* (Arnold, Kuhn, and Furmans 2008, Wannenwetsch 2010).

As the four forms of *Efficient Replenishment (VMI, BMI, CMI* and *SMI)* are often used synonymously, we further use the term *Vendor Managed Inventory* for all three concepts.

Primarily all *Efficient Replenishment* concepts are characterized by close relationships (Alicke 2005) between the supply chain partners and aim at creating benefits for all partners such as (Kuhn and Hellingrath 2002, Mentzer 2001, Arnold, Kuhn, and Furmans 2008)

- reduction of transaction costs,
- optimized and integrated inventory management and reduction of inventories,
- efficient, value added and lean processes,
- enabled expeditious and flexible reaction on occurring demand modifications,
- competitive capability,
- reduced uncertainties concerning customer requirements and
- increased supply and service rate.

Concerning the successful implementation of *VMI* the *ETH Zurich* developed a checklist to assess the readiness of companies for *VMI* (Niranjan, Wagner, and Thakur-Weigodl 2011). But this checklist does not provide information which process modifications need to be done when implementing *VMI*. Best practice processes of a reference model can close this gap and support a successful realization of *VMI* (Becker, Kugeler, and Rosemann 2005).

2.2. Process Reference Models

Reference models are a composition of approved best practice processes and theoretical knowledge about business processes that can be used as guidance models by companies for modeling their own business processes (Becker and Delfmann 2004, Schulte 2009).

These reference models are characterized by various properties. Hinkelmann (2008) states that reference models illustrate structures, properties, relations and behavior of objects of a specific application domain in a generally accepted and applicable form. Consequently they (Becker and Delfmann 2004, Schulte 2009, Corsten and Gössinger 2001, Nikodemus 2005)

- serve as guidelines,
- are generally accepted,
- provide a basis for further development of company-specific models,
- are used as an analysis and optimization tool (i.e. weak-point analysis) and
- are used for optimization of existing models.

To provide these capabilities reference models have to fulfill high requirements. They should not be too general, because they would not provide enough guidance for the development of company-specific implementations of these processes. On the other hand they should not be too precise either, as they have to be applicable for different situations and companies. In addition, they must not be influenced by market changes which ocurr or other external influences, but have to be flexible, as they must be individually adaptable and expandable (Schulte 2009).

Especially for the area of *Supply Chain Management* the *Supply Chain Operations Reference (SCOR)* model was developed by the *Supply Chain Council (SCC)*. It is a reference model which is based on a framework that links business processes, best practices and technology features and aims at reproducing the supply chain in a transparent way. Generally, reference models of various areas and for different purposes are existing, such as *ITIL* or *SAP*, but for the area of Supply Chain Management *SCOR* is very famous and aims at implementing state-of-the art systems and practices (Supply Chain Council Inc. 2010).

Another process reference model in the area of *Supply Chain Management* is *LogWIN-P,* which was developed by the research institution *Logistikum* of the *University of Applied Sciences* in *Steyr/Austria*. It is an intersectoral model which is applicable for any industrial company and gives a current description of process steps and interfaces in great detail (Ortner, Rothböck, Stüger, Unterbrunner, and Wallner 2005).

3. METHODOLOGY

In order to develop an extended reference model, a multi-staged approach was chosen. In a first step a comprehensive literature review concerning the topics *VMI*, process management and process reference models was conducted. This included bibliographies, journals and the digital data bases *EBSCO*, *Emerald Management Xtra*, *IEEE Xplore*, *ISI Web of knowledge* and *WISO*.

Concerning the subject area *VMI*, the literature review was based on the notes *Vendor Managed Inventory, VMI, Supply Chain, Supply Chain Management, Logistical Concepts, Logistics, Network, Cooperation or Collaboration*. The search for process management and process reference models was based on the notes *process management, process reference* *models, processes, SCOR, Logistics processes, process modeling, process design* or *process optimization*. Overall, 48 bibliographies and 72 journals were reviewed. Out of them, relevant literature was selected concerning the connection to *VMI* and processes, which means that 36 bibliographies and 32 journals were used for developing the reference model.

This review was the basis for identifying different variations of *VMI* and deducing a general version based on current literature.

To compare the variations of *VMI* mentioned in literature with the used variations in practice by companies, an empirical study was designed. Based on the identified *VMI* variations in scientific literature a questionaire was developed to compare these results with expert knowledge in practice. For this purpose half-standardized interviews with participants from companies operating in the sectors automotive industry (4), engineering (2), agriculture (1), cosmetics sector (1), food sector (1) or other (1) were conducted. The aim of this empirical study was to evaluate the

- relevance of *VMI* in practice,
- the practical suitability to meet business requirements and
- the existing variations of VMI in practice and theory.

Generally, this empirical study showed that the variations mentioned in literature are similar to the implemented variations of VMI in companies. Subsequently, the deduced *VMI* version from the literature study was extended and adapted based on the findings from the empirical study.

To show the effects of *VMI* on the business processes, a reference model with a high level of detail was required. Although the *SCOR* model is widely accepted and includes processes of the supply chain, the level of detail was not high enough to show the changes in the processes which are necessary in order to implement *VMI*.

The process reference model *LogWIN-P* includes processes in higher level of detail, so it is appropriate to show the influence of implementing *VMI* on the processes. So *LogWIN-P* was used as the basis to develop the *VMI* process reference model.

For developing this extended *VMI* model, a review of the existing model *LogWIN-P* was necessary. All levels of the model were checked and the potential *VMI* processes were marked, to pre-simplify the following modeling process.

Therefore the effort for modeling the *VMI* process based on the *LogWIN-P* model is very low and such models ensure that all important business areas are considered in the final reference model. Experiences of other firms and people are used for modeling the company's own processes, which helps to achieve a successful implementation of *VMI* (Becker and Delfmann, 2004, Schulte 2009, Hinkelmann 2008, Stary 2003).

This developed and extended model is called *LogWIN-P_VMI* and shows the ideal realization of *VMI* and helps to implement the necessary modifications.

The literature review and the findings of the empirical study were used to set up the *VMI* process.

LogWIN-P_VMI was developed based on the literature review and the empirical study. As *LogWIN-P* has a high level of detail, a top-down approach was chosen to set up all including processes.

Then the connections to the other existing processes of the reference model were evaluated and checked for accuracy. Following that, the modeled process was reviewed again and necessary adaptions were made.

4. IMPACTS OF VMI ON BUSINESS PROCESSES

The successful implementation of *Vendor Managed Inventory* requires a process redesign of existing business processes. For the redesign, knowledge about current processes and future *VMI*-processes is required (Arnold, Kuhn, and Furmans 2008, Alicke 2005). This implies that redundant processes are omitted and the responsibility for the execution of tasks can change sides, i.e. from the customer to the supplier or the other way round.

To implement this concept the use of a process-reference model can lead to essential benefits. It supports the reasonable and transparent visualization of processes, shows cut surfaces, simplifies the complex reality and serves as a common language between the supply chain partners (Alicke 2005).

4.1. The Process of Vendor Managed Inventory

The operative process of *Vendor Managed Inventory* (cf. Fig. 1) starts with the transfer of important information about current inventory and requirements (also including sales data, storage data, planned promotions and sales deals, future requirements, loss etc.) to the supplier. This data has to be transferred periodically (i.e. hourly, daily or weekly) and should be refreshed continuously to keep the information up to date, because production and transport cycles influence the inventory levels (1).

The received data gets checked by the supplier and a forecast for future requirements is created. Based on these forecasts the supplier schedules production, calculates necessary inventory levels and therefore confirms the order (2).

In the next step the supplier determines the net requirement of the customer and integrates it into the production planning process. The results of these three steps are the scheduled delivery dates and quantities. The supplier communicates these dates and quantities to the customer (3).

Subsequently the supplier delivers the goods to the customer. These deliveries have to fulfill the predefined conditions of the customer (i.e. minimal stock level). Together with the provided goods the delivery receipt is handed over to the customer (4), who checks the goods and the delivery receipt, confirms the delivery (5) and stores the goods. From this point on, the customer is the new owner of the goods (unless otherwise expressly agreed) (6).

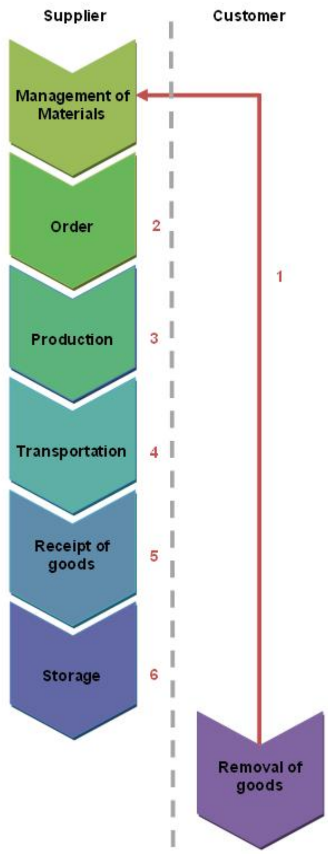

Figure 1: Process with *VMI*

Finally, the customer pays the invoice – mostly on a monthly basis as a collective invoice (Alicke 2005, Arnold, Kuhn, and Furmans 2008).

4.2. The traditional Process without VMI

As mentioned above, the process reference model *LogWIN-P* was used for developing the extended model with *VMI*. In *LogWIN-P* the traditional business processes are *Order Management*, *Planning*, *Procurement*, *Production of Goods and Services*, *Distribution* and *Research and Development* (Ortner, Rothböck, Stüger, Unterbrunner, and Wallner 2005).

In contrast to the in 4.1 described *VMI* process, in the traditional process (cf. Fig. 2), the customer creates the demand forecast and observes the inventory (1). Subsequently, the order size is defined and the ordering process is initiated (2). The supplier receives the order and processes it (3). Then the supplier delivers the ordered goods including the delivery note (4). The receipt of these goods is then confirmed and the payment is made by the customer, who takes over the ordered goods at this point (5) and stores them (6).

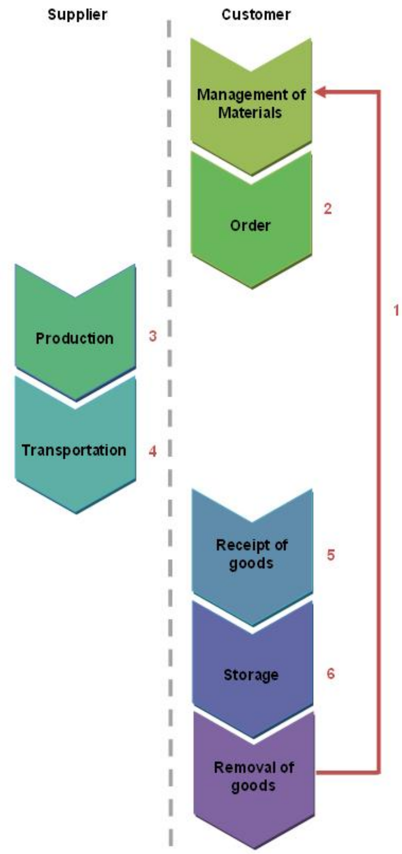

Figure 2: Traditional Process without *VMI*

As the description of these two procurement processes prove, the implementation of *VMI* affects the supplier as well as the customer. In the following sections these differences are therefore described separately for the supplier and the customer sides.

4.3. Affected Processes of the demand side

From the point of view of the customer mainly the procurement process is affected by *VMI*. As mentioned in chapter 3 Methodology this process information was generated from the literature review combined with an empirical study. To provide an overview, the traditional processes of *LogWIN-P* and the processes with *VMI* are shown in Figure 3 and Figure 4. The marked red processes point out the processes which are significantly, mainly or not affected by *VMI*.

The procurement process is separated into three main parts, which include detailed processes. These three parts are *procurement strategy*, *operative procurement* and *procurement infrastructure* (Ortner, Rothböck, Stüger, Unterbrunner, and Wallner 2005).

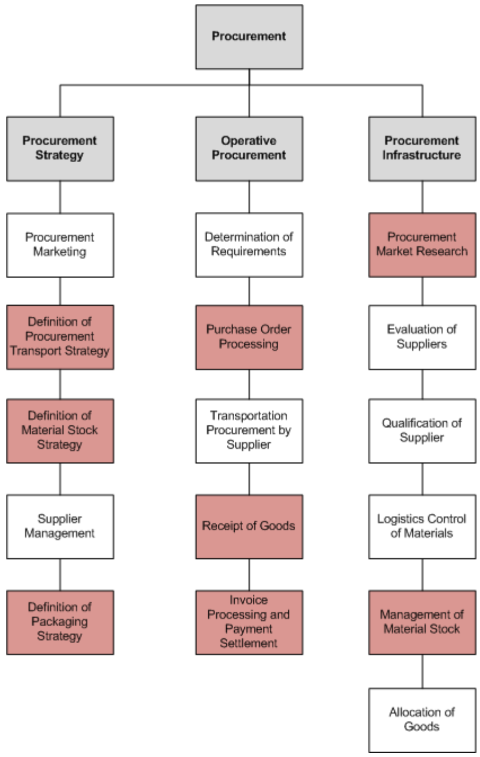

Figure 3: Traditional Procurement Process

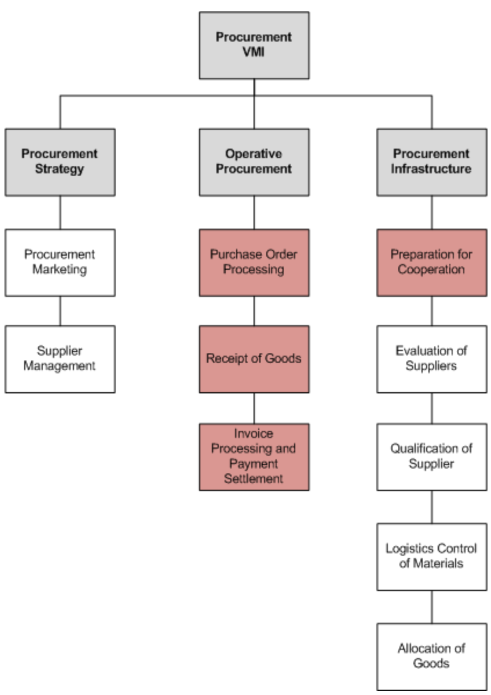

Figure 4: Procurement Process with *VMI*

The implementation of *VMI* can lead to the relocation of some processes to the supply chain partner (in this case to the supplier). In the following part the most essential modifications are explained in further detail.

4.3.1. Purchase Order Processing

The main steps of the *operative procurement process* are:

- ordering required goods by the customer,
- transporting these ordered goods by the supplier and
- receiving these goods at the customer's ramp.

The implementation of *VMI* implicates some changes in this process. Originally, the customer orders the products after checking the inventory levels as the supplier does not have access to the inventory and usage data of the customer. Then the supplier delivers the goods to the purchaser.

Within the *VMI*-process, the supplier receives inventory data and material requirements forecasts from the customer. This implies that inventory management is carried out by the supplier. Compared to the traditional process without *VMI*, the supplier retrieves the required data and sends an order acceptance notification via electronic data transmission to the customer. This order acceptance includes information about the scheduled delivery date and quantity (unless otherwise agreed).

After managing the inventory stock and completing the ordering process, the transport of ordered goods is arranged. The supplier is responsible for this activity – in contrast with to the traditional process.

The supplier can commission a third party provider (i.e. logistics service provider) to conduct this transport.

4.3.2. Receipt of goods

This process is part of the *operative procurement* and characterized by four main activities:

- receiving the ordered goods,
- inspecting the received wares,
- giving notice of goods receipt and
- storing them.

The process is initiated with the transportation of the ordered goods to the customer. There, these delivered goods are checked on the basis of a random sample or by in form of a complete examination and then the confirmation of receipt of goods is made. If the examination of goods is correct, the products are stored in the customer's warehouse. If the examination is not correct, a claim is made.

At this point, the goods are in the customer's warehouse and the customer becomes the owner (unless otherwise agreed). Subsequently, the invoice is generated and the payment is made. Furthermore, the supplier has to register the purchased goods in the inventory management system.

In the traditional process the received transport documents (dispatch note, transport notification) are compared with the order documents. This step is dropped in the *VMI* process, as the supplier organizes the whole replenishment process independently within contractually defined constraints.

4.3.3. Invoice Processing and Payment Settlement

The traditional payment process, which is also part of the *operative procurement*, starts with the change of ownership of goods after their delivery. Then the invoice is made and compared with the dispatch note or transport notification. If the invoice is correct, the payment is executed, if it is incomplete or incorrect a claim is initiated.

With *VMI*, the customer does not get the invoice directly with the supplied goods. In the majority of cases, the invoice is received and paid monthly. This collective invoice is compared with the dispatch notes and transport notifications of the whole accounting period. If the invoice is correct, the goods are paid. If the invoice is not correct or complete, the customer sends a complaint.

The major difference between the traditional and the *VMI* process lies in the delayed invoicing and payment.

4.3.4. Preparation for Cooperation

Preparation for Cooperation is a *procurement infrastructure process* which does not exist in the traditional *LogWIN-P* model, as implementing a logistical concept such as *VMI* requires an intensive preparation for this collaboration.

A properly functioning partnership is the basis for *VMI*. Initially, all activities and responsibilities have to be planned and coordinated. Afterwards, potential subcontractors have to be evaluated according to determined criteria (i.e. long term suppliers, certain appropriate products). Based on this evaluation qualified suppliers are contacted. If they agree to form a cooperation, common expectations and objectives have to be developed, discussed and defined in a cooperation agreement. This contract includes for example determined minimum/maximum inventory levels, transportation agreements or delivery times. Finally, the order processing according to *VMI* can proceed.

4.4. Affected processes of the supply side

From the supplier's point of view, it is the distribution process which is mainly affected by *VMI*. This process is separated into the three parts distribution strategy, operative distribution and distribution infrastructure. Figure 5 and Figure 6 provide an overview of the whole traditional process and the process with *VMI*.

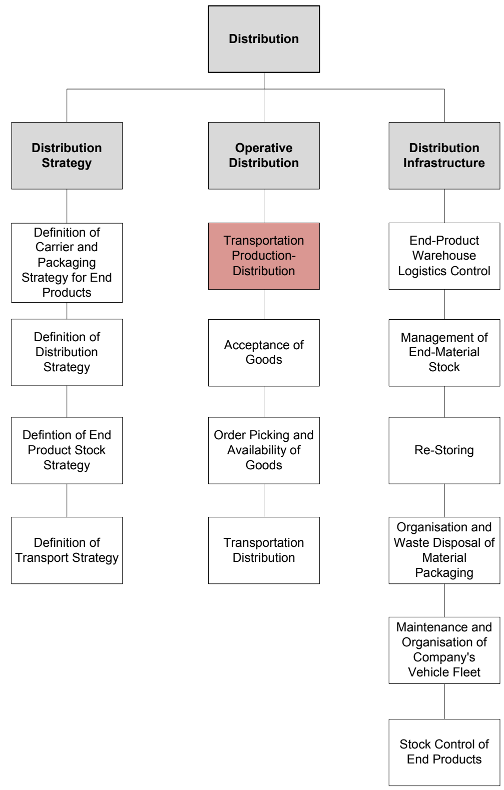

Figure 5: Traditional Distribution Process

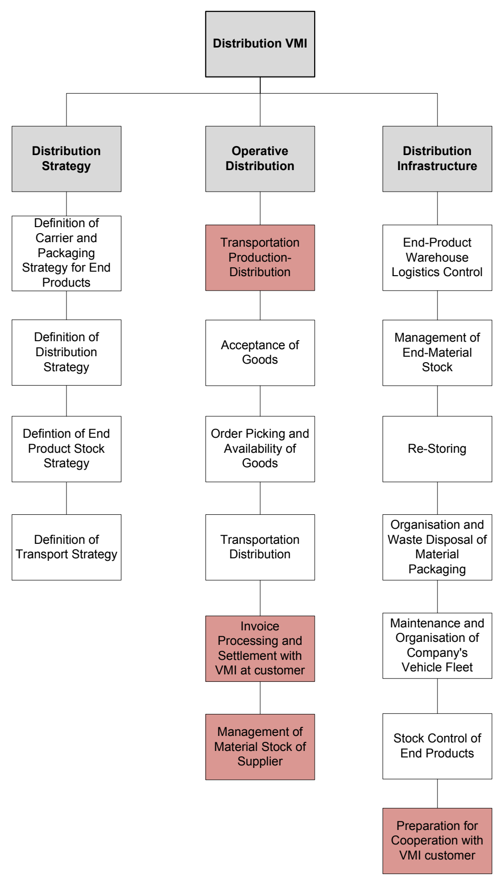

Figure 6: Distribution Process with *VMI*

The next section describes the main process modifications in the *LogWIN-P_VMI* model and the differences to the traditional process.

4.4.1. Transportation Distribution

The *transport distribution* is part of the *operative distribution* and is initiated by the customer removing goods from stock. This removal influences the inventory management of the supplier. If a certain pre-defined inventory level is reached, the supplier plans the replenishment of goods and transmits an order confirmation to the *VMI*-partner.

Subsequently, the transportation of goods is executed by the supplier, a logistics provider or the customer himself. Without *VMI*, the shipping documents are transferred directly to the customer and the delivery services are brought to account.

In comparison, the transportation according to *VMI* is done by the supplier or by a logistics provider, but not by the customer. The reason for this is that the point of transfer of ownership is relocated to the customer (the customer becomes the owner). The supplier is responsible for managing the customer's warehouse and consequently for the transport as well.

Furthermore, the process with *VMI* shows differences to the traditional process concerning payment of delivery.

After transportation, the shipping documents are handed over to the customer and the delivery is added to the collective invoice, which is usually sent to the client on a monthly basis.

4.4.2. Invoice Processing and Payment Settlement with customer

As mentioned in section 4.4.1 the process of generating the invoice and initiating the final payment according to *VMI* differs from the traditional process. This is a new core process, which does not exist in the traditional process reference model *LogWIN-P* and is part of the operative distribution.

In comparison to the traditional process, the payment is not made directly after delivering the goods, but is initiated periodically. The gathered dispatch notes of the specified accounting period are compared to the received invoice. If the charged goods and services are correct, the client pays the wares, if they are not correct the customer has to claim.

4.4.3. Management of Material stock of supplier

In the *LogWIN-P_VMI* model this process is now part of the *operative distribution*. In the traditional model, the inventory management is located in the procurement part. Within the framework of *VMI* this process has been outsourced to the supplier. As a consequence, the subcontractor takes over the responsibility of managing the inventory stock of the *VMI*-customer.

After removing goods from stock at the customer's warehouse and falling below the defined inventory level, the supplier receives a note of demand The *VMI*-supplier is able to retrieve the latest information (i.e. inventory or sales data or requirement forecasts) of the customer's *IT system* and checks the availability of goods in the supplier's warehouse.

If the required goods are available, the *VMI*-customer may receive information about delivery date and quantity and, additionally, the confirmation of order. If the goods are not available, the supplier informs the customer about the remaining quantity to be delivered and the delayed delivery date and additionally transfers the confirmation of this specified order. In the majority of cases, this occurs after unscheduled removal of goods.

4.4.4. Preparation for Cooperation with VMI-customer

As mentioned in section 4.3.4 *Preparation for Cooperation* (demand side) the preparation for implementing *VMI* is essential and therefore, the supply side of the *LogWIN-P_VMI* model was extended by this process as well. *Preparation for Cooperation* is part of the *distribution infrastructure*. If the implementation of VMI is initiated by the supplier, the planning and preparation takes place within the strategy development. However, in most cases, the client expresses the request for cooperation.

4.4.5. Summarized overview of the impact on the processes of LogWIN-P

After modeling the *VMI* process, the affected processes and modifications compared to the traditional process were shown. The following Table 1 and Table 2 provide an overview of all procurement and distribution processes of *LogWIN-P*. Based on the *LogWIN-P_VMI* model the tables are divided into the demand side and the supply side and show the *LogWIN-P* processes which are new or affected (significantly, partly or not affected) or sourced out to the partner.

Concerning the procurement process, a lot of processes are affected significantly or partly, and a lot of processes are outsourced and now part of the supplier's responsibility. Only the process *Preparation for Cooperation* is new in the *LogWIN-P_VMI* model.

Table 1: Impacts on Procurement Processes of *LogWIN-P* – demand side

			Affected			
	Procurement Process	New	Significantly	Partly	Not Affected	Outsourcing to partner
Demand Side	Procurement Marketing			x		
	Definition of Procurement Transport Strategy					x
	Definition of Material Stock Strategy					x
	Supplier Management			x		
	Definition of Packaging Strategie					x
	Determination of Requirements					x
	Purchase Order Processing		x			
	Transportation Procurement by Supplier					x
	Receipt of Goods		x			
	Invoice Processing and Payment Settlement		x			
	Procurement Market Research					x
	Evaluation of Suppliers			x		
	Qualification of Supplier				x	
	Logistics Control of Materials				x	
	Management of Material Stock					x
	Allocation of Goods			x		
	Preparation for Cooperation	x				

From the supplier's point of view most processes are new or not affected. Just one process is affected significantly, three are affected partly. Furthermore, no activity is outsourced to the partner of the supply chain (the customer).

Table 2: Impacts on Distribution Processes of *LogWIN-P* – supply side

	Distribution Processes	New	Affected: Significantly	Affected: Partly	Not Affected
Supply Side	Definition of Carrier and Packaging Strategy for End Products				x
	Definition of Distribution Strategy			x	
	Defintion of End Product Stock Strategy				x
	Definition of Transport Strategy				x
	Transportation Production-Distribution			x	
	Acceptance of Goods				x
	Order Picking and Availability of Goods			x	
	Transportation Distribution		x		
	End-Product Warehouse Logistics Control				x
	Management of End-Material Stock				x
	Re-Storing				x
	Organisation and Waste Disposal of Material Packaging				x
	Maintenance and Organisation of Company's Vehicle Fleet				x
	Stock Control of End Products				x
	Invoice Processing and Settlement with VMI at customer	x			
	Management of Material Stock of Supplier	x			
	Preparation for Cooperation with VMI customer	x			
	Processes from Partner				
	Definition of Procurement Transport Strategy	x			
	Definition of Material Stock Strategy	x			
	Distribution processes	x			
	Determination of Requirements	x			
	Transport Procurement by Supplier	x			
	Procurement Research	x			
	Management of Material Stock of Supplier	x			

The comparison of these two tables shows that some core processes of the customer and of the supplier are affected by *VMI* essentially or even partly. Another important outcome of this comparison is that a lot of activities of the customer were relocated to the area of responsibility of the supplier.

Therefore the supplier gains more flexibility concerning the planning and distribution process.

CONCLUSION

The implementation of *Vendor Managed Inventory* requires a modification of internal and supply chain processes. Primarily, the procurement and the distribution processes are affected by *VMI*. The customer outsources some activities to the VMI-supplier and the supplier is consequently more flexible in generating demand forecasts and planning production and distribution of goods.

The use of *LogWIN-P_VMI* can help both partners implement *VMI* and reduce the effort of adopting internal and supply chain processes.

For modeling this *LogWIN-P_VMI* model the *VMI*-process was designed based on a literature review and on an empirical study including information about the process-steps and the affected processes by *VMI*.

With this extended process reference model we think that companies, especially *SMEs*, get a support for modifying and adopting their business processes to *VMI*. It helps to estimate the impact of this supply chain concept on the internal and supply chain processes and supports the successful realization of *Vendor Managed Inventory*.

Based on these results we want to extend *LogWIN-P* by processes of other supply chain concepts such as *Just-in-time, Quick Response and Cross Docking*. This extended model will be an essential part of the research project *ILOG*, which investigates the implementation of supply chain concepts from the point of view of the three areas processes, information technology and logistics technology.

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GLOBALOG: A SIMULATION CASE OF FREIGHT MULTIMODAL TRANSPORTATION

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ABSTRACT
GLOBALOG is a Spanish multidisciplinary project aimed at promoting logistics as a competitiveness factor. This paper presents the work carried out for the modelling and long-term analysis of multimodal transportation networks, leading to the first complete multi-regional maritime-road multimodal freight transportation model in Spain. The classical four steps approach has been adapted to the specific characteristics of multimodal freight transportation and the available data sources. Road and maritime-road multimodal mode choices have been analysed and fitted to a model based on historical data. Along with provided origin-destination matrices, a model for mode distribution forecasting has been implemented in the TransCAD transport planning software. A set of scenarios of cuts in port services fees and reductions in maritime transportation times has been analysed. Although several data pitfalls raise concerns on the validity of the numerical results obtained, this paper demonstrates the potential of this methodology for the improvement of multimodal networks.

Keywords: logistics, freight transportation, multimodal, simulation, supply chain.

1. INTRODUCTION

Improving supply chain efficiency increases the companies' competitiveness in a globalized environment. The development of logistic know-how, methodologies and practices by the use of information and communication technologies is necessary to achieve this objective.

GLOBALOG (PSE-370000-2009-11) is a project promoted by the Ministry of Science and Innovation of the Government of Spain which aims at obtaining this goal. During four years (2006 – 2010) and with a total budget of €8 million, twenty seven agents including universities, public and private R&D centres, Port Authorities and important logistic companies are involved in its development (Globalog 2011).

The project involves research activities and methods for improving supply chains and transportation networks along the next 15 years. The scope of the project is shown in the organizational scheme in Figure 1. It comprises a series of subprojects addressing the improvement of the characteristic elements involved in the management of logistic processes of different types of supply chain.

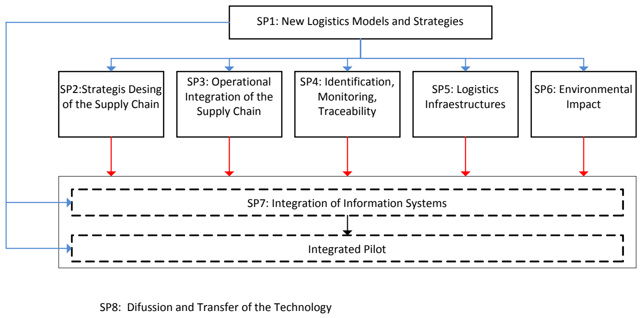

Figure 1: GLOBALOG Work Packages Diagram

This paper describes the work carried out within the Subproject 5 (Figure 1) by the Integrated Group for Engineering Research (GII) of the University of A Coruña (Spain). The objective of the SP5 is the assessment of new logistic infrastructures for the Spanish freight transportation between the Spanish Mediterranean and Atlantic regions. To do so, a simulation-based multimodal transport modelling has been developed.

The maritime-road multimodality option is the chosen one due to some reasons. On the one hand, in Spain most of the freight transport is carried out by road. This initiative will provide with recommendations in order to promote the use of alternative transport modes. As a consequence, it will reduce the possible road congestions and the CO_2, NO_x, and other emissions. On the other hand, the European Authorities specifically support this intermodality by means of several initiatives and legislation. The "White Paper- European Transport Policy for 2010: Time to Decide" (EC 2011) gathers the state of the transports nowadays and some objectives for the future of the transport. It highlights the problems of congestion and pollution among others, which would be prompted by an increase of 50% of road freight in 2010. The Marco Polo project (Marco Polo 2011) follows the objectives of the White Paper. This project attempts to reduce the congestion of the road infrastructures and to improve the transport effects on the environment by transferring part of the road freight to the Short Sea Shipping (SSS), railway and inland waterways.

Other initiatives related with the above mentioned are the promotion of the SSS and the Motorways of the Sea (MS) concept. SSS is the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non European countries having a coastline on the enclosed seas bordering Europe (SSS 2011). A Motorway of the Sea is a sea length between ports that are also interconnected with transeuropean networks and intermodal corridors, safeguarding social cohesion, providing with an efficient intermodal system where goods are rapidly transferred between different modes through the optimization of port operations, overcoming natural barriers and sensitive areas and other geographical obstacles (MS 2011).

Finally, the opportunity of future exploitation has been considered. The strategic location of two new important port facilities on the Atlantic Spanish shore would play an active role in attracting freight flows from the Panama Channel extension, serving as hub ports for successive feeding operations.

All this expresses that the maritime-road multimodality is a highly opportune option, not only for the know-how improvement but the utility of the model to evaluate the options promoted by Europe.

The road-railroad multimodality has been also considered. However, nowadays railroad is losing market share and the Spanish infrastructure is insufficient. Besides, the current period of crisis does not seem to be the best moment to invest in those infrastructures. The present investments in this kind of transport have the goal of finishing the started building works related to high speed lines for passengers transport.

A Modelling and Simulation (M&S) approach for the multimodal freight transport is a total innovative initiative. As a consequence, a great previous data collection, infrastructure characterization and decision maker behaviour modelling have been developed. On section 2, those previous works will be described, together with the simulation tool and the methodology. In section 3, the scenarios and results of the experimentation will be explained. The lack of appropriate public data and other limitations that appeared during the study are provided in section 4. Finally future work lines and conclusions are described in sections 5 and 6.

2. THE MODEL.

2.1. Data collection.

A first phase in the model construction is to identify the possible sources of information and the available data.

As this is a transport model, it is necessary to know the freight flow. It will be considered the road freight flow, because it is the transport mode that is wanted to decongest. The Road Freight Transport Permanent Survey of the National Statistics Institute of Spain (INE) provides with the Origin-Destination (OD) Matrix, in thousands of tonnes, between Spanish Autonomous Regions. These goods are not separated by their nature.

A GIS (Geographic Information System) has been developed by other member of the subproject 5 providing the graphical part and geographical data needed to define the traffic analysis zones and the network used for the transport. The road lengths are an example of the data that can be obtained from the GIS.

Other source of data for road transport are the documents from the Observatory of Road Freight Transport of the Ministry of Public Works of Spain. These documents gather the road freight transport costs depending on the vehicle used, and also the terms of this cost chain.

In the maritime case the cost chain has been generated by the research group. Later on the paper, the construction of this cost chain will be described. The data needed come from official organizations related with the maritime realm. Particularly they come from Yearbooks of the State Ports, reports from Manager’s Office of the Naval Sector, Ministry of Industry, Tourist and Trade, web sites of the shipping companies and legislation.

It is also necessary to know the sea lengths between ports, because although sea transport does not need physical infrastructures it follows the lines of the navigation charts. These lengths have been obtained on a website for merchant navy captains (Capitanes, 2011).

Finally the relevant legislation has been taking into account such as E.U. Regulation nº561/2006 that explains the break time for road transport.

2.2. The tool.

TransCAD is the tool chosen for the transport simulation. It is a software package that fully integrates GIS with demand modelling and logistic functionality.
This software has been specifically developed for passenger transport modelling.

2.3. Previous Steps: TAZs and Network definition.

As mentioned, the model is for freight transport so the first step is to decide the origin and destination of the flows. Then it has to be defined the network used for the transport.

These zones are the Traffic Analysis Zones or TAZs. They have to be capable to generate or to attract significant amounts of goods, so two criteria are used to choose them. A first criterion is the relation with the supply chain. Freight terminals, Logistic Centres and Ports are important points of generation and attraction of goods. But the population also consumes and generate freight, so the second criterion is related with the number of inhabitants in a zone. Figure 2 shows the TAZ used in GLOBALOG.

Figure 2: TAZs for GLOBALOG.

As stated in the introduction, the road and multimodal (road-maritime) options will be modelled; therefore the needed network must include the Spanish roads and a set of maritime lines to build the multimodal chain. The roads used (motorway, dual carriageway, main national roads) come from the developed GIS for the project.

For the maritime net, the GII has carried out a layer with the maritime legs. The proposed maritime lines come from the reutilization of the regular commercial routes and the routes of internal cabotage approved by the Ministry of Public Works which exist nowadays. The length of these legs is the real distance by sea between ports, obtained in the before-mentioned website for merchant navy captains.

2.4. Transport unit.
The transport unit chosen has to be compatible with all transport modes. So TEU (Twenty Foot Equivalent Unit) is the transport unit chosen.
This unit is a container of twenty feet, widely used in maritime transport, and that can be used in road transport by a container vehicle.

2.5. Transport Modes Characterization.
The characterization of the transport modes is a function of two main characteristics: time and cost per transport unit.

Besides, time and cost are a function of the travel length so these lengths are calculated. TransCAD is used to obtain them, by short path methods.

2.5.1. Road time:
It has a part function of the speed and length and another function of the break time regulation (E.U. Regulation nº561/2006).

This allows us to build a function for road time. As it can be seen for a particular stretch, time is the addition of the time $t_{ij} = \frac{l_{ij(km)}}{v_{(km/h)}}$, where l is the length in kilometres and v the speed in kilometres per hour, and the break time derived of the regulation. In this case the speed is 80 km per hour. The travel distance versus the real time is represented on Figure 3. As a result, the time function is obtained (Equation 1).

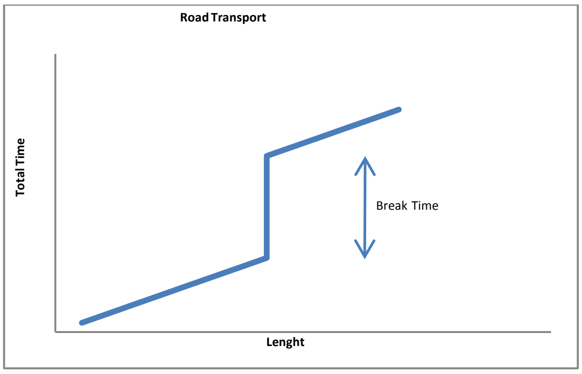

Figure 3: Total Road Time

$$t_{ij} = 0.0254 \times d_{ij} \qquad (1)$$

2.5.2. Road cost.
Data of the Observatory of Road Freight Transport is used to obtain the road cost. This Observatory gives the cost per km and per type of vehicle. It is calculated as an addition of the following elements:

- Vehicle amortization.
- Vehicle financing.
- Staff.
- Insurance.
- Fiscal Cost.
- Allowance.
- Fuel.
- Pneumatics.
- Maintenance.
- Repairs.

This division allows building the cost which directly depends on the distance and the one that depends on the time.

2.5.3. Multimodal Time.
The multimodal chain is made up of road and maritime transport. So the total time is the sum of both of these times. The road time is calculated as previously shown.

The travel time by sea is calculated by the following expression:

$$t_{ij} = \frac{l_{ij(km)}}{v_{(km/h)}} \qquad (2)$$

where v is 33.3 km/h=18 knots, that is the average of the speed of the vessels working in regular lines that have been employed to build the maritime geographic file. The vessel loading and unloading times and the routes scheduling are related to the waiting time in port when transhipment operations are required.

Table 1: Summary of Costs.

Type	Cost	Formula	Unit
Road	Travel	$C_{ij} = 1.167 \times d_{ij}$	Euros
	Inventory	$C = \propto \times 0.0254 \times d_{ij}$	€/TEU
Port	Operations	$C_{op} = 43.26 \times S^{0.847}$	€
	Inventory	$C_{inventory} = \propto \times T_{op}$	€/ TEU
Sea	Capital	$C_{capital}(S) = 0.22 \times S$	€/day
	Maintenance, Insurance, Repairs	$C_m = 0.008 \times S$	€/ day
	Crew	$C_m = 322.61 \times S^{0.094}$	€/ day
	Taxes	$C_{taxes}(S) = 1.58 \times \frac{S}{100} + 57.69 \times 0.347 \times S^{0.84771} + 0.80 \times \frac{S}{100} + 0.7199 \times S^{0.6204} + 67.03 \times T_{op}$	€/stop
	Fuel	$C_{fuel} = 0.10 \times S^{0.738}$	€/ day
	Inventory	$C_{inventory} = \propto \times \frac{d_m}{v}$	€/TEU

2.5.4. Multimodal cost.

As is the case of time, the multimodal cost is the sum of maritime and road cost. Road cost is calculated as said before.

The cost chain for maritime transport has been determined. This chain includes the following elements:

- Cost of Capital.
- Maintenance, Insurance, Administrative Taxes.
- Crew.
- Port Taxes.
- Fuel.
- Inventory.
- Port Operations.

These costs are calculated as a function of the Gross Tonnage, GT, (S, in Table 1) of the vessel.

2.6. Methodology.

The following task is the construction of the simulation model. The Four Steps Model is the methodology used to build the transport model. This is frequently used for passengers transport but not for freight transport, so some approximations had to be done in order to use it for freight transport simulation.

The four steps are:

1. **Trip Generation**. Estimates the extent, for a given spatial unit, for which it is an origin and destination of transport movements.
2. **Trip Distribution**. Commonly a spatial interaction model that estimates movements between origins and destinations and which can consider constraints such as distance.
3. **Modal Split**. Movements between origins and destination are then disaggregated by modes. This function depends on the availability of each mode, their respective costs, and preferences.
4. **Traffic Assignment**. All the estimated trips by origin, destination and mode and then "loaded" on the transportation network, mainly with the consideration that users want to minimize some kind of "cost" ("cost" = length, for example).

This approach starts by considering a zoning and network system and the collection and coding of planning, calibration and validation data (Ortúzar and G. Willumasen 2011), as shows in Collection Data and Previous steps sections.

As said before, this methodology is widely used for passengers transport but not for freight transport. So an original approach has to be made to use it. Figure 4 depicts this approach.

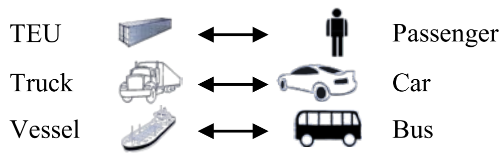

Figure 4: Similarity Relationship between Passengers and Freight Transport.

2.6.1. Trip Generation.

In this case the OD matrices are known, so the Trip Generation Modelling is not necessary.

These matrices are data of freight transport from National Statistics Institute of Spain, and their units are thousands of tonnes. The flows are between Autonomous Regions.

The definition of the project marks the election of the TAZs. In the Previous Steps point appears the TAZs chosen and the criteria for the election.

2.6.2. Trip Distribution.

The TAZs represented a level of aggregation lower than Autonomous Regions. Accordingly, a population criterion is used to disaggregate the data of the OD matrices. A population weight, for every pair Origin-Destination, is calculated in the following way:

$$w_{ij} = \frac{p_i \times p_j}{\sum_A p_i \times \sum_B p_j} \tag{3}$$

Where:

p_i TAZ Origin Population
p_j TAZ Destination Population
A Autonomous Region of the TAZ Origin
B Autonomous Region of the TAZ Destination

These weights multiply the flow between A and B and give the flows between i and j. It can be seen easily with an illustrative example.

$$w_{Vigo\_Oviedo} = 0.114$$
$$T_{Galicia\_Asturias} = 2694.10 \cdot 10^3 \, tonne / year$$
$$t_{Vigo\_Oviedo} = 0.114 \times 2694.10 \cdot 10^3 = 307.13 \cdot 10^3 \, ton / year$$

The transport unit is not tonne but TEU. To convert tonnes in TEU, the flow between TAZs is divided by 20 tonnes (average weight of a TEU). The data are per year, so these data are divided by 365 days per year to obtain values per day.

All of this allows building the OD Matrices between TAZ per day and with units in TEUs.

2.6.3. Modal Split.

The Modal Split is a key part of the model. It determines which fraction of the flow between each origin-destination pair uses each mode. A widely employed statistical model is the Multinomial Logit Model (MNL). It consists of a logit function that weights the attractiveness of each transportation mode given by a utility function. Standard methods for fitting MNL rely on datasets of paired observations of utility drivers and single realizations of the chosen mode. They are usually gathered by means of a Mobility Survey or a Market Research.

However, as it was not within the original scope of the Globalog project, the lack of a market research or survey task to provide us with has significantly hampered our advancements. Also, as many other European countries, Spain lacks of a nationwide survey to cope with this point as well. Historical data of flows by mode were employed instead. This raises two issues. The first is that the model's ability to forecast results out of the historical data range is severely harmed. The second is that the MNL fitting method implemented in TransCAD could not be applied to data in which the mode choice variable is a fraction instead of a binary variable, so it had to be fitted by means of an external tool (the R free statistical software environment, 2011).

A simpler logistic regression model (Equation 4) was selected instead of an MNL due its lower number of parameters for an obtained similar quality of fit. The one utility function per mode approach of MNL was replaced by a single utility function that represents the *relative* attractiveness of multimodal transportation compared to that of road transportation. The selected utility drivers were the relations between road and multimodal costs and times.

$$p(U_{MM/R}) = \frac{1}{1+e^{-U_{MM/R}}} \quad (4)$$

Several different utility functions were tested. The one found to be more statistically significant was a linear model that includes a first order interaction effect as well. Equation 5 shows the fitted model

$$U_{multimodal,q} = \beta_0 + \beta_1 \times \frac{C_r}{C_m} + \beta_2 \times \frac{T_r}{T_m} + \beta_3 \times \frac{C_r T_r}{C_m T_m} \quad (5)$$

Table 2 presents the parameters values and their significance levels. It can be seen that all the selected factors are useful for predicting the mode choice. The negative value of β_2 implies that, within this model, an increase in multimodal transportation times would increase its utility. This is a hardly reliable result. However, this term is dominated by the interaction term so that an increase in multimodal time leads to an overall reduction of its utility. Figure 5 shows a surface response curve for the predicted multimodal absorption rate versus the costs and times relations. It can be noted that cost and time relations that are separately favourable to multimodal transport, lead to low multimodal rates. It is the combination of favourable time and cost relations that poses a noticeable effect in multimodal flow absorption rates.

Table 2: Results of the Logistic Regression.

Coef.	Value	Std. Err.	t-value	p-value	S.L (†)
β_0	-3.948	0.260	-15.209	< 2e-16	***
β_1	1.161	0.545	2.130	0.0340	*
β_2	-3.794	0.974	-3.895	0.0001	***
β_3	8.955	1.928	4.644	5.02E-06	***

(†) Significant Level codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '1

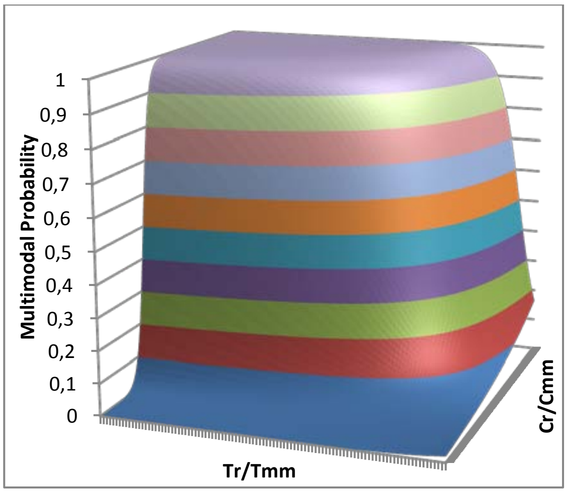

Figure 5: Multimodal Probability.

Then the multimodal utility function is:

$$U_{multimodal,q} = -3.948 + 1.1606 \times \frac{C_r}{C_m} - 3.7944 \times \frac{T_r}{T_m} + 8.955 \times \frac{C_r T_r}{C_m T_m} \quad (6)$$

Where C is the cost (in €/TEU) divided by 100 and T is the time divided by 10 (in h/TEU), both for the same trip between Origin and Destination.

Concerns on model's validity are raised by the negative value of β_2 and the trend for the model to predict multimodal absorption rates near 100% for OD pairs favourable to multimodal in terms of cost and time. This absorption rate is not realistic since there are non-accounted factors in the model that would restrain the flow of certain types of freight through the multimodal network. However, given the limitations in the provided data, a greater effort in this modelling step was disregarded. The only way for improving model's validity would be by means of a larger dataset. Still, the model is useful for estimation of model choice as far as the studied scenario keeps close to the historical data employed, which fits relatively well.

2.6.4. Traffic Assignment.

The last step of the model is the Traffic Assignment Modelling. The traffic assignment model predicts the network flows that are associated with future planning scenarios.

The method used in the project is the "All or nothing" one. This method assigns all traffic flows between Origin and Destination pairs to the shortest paths connecting them. Yet this is not the most appropriate method as it ignores the fact that link travel times are flow dependent, the lack of data -like road capacity- prevents the use of more accurate methods.

In the Model Split point the obtaining of the probabilities of every transport mode was presented. Multiplying these probabilities by the OD Matrices, the OD Multimodal and OD Road Matrices are obtained. These are the matrices that we have to use in the Traffic Assignment. Figure 6 shows an example of this assignation.

Figure 6: Traffic Assignment Example.

3. EXPERIMENTATION

3.1. Scenarios.

Once the transport model has been built, it allows doing a set of simulations. The objective of these simulations is to evaluate the influence of the changes on the transport variables over the decision makers' choice.

The variables that characterize the transport are time and cost. So these are the variables which could be varied. Time only changes if changes in technology, infrastructure or legislation occur.

For road transport, we suppose that the changes in technology will not be as important as for entailing a large decrease on the travel times. Furthermore it would have to go accompanied by a legislative relaxation in terms of transport, in clear opposition with nowadays restrictive trend. So we will not vary the road time in the scenarios.

But in the case of maritime time the speed used in the model is the average speed of the vessel that operated in the regular lines used. This speed is 18 knots, but the speed of this kind of vessels varies between 15.5 and 26 knots. Another variable time in the maritime transport is the waiting time, whenever transhipments of containers are carried out.

Another issue that give us the framework to define the scenarios is that provided by the Spanish law 33/2010 about the liberalization of port management. In other countries this kind of initiatives has led to the decrease in port taxes, so the decision of scenarios with this kind of decrease seems to be justified.

The work strives for identifying the conditions that increase the multimodal transport choice. As a result, the scenarios to assess are due to variations in multimodal cost and times.

The first proposed five scenarios involve a proportional decrease of the taxes, as shown in Table 3.

Table 3: Scenarios Variables.

Scenario	Annual Decrease	Total Decrease	Vessel Speed (knots)	Max Waiting Time (days)
E1	0.67%	10%	18	--
E2	2.00%	30%	18	--
E3	2.67%	40%	18	--
E4	3.33%	50%	18	--
E5	4.67%	70%	18	--
E6	4.67%	70%	26	1
E7	--	--	26	1
E8	--	--	22	3

In terms of time, two scenarios are evaluated. The first one jointly considers a maximum waiting time for a container of one day, and a vessel speed of 26 knots (E7). The second one supposes a maximum waiting time in port of 3 days and 22 knots of vessel speed (E8).

The last scenario (E6) is a combination of 70% taxes decrease, 1 day for maximum waiting time and 26 knots of speed.

3.2. The Results.

The work aims at assessing the possible absorption of road flows by multimodal transport. So the freight that is being distributed between both modes is the forecast of the road freight. Thus, two ways for the assessment of the obtained results are proposed.

The first one takes into account all the containers moved between TAZs, except those ones moved within a TAZ. Figure 7 and Figure 8 show the percentage of multimodal and road transport for this option.

In all cases time and taxes cuts cause increases on the multimodal flows, but limited to a 3.1% for the best scenario in the last year of the simulated period. Probably these poor values are because of the considered multimodal network, as the sea legs of the multimodal route are not specifically designed for it and the waiting times and lengths are too long for a short shipping operation.

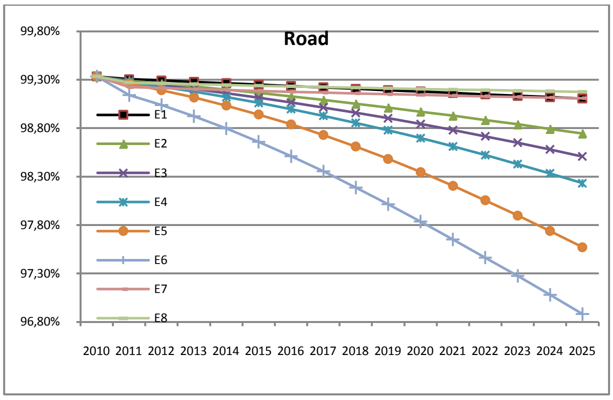

Figure 7: Road Percentage.

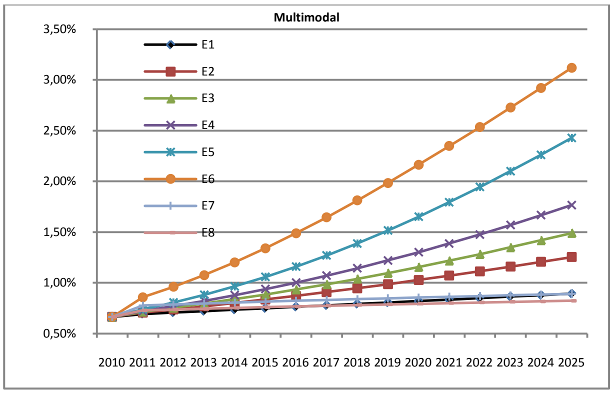

Figure 8: Multimodal Percentage.

The second option to evaluate the results comes from the EMMA study (European Marine Motorways Study) which states that the optimal distance between ports for Short Sea Shipping is between 500 km and 1400 km. So this second option takes into account the flows between TAZs separated by sea distances higher than 500 km. So we consider the flows between the TAZs in the Atlantic cost and the TAZs in the Mediterranean. Figure 9 and Figure 10 show these second values.

In this case the values are a slightly better than in the previous one. The better scenario (E6) allows reaching a multimodal quota near to the objectives of the National Strategic Plan for Freight Transport (PEIT). PEIT pursues a participation share for multimodal transport of 8-10% in 2020.

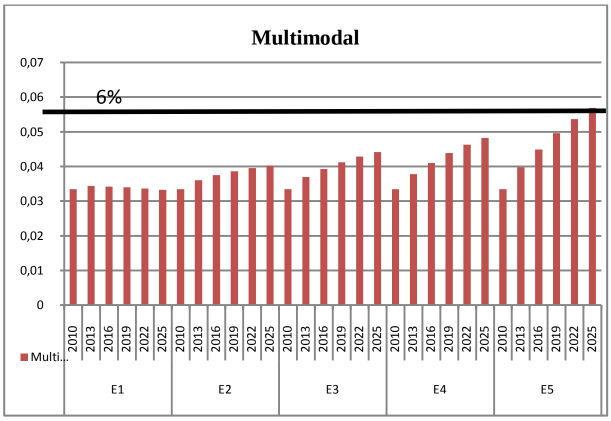

Figure 9: Second Option. Multimodal Absorption Percentages (a).

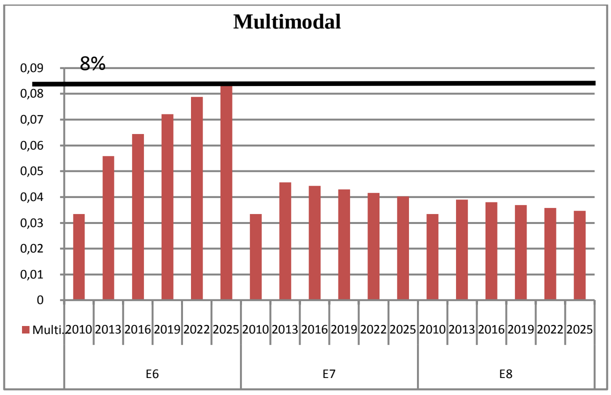

Figure 10: Second Option. Multimodal Absorption Percentages (b)

Another observed result from the experimentation is the variation of the multimodal transport absorption with the accumulation of the taxes reduction. In the following table we can see the increase on the flows respect the initial one corresponding to a 1% increase in the taxes diminution.

Table 4: Flow Increment.

Scenario	% Flow Increase Over Initial Year
E1	6.05
E2	3.21
E3	2.91
E4	2.76
E5	2.62

4. LIMITATIONS FOUND.

The development of the project shows a set of limitations in the freight transport theme, in the Spanish case.

4.1. OD Matrix:
Available data are between Autonomous Regions and without distinguishing the nature of the goods transported. OD Matrices for every kind of good are important. Also the origin and destination should be considered in a spatial level lower than Autonomous Regions, as province or municipality.

4.2. Characterization of the transports:
Cost chains could not be found for each of the transport models used in the model, particularly multimodal cost chain has been an original development of this work. Another type of problem is the graphic documentation. The geographic layer of the maritime transport has been also specifically developed by the GII research team.

4.3. Mobility Survey and Market Research:
The choice model requires a set of data to be introduced in order to create the decision function. These data assess the decisions taken by a number of components with certain features on a range of means of transport, from which their characteristics are known. They are usually obtained from a survey of mobility in the case of passenger transport, and in a market study, for freight transport.

- These market studies are not available. Therefore, to solve this absence a "survey" with the available data has been generated. Thus, we have characterized the transport time and cost.
- A complete study would take into account a number of variables that would make the model more robust. There are features of transport, more qualitative than quantitative, which greatly influence the decision, such as perceptions of risk. There are also very important reliability data, difficult to quantify and obtain.

4.4. Geographic Information System.
Although the GIS has not meant a limitation - as it has been developed for the project- it is desirable the availability of a general nature GIS adapted for analysis tasks and not only for graphical representation. It should collect data on all existing transportation infrastructure in the country, as well as demographic, economic, travellers and goods data available.

5. FUTURE WORK.
As a consequence of the project development, some future works are intended.

- Development of specific routes designed for multimodal transport. Routes used in the model are existing regular routes, and therefore the vessels and waiting times are not specifically designed for multimodal operation. This is in line with initiatives such as motorways of the sea, for example Vigo-Saint Nazaire or Gijón- Saint Nazaire, but limited to national territory. The development of such routes would be clearly consistent with the objective of improving the companies' supply chains.
- Environmental impact assessment. The use of multimodal chain removes items of road transport. This implies a reduction of emissions from the combustion process. The development of emission models for these modes of transport would assess the amount of emissions savings.
- Intensive study of the elements of cost chains. A particular example of this is fuel costs. In the current situation of rising oil costs is very important to study the plausible scenarios of evolution.
- Development of multimodality option with the railroad. The establishment of multimodal model and the needs of its construction lay the foundations to develop the rail option. This is limited by the possibility of acquiring all the necessary data from this transport.

6. CONCLUSIONS.
This paper presents the first comprehensive and effective approach to the development of a simulation model of multimodal freight transport in Spain for the evaluation of interregional flows. The classical four steps approach has been adapted to the specific characteristics of multimodal freight transportation and also to the available data sources. Road and maritime-road multimodal mode choices have been analysed and fitted to a model based on historical data. Along with provided OD matrices, a model for mode distribution forecasting has been implemented in the TransCAD transport planning software. A set of scenarios of cuts in port services fees and reductions in maritime transportation times has been analysed.

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BUS FOR HLS LINES IN URBAN CONTEXT

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ABSTRACT
In many european cities, public transportation systems on reserved way are spreading; interesting experiences are those relating to BHLS, thanks to their superior performance, compared to traditional bus lines, and relatively low cost of implementation and management. The paper offers some insights on BHLS lines vehicles, and their related performance and potential. It is part of research activities inside European Project COST TU603 (www.bhls.eu).

Keywords: Buses with a High Level of Services, BHLS, Public transport, Bus performance, ITS

1. INTRODUCTION

The experiences of buses with high level of service (BHLS) is spreading throughout Europe. Different from the American Bus Rapid Transit (BRT) for several reasons, European BHLS are proposed as an alternative urban public transportation system, particularly in medium and small cities where tram solution is difficult to implement.

BHLS are not intended as a substitute for other types of public transport such as trams or ordinary buses, but they may represent a a good alternative in relation to a specific context. The choice of a technology must address with many variables of wich are analysed in the feasibility study.

In this paper, attention is paid to these proposed systems, with hints of representative applications in european urban environments. Attention is further focused on vehicle component, highlighting the innovation elements arising from the interaction between demand and manufacturing companies.

Some new performance models were developed, and they may contribute to simulate the operativity of a transit system.

2. KEY FEATURES OF URBAN PUBLIC TRANSPORT. BRT AND BHLS

In order to enhance urban public transportation, many government authorities try to create reserved lane systems in order to limit the excessive and often disruptive presence of private car,. The choice of more efficient technologies is never easy. The technological solution must be related to:

- desired demand;
- dimensions of the served urban area;
- density and settlements along the line corridor;
- morphology of the land and urban fabric,
- characteristics of the population.

The idea of a transport system able of providing a service level higher than that of conventional bus services along major corridors, in terms of frequency, comfort, commercial speed, reliability, accessibility, has already established in America (Diaz 2009). Transport networks were made based on a hierarchy with primary lines (HLS) and more traditional feeder lines. In North America BRT lines focused on attributes such as target speed and comfort of travel (Levinson et al. 2003). In South American wide urban areas, the choice of BRT was due to the unavailability of larger financial resources for ordinary subway systems. The features include:

- a reserved and protected roadway;
- stops functional organization similar to subway stations;
- use of centralized control systems and ITS technologies;
- integrated service management; and
- high frequencies and speeds.

This aim to increase lines transportation capacity responds to a fairly strong demand that could not be met by traditional systems.

European BHLS detach themselves from the dominating rapidity concept, which is the heart of the american BRT system, and aims to fulfill needs for quality, service reliability, operational flexibility and positive impact on urban environment needs. In some aspects it tends to close the tram performance levels, limiting costs and the issues related to rails. The idea of structuring transport networks on a hierarchical basis persists, however. A common feature lies in centralized vehicles control system. Information about vehicles status and location is continuously monitored and directs real-time news to users on board and at stops.

3. BHLS EXPERIENCES IN EUROPE

Although there is no settled definition of BHLS yet (Babilotte et Rambaud 2005), when referring to these systems, a high degree of separation of bus lanes able to offer higher performance than traditional bus is expected. A wealth of experience confirms this idea, and systems features vary according to the differences in the composition of the system's features. Firstly, substantial differences in terms of infrastructure, related to both urban context and desired service levels, can be observed. Type and geometry of roadway, inclusion of reserved lanes and type of intersections are among the key factors that come into play. The roads can take on different arrangements, depending on the degree of separation from other transport systems: there are bus only lanes and lanes also opened to other vehicle categories such as taxis, bicycles and emergency vehicles. A degree of physical protection can be determined through different floors and/or colors of the roadway, light separators elements such as curbs, speed bumps and warning signs, or non-crossable elements avoiding interferences. As there are not many resources available to ensure the respect of prohibitions, reserved and protected lanes are essential to keep high service levels achievable to BHLS, in relation to the regularity of travel and commercial speed.

A BHLS line is often an important opportunity for the rehabilitation of public spaces along the corridor served. This typically tends to redevelop the entire route, creating cycle lanes and pedestrian areas, improving urban design, better equipping stops, and reducing road space for private car use.

3.1. BHLS experiences in Germany

The first commercial kerb guided bus operation started in 1980. The city of Essen created a fully protected way (the O-Bahn) on a peri-urban path parallel to a motorway. The infrastructure is made of prefabricated concrete beams, arranged in series for a total length of 4 km, and the curb side is used as a directional constraint for vehicles equipped with guide-wheels.

OPNV Trasse operates in the city of Oberhausen sharing the road with tram (Figure 1). Made up of 125 buses, of which approx half are articulated, the system carries an average of 40.2 million passengers per year.

Figure 1: OPNV Trasse in Oberhausen

The Metrobusse BHLS system of Hamburg uses articulated and double-articulated vehicles (Figure 2), all equipped with user information system. The high frequencies results in a considerable transport capacity: an average of 60,000 passengers uses the system daily.

Figure 2: Hamburg XXL

3.2. BHLS experiences in France

Rouen BHLS system Teor (3 lines, of which 45% are on protected lanes) is one of the most interesting and extended in Europe. Teor vehicles has semi-automatic guidance: an optical unit recognizes the way through two dotted lines placed down the centre of the lane. Automatic guidance is activated only at stops and allows perfect vehicle alignment with platform. The network moves about 45,000 people every day.

Nantes Busway was created in 2006 from the disposal of a highway that penetrated the city center. A special type of intersection, with roundabouts and diametrical crossing for buses, was also adopted (Figure 3). 20 articulated buses travel the line carrying an average of 25,000 passengers daily.

Figure 3: Bus crossing a roundabout in Nantes

Trans Val de Marne (TVM) BHLS line is located near Paris. It runs for 85% of its length on reserved lanes. 39 articulated buses operates carrying an average of 65,000 passengers daily.

Triskell BHLS has operated in Lorient since 2007, crossing the city centre on reserved lanes. Like Nantes, there is a particular priority system at intersections, crossing roundabouts with or without traffic lights. Great attention was given to the stations' design. In addition to their transport function, they represent meeting places for local inhabitants.

3.3. BHLS experiences in Sweden

In Jonkoping (Figure 4) a 3-line BHLS network with 100 vehicles operates. Current low traffic counts on the road network, combined with the priority systems at intersections, allow the service to achieve good performance even without completely reserved lanes.

Stockholm Blue Bus BHLS network was designed to support the metro in the poorly served suburbs. It has 4 lines. Articulated vehicles are equipped with automatic location system. The network is moving some 150,000 passengers each day.

Goteborg 4-lines BHLS system has an infrastructure made of rounded curb stone. The system uses double-articulated buses with a capacity up to 165 passengers, moving around 64,000 passengers daily.

Figure 4: A Jonkoping BHLS vehicle

3.4. BHLS experiences in the United Kingdom

Located east of Leeds on two major road corridors (Figure 5), Quality Bus Initiative provides the main transport link for many residential communities along the corridor, serving some 100,000 residents. The scheme comprises bus lane and cycle lane, bus priority at junctions through selective bus detection, over 330 enhanced stops and double-decker buses fitted with guide wheels, low floor and full accessibility. There is evidence of modal shift away from the car with 7% of users indicating that they would have previously made their journey by car.

In the Thames Gateway area of Kent, 16.000 passengers are carried daily through two Fastrack lines . Signal priority, reserved lanes (24% of the total), and dedicated busways (32% of the total) allow Fastrack vehicles to avoid traffic. The fleet is made up of 26 articulated vehicles, all equipped with passenger information screens, voice announcement systems and CCTV. Tickets are sold by the driver, but passengers can also buy tickets from roadside machines at certain bus stops or through their own mobile phones.

The city of Manchester has created 24 lines of Quality Bus Corridors (QBC). The 281 km network is characterized by reserved lanes, priority systems at intersections for its double-decker vehicles, wide waiting areas allowing easy user access and information systems on-board and at stops.

Figure 5: Guided bus corridor in Leeds

3.5. BHLS experience in Ireland

A network of Quality Bus Corridor (QBC) runs along the main roads of Dublin. The network covers about 200 km and includes 15 lines. The vehicle fleet consists of 52 double-decker buses (Figure 6). The number of daily passengers is approximately 35,000.

Figure 6: Dublin double-decker bus

3.6. BHLS experience in Switzerland

In Zürich, BHLS Line 31 is characterized by dedicated lanes and priority systems at intersections and it was created in 2007. Information on status and position of vehicles is broadcasted in real time to information panels on-board and at stations. A number of 35,000 passengers is carried daily by high capacity double-articulated buses (Figure 7).

Figure 7: A double-articulated bus in Zürich

3.7. BHLS experiences in Spain

In 1995, for the first time in Europe, a corridor reserved for the movement of buses was created within a highway that goes from the outskirts to the centre of Madrid. The system, called Bus-Vao (High Occupancy Vehicle), get over 120,000 daily passengers. A new project aims to create a typical BHLS network, involving the insertion the addition of 8 new lines serving the outskirts of Madrid.

In 2008 the city of Castellón implemented a BHLS line (TVR) with trolley in reserved lanes and optical guidance system. The line has 5 stations, connects the downtown area with the university (with only 2 vehicles in service) and moves an average 3,200 passengers per day.

Figure 8: Optical guided trolleybus in Castellon

3.8. BHLS experiences in the Netherlands

Eindhoven was the first city to implement a magnetic guidance system. Fleet is made up of 11 single-articulated (Figure 9) and 1 double-articulated vehicle. Vehicles mainly drives on bus lanes, with a pre-programmed route continuously verified by magnets set into the asphalt.

The Zuidtangent is a suburban route that offers high reliability and an over 40,000 passengers daily ridership. Zuidtangent buses run on dedicated bus lanes from Haarlem to Schiphol Airport and use normal roads and motorways for the rest of the route. They have priority at road crossings throughout.

A network of High Quality Bus infrastructure, called HOV Om de Zuid, connects Utrecht main railway station with the university in the east suburbs, running double-articulated vehicles through segregated bus lanes. The system provides a ridership of 45,000 pax/day.


Figure 9: Articulated bus in Eindhoven

Table 1 provides an overview of the BHLS main features (length, average distance between stops, frequency and commercial speed) in different European contexts.

Table 1: European BHLS systems

	L (km)	D (m)	q (runs/h)	v (km/h)
Essen	4.0	800	6	30.0
Oberhausen	6.8	1000	30	34.0
Hamburg	15.0	510	18	18.8
Rouen	29.8	530	10	17.5
Nantes	7.0	500	15	22.0
Paris	22.0	700	15	22.0
Lorient	4.6	270	6-15	19.0
Jonkoping	39.2	440	2-6	22.0
Stockholm	79.7	450	6-15	16.5
Goteborg	16.5	700	6-20	21.0
Leeds	2.6	-	2-6	18.5
Kent	25.0	-	4-6	18.3
Manchester	15.5	310	6-10	18.4
Dublin	200.0	250	20-30	17.5
Zürich	22.2	400	6- 8	16.3
Madrid	16.1	450	17	33.5
Castellón	2.0	500	7-12	18.0
Amsterdam	41.0	1900	10	36.0
Utrecht	12.5	360	30	22.7

4. BUS FOR HLS LINES

A BHLS vehicle is not simply a bus. Its tecnology affects system performance, as it underlies the ability to meet demand, and determine some design choices related to the infrastructure.

The choice of vehicle layout may be influenced by the characteristics of the infrastructure (slope, winding, cross-section). Propulsion system influences variables of great interest for urban communities, such as pollution production rate. The vehicle equipment in terms of technological components are fundamental as regards comfort, safety and information. System performance, including commercial speed, frequency, and transport capacity, are generally significantly higher than traditional urban bus lines, although there are a wide range of solutions.

4.1. Vehicle layout

Generally a BHLS line tends to use large vehicles, such as articulated and double-articulated buses. They are the preferred as they enhance the transport capacity, creating an attractive image of service and reducing costs. Vehicles with a length up to 25-26 m are commercially available. There are some problems with interaction between vehicle and infrastructure, so a lot of attention is paid to parameters such as curvature radius and overhang dimensions.

Interior vehicle design (Figure 10) is related not only to the level of comfort offered and degree of security but also to expected peak demand. It is expressed through the distribution of spaces: seats, standing area, cockpit, space for disabled people, corridors, etc. Passengers prefer seats, but their number is limited. Even if a standard of 6 people per square meter is possible, BHLS lines tend to avoid overcrowding.

Positioning the engine in the rear of the vehicle allows the construction of fully low floors, making simple access for wheelchairs and disabled people possible.

Quality features such as tram-like sliding doors, closed area for the driver, soft and indirect lighting, confortable seats, insulation with double-glazed windows, tend to become widespread.

Manufacturers guarantee legal security standards (corridors, number and type of doors) inside vehicles. Among the innovative features there is the possibility of having doors on both sides, making boarding and alighting operations easier and faster.

Figure 10: Interior layout in an articulated vehicle

4.2. Guidance systems

Several technological solutions are aimed to ensure better performance of vehicles, in terms of trajectory control and approach, longitudinal and side precision dockings at stops, even allowing in some cases the automatic guidance of vehicles, are available today.

Among the mechanical systems, guide wheels with vertical axis (Figure 11) run along the curb side of the infrastructure, ensuring the trajectory of the vehicle. At bus stops with appropriate kerb height, the vehicle's guide wheel allows the driver to 'dock' against the stop achieving a uniform close contact to allow easy, level boarding.

Figure 11: Curb guided system in Essen

Optical guidance systems (Figure 12) use a camera located on front of the vehicle, a specialized image processing software, an automatic drive device. Through image recognition (two dotted lines in the middle of the lane) the vehicle is guided along the way. However, the driver can take manual control of the vehicle at any time. The system makes the docking into the stop easier, ensuring minimum distance of approach, avoiding collisions with the dock and increasing commercial speed.

Figure 12: Optical guidance bus in Rouen

In magnetic systems (homologation in progress), guidance is provided by magnets placed in the roadway and in close sequence along the route, and magnetometers placed on the bus (Soulas 2003). Magnetometers detect the magnetic field generated by the devices drowned in the infrastructure. The magnetic transducer converts signal into information for the automatic drive device. Automatic guidance can be used along entire line or can be enabled only in specific sections, such as stopping and linear sections.

4.3. Propulsion Systems

Propulsion technology has a deep impact on system performance in relation to operating costs, maintenance, environmental impacts.

The most common system uses an internal combustion engine, which drives a torque converter connected to a 4, 5 or 6 automatic transmission linked with a transmission shaft. Power outputs usually range between 180 and 250 kW (up to 350 kW for articulated vehicles operating in hilly places).

Today alternatives to traditional diesel oil are today commercially available (i.e. low-suphure diesel, bio-diesel, etc.), allowing considerable reductions of pollutant emissions. Another type of fuel used is natural gas (CNG), typically stored in large cylindrical tanks placed on vehicle's roof. CNG has environmental, economic and noise advantages. But these vehicles are still not the best solution because the tanks reduce the passenger capacity, problems may arise at certain temperatures and certain slopes, and vehicles require long refuelling times.

Electric and hybrid vehicles are preferred, as they limit pollutants emissions. Figure 13 shows the functioning of different propulsion systems.

Electric buses can use electricity by means of an overhead wire (trolleybus) or an on-board storage system, i.e. a battery. Their most prominent advantage is that they produce no emissions at their point of use. Thus the environmental impact of electric vehicles lies primarily in the electricity generation, through which, for instance, greenhouse gases are released. Exact nature and extent of these impacts depends on the means of electricity production: the use of renewable energy increases overall environmental efficiency.

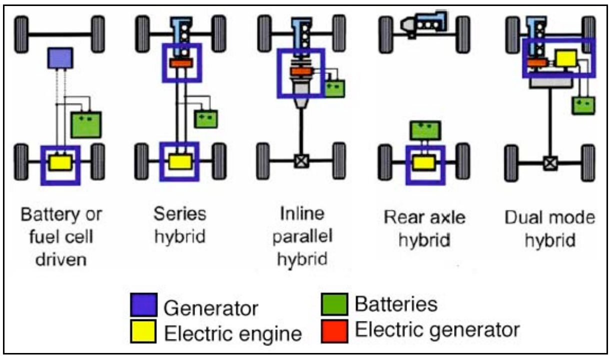

Figure 13: Alternative propulsion systems

In trolleybuses, two wires and pantographs are required to complete electrical circuit. This differs from a tram, which normally uses the track as the return part of the electrical path. Trolleybuses are advantageous on hilly routes, more effective than diesel engines in providing torque at start-up. Trolleybuses rubber tyres have better adhesion than a tram's steel wheels, giving them better climbing capability and braking. A further advantage of trolleybuses is that they can generate electricity from kinetic energy while braking (regenerative braking).

In battery-powered electric vehicles, energy can be stored onboard the vehicle. When required, energy is drawn from the batteries and converted to motive power by the use of an electric motor. Although full-sized battery-electric buses have been successfully operating, their performance limitations make them preferable for routes requiring only minibus vehicles and small operating ranges.

A dual-mode vehicle can run independently on power from two different sources, typically electricity (from overhead lines or batteries) alternated with conventional diesel fuel. Many modern trolleybuses are equipped with auxiliary propulsion systems, either using a small diesel engine or battery power, allowing a limited off-wire movement.

Hybrid vehicles incorporate on-board equipment to capture the energy that is normally lost through braking or coasting, and store it in batteries or ultra capacitors. They use both an internal combustion engine and a battery/electric drive system to improve fuel consumption, emission, and performance. These vehicles are classified by the division of power between sources: in parallel hybrids, sources operate to simultaneously provide acceleration, instead of series hybrids, where one source exclusively provides the acceleration and the second is used to augment the first's power reserve. The sources can also be used in both series and parallel as needed.

A fuel cell bus uses hydrogen to produce electricity, powering its onboard electric motor. This vehicle emits fewer pollutants, producing mainly water and heat. But the production of hydrogen would not be economically and environmentally convenient unless the hydrogen used in the fuel cell were produced using only renewable energy.

Currently, internal combustion engine is still the most used propulsion system. Hybrid and fuel cell technologies are still in prototype stage.

4.4. ITS technologies

Although not strictly required for a BHLS line, the use of Intelligent Transportation Systems (ITS) is becoming important, expecially with the increase of a service's complexity. ITS allow to make a large number of operations. It is possible to:

- know in real-time the vehicle's position and speed;
- activate priority systems at intersections;
- constantly connect driver and control center;
- know technical status of vehicles;
- acquire data for the evaluation of efficiency, reliability, consistency, security, vehicle's degree of utilization;
- provide user information at stops, such as waiting time; and
- provide user information on-board (Figure 14), such as time to next destinations.

The ITS effectiveness depends on the functionality of central control center. There are also specific components aimed to limit timewasting.

Figure 14: On-board real time information system

For example, specialized ticketing machines (Figure 15) increase service efficiency, especially during peak hours, avoiding the sale from the drive. Regarding tickets validation and checking, the trend is to avoid traditional on-board control. Devices limiting access to waiting areas exclusive to ticket holders can be used. Users flow controls can also be implemented through Automated Passenger Counters (APC), allowing a timely monitoring of transportation demand and the resulting measures to optimize operations.

Figure 15: Electronic ticketing validation machines

Video-control systems (Figure 16) became frequent in BHLS systems. Besides being useful for system management, they act as a deterrent against vandalism or criminal actions. Cameras provide complete coverage of buses and stations, operating real-time connections with control centers or video recordings.

4.5. On-board equipment

BHLS tends to be equipped in a richer way than traditional buses. Beside ordinary items such as first aid kits, fire extinguishers and "break-glass" hammers, there are baskets, jump seats, ticket vending machines, spaces and buttons for disabled users, audio-visual dynamic information systems and manual or automatic devices for the activation of wheelchairs ramps. Sometimes the carriage of bycicles is permitted on buses, but as a BHLS operates in highly crowded urban contexts, this solution is impractical.

Figura 16: On-board vehicle camera

4.6. Vehicle Performance

BHLS are characterized by higher performance than ordinary buses, in terms of commercial speed, vehicle and line capacity, energy consumption, emissions, comfort offered to passengers. Higher commercial speed comes from measures such as lanes protection, priority at intersections, reduction of boarding/alighting times and higher distance between stops.

Most of the elaborations proposed in this paragraph come from a COST (Cooperation in Science and Technology) database, created as part of Action TU0603. Data has been enhanced through a scientific research in Zürich.

The single vehicle length affect vehicle capacity. (Figure 17). Moreover, it is possible to relate the whole line capacity with runs frequency, for each type of vehicle (Figure 18).

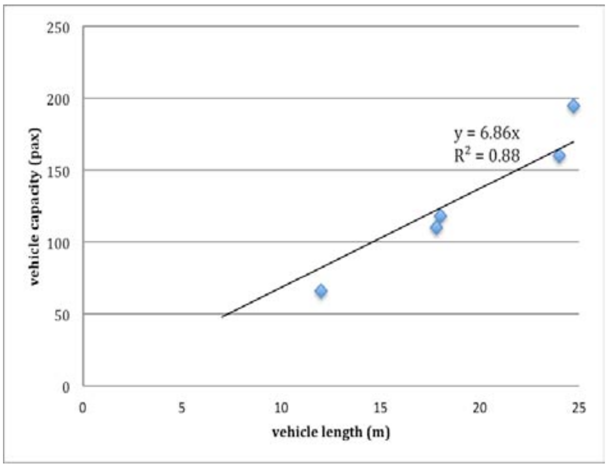

Figure 17: Vehicle capacity vs vehicle length

Many different studies identify speed as the main affecting factor on fuel consumption. The speed achieved by a vehicle is the result of interactions between factors like congestion, characteristics of vehicle and infrastructure, user behaviour and uniformity of running.

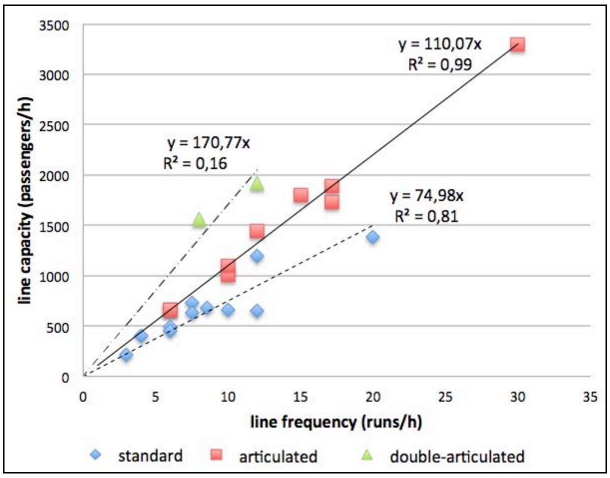

Figure 18: Line capacity vs line frequency

Several empirical models demonstrated that specific fuel consumption is relatively high at low speeds due to congestion. Moreover, consumption is influenced by vehicle size (Figure 19).

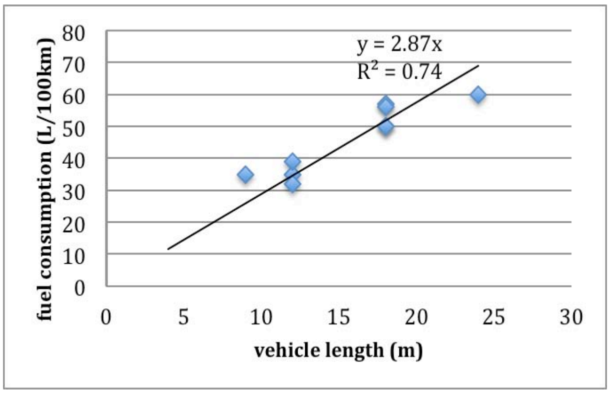

Figure 19: Fuel consumption vs vehicle length

Assuming an increase of 1.44 tons for each meter of length (resulting by a specific correlation analysis), it is possible to relate fuel consumption to vehicle gross weight, as shown in Figure 20.

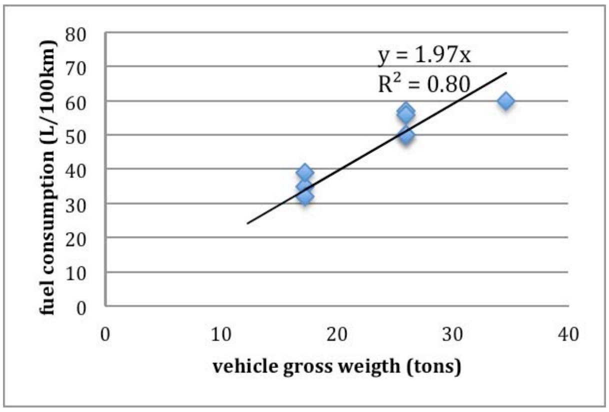

Figure 20: Fuel consumption vs gross weight

Other vehicle factors that give an important contribution in affecting the amount of fuel consumed during a trip are:

- air conditioning, which increases vehicle weight and is directly driven by the engine, with an increase of required energy of about 10-15% (Wilbers 1999);
- low tyre pressure, that increases vehicle rolling resistance and increased fuel consumption by 5–10 % (Nylund 2007);
- aerodynamic profile, affecting the air resistance acting on the vehicle;
- age of vehicle, as performanc decreases due to the wasting away of its component;
- number of stops (Figure 21): for a given distance, an increase of stops implies more acceleration-deceleration processes thus a relevant effort to achieve desired speed;
- priority at intersections: the higher the number of priorities at intersection the lower the fuel consumption; and
- congestion level: when the vehicle is embedded in flow, its running is disturbed and irregular, with many acceleration-deceleration processes.

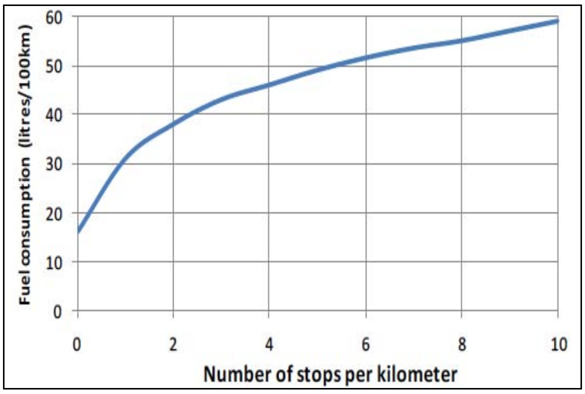

Figure 21: Fuel consumption vs stops per kilometer (Société de Transport de Montréal 2009)

European emission standards indicated in Table 2 define the acceptable limits for exhaust emissions of new vehicles sold in EU member states. EEV is the acronym of enhanced environmentally vehicle.

Table 2: Emission standards (g/kWh) for diesel buses. Source: European Environment Agency

	CO	HC	NO_x	PM
EURO I (1992)	4.5	1.10	8.0	0.36
EURO II (1998)	4.0	1.10	7.0	0.15
EURO III (2000)	2.1	0.66	5.0	0.10
EURO IV (2005)	1.5	0.46	3.5	0.02
EURO V (2008)	1.5	0.46	2.0	0.02
EEV (1999)	1.0	0.25	2.0	0.02
EURO VI (Jan 2013)	1.5	0.13	0.4	0.01

As regards to noise, that produced by a standard bus reaches values between 80 and 85 dB, whilst that produced by an electric propulsion vehicle ranges between 60 and 70 dB. Fuel cell vehicle noise is rather close to zero.

A road enlargement is required in a curve (Figure 22). For an articulated bus it is given by:

$$e = \sqrt{(p_2^2 + [\sqrt{(R + \frac{L}{2}) + p_1^2 - o^2} + \frac{L}{2}]^2} - (R + L) \tag{1}$$

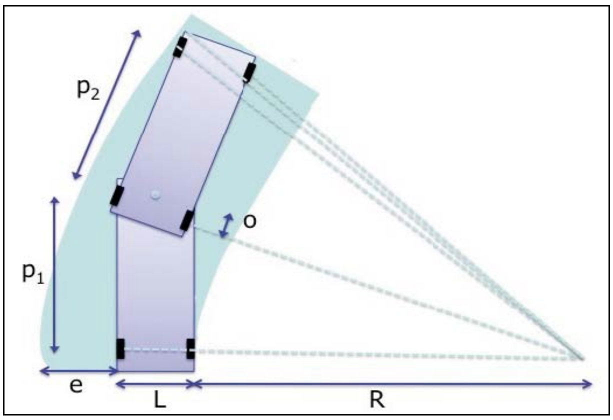

Figure 22: Road enlargement for articulated bus

The turning radius tends to increase with the length of the vehicle when passing from standard to single-articulated vehicle (from 9 to 11.2 m). In double-articulated buses, the peculiar partition of vehicle allows to keep radii on lower values (Figure 23). A further reduction of turning radius can be obtained by vehicles with all steering axles.

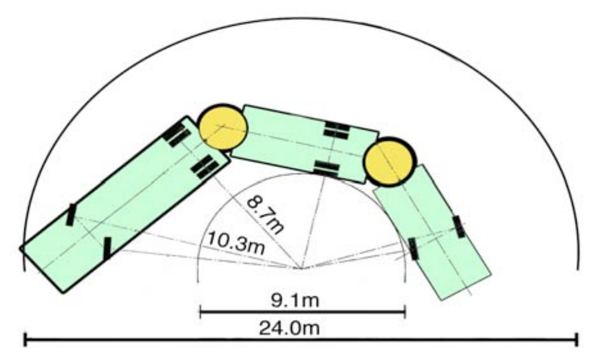

Figure 23: Double-articulated minimal turning circle
Source: elaboration on a Hess leaflet basis

Two main factors influence the motion on uphill roads. In relation to the variation of slope, front and rear overhangs impose the maximum angle (Gattuso 2008):

$$\alpha \leq min\ (\alpha_1,\alpha_2) \quad (2)$$

with: $\alpha_1 = arctg\ (h/s_a)$ $\alpha_2 = arctg\ (h/s_p)$ (Figure 24)

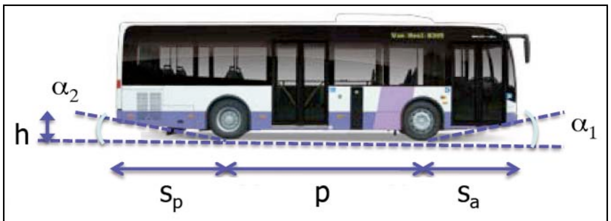

Figure 24: Maximum allowed slope

A second factor is the type of propulsion system used, and therefore the power required to overcome the motion resistances. As indicated in Figure 25 (Khanipour et al. 2007), if a path is winding, commercial speed is low and the engine is subjected to an anomalous and relevant effort.

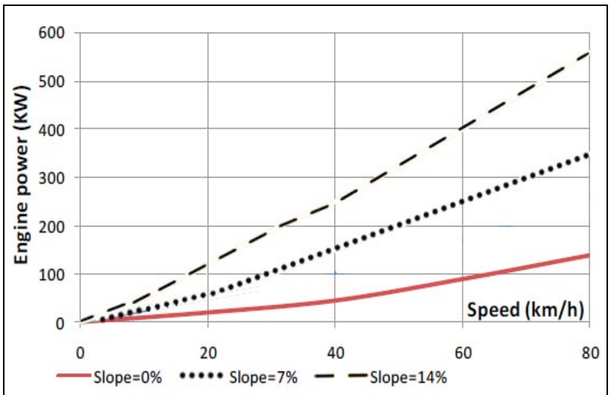

Figure 25: Required engine power vs speed and slope

A performance indicator relating to door numbers n and vehicle capacity w is the capacity per door c_d (spaces/door):

$$c_d = w / n \quad (3)$$

A low value of c_d makes passenger boarding and alighting more comfortable. Table 3 indicates typical entrance factor ranges. The highest values were observed at double-decker vehicles.

Table 3: Vehicle capacity per door

vehicle type	c_d (sps/door)
Standard	22-34
Articulated	28-34
Double-articulated	38-40
Double-deck	38-76

The effects of number of doors on boarding and alighting times are shown in Table 4 (source: Kittelson and Associates 1999). Increasing from one to two doors reduces boarding time 40%, from 2.5 to 1.5 seconds per passenger. Similar reductions are given for front and rear alighting.

Table 4: Passenger service times (s/pass) for low-floor buses.

door channels	boarding	front alighting	rear alighting
1	2.0	2.8	1.6
2	1.2	1.5	0.9
3	0.9	1.3	0.7
4	0.7	0.9	0.5
6	0.5	0.6	0.4

4.7. Vehicle costs

Since different configurations of vehicle type, propulsion systems, guidance systems, on-board equipment are possible, the result is an extreme variability of costs. Table 4 provides an order of magnitude of purchase costs for different types of vehicles.

Table 4: Average vehicle purchase costs (€)

propulsion	standard	articulated	double-art.
Diesel	200,000	300,000	600,000
CNG	250,000	350,000	650,000
Hybrid	300,000	500,000	850,000
Trolley	400,000	650,000	1,000,000
Fuel Cell	> 1,000,000	-	-

Within a propulsion system category, vehicle costs can be related to its length. Figure 26 refers to internal combustion engine vehicles.

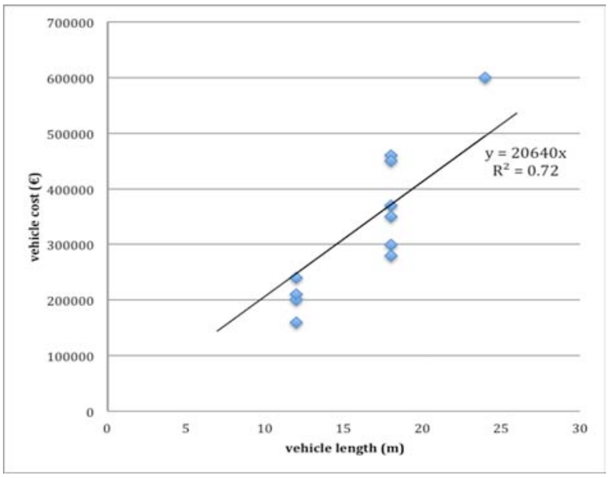

Figure 26: Vehicle cost vs vehicle length

A specific design of vehicle, can provide higher cost (+20÷50%). CNG articulated bus cost, for example, in Nantes city is 460.000 Euros.

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5. CONCLUSION

After a description of BHLS features and a review of experiences across europe, this paper focuses on the most widely used vehicles, in terms of external and internal layout, guidance and propulsion, ITS technologies and other on-board equipment.

The key factors that arise over traditional buses are identified. Plus, the paper introduces some performance models, mainly related to vehicles, line capacity and fuel consumptions. These models represent a starting point for the simulation of specific public transportation systems.

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MODELING THE EMPTY CONTAINER FLOW: IDENTIFYING PRIMARY INFLUENCING FACTORS THROUGH SCENARIO ANALYSIS

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ABSTRACT
Empty container management is a critical managerial area that affects the profitability of the container industry. Multiple factors that include the trade imbalance, storage costs, tariffs, taxes, handling costs and cost of manufacturing new containers affect the flow of empty containers. Trade imbalance is generally known as the primary influencing factor that leads to empty container accumulation. This study presents a view that trade imbalance is just an enabling factor and that the underlying reasons for accumulation of empty containers are the dynamics associated with the container leasing industry. The present study capitalizes and extends a previous study developed by Tulpule, Diaz, Longo, & Cimino (2010) that concerns with identifying the critical factors that intervene in empty containers management and creating a system dynamics framework for modeling this system. This extension further characterizes containers 'owned' by the shipping company and those 'leased' by the same company. Moreover, this new model includes new container manufacturing capacities and is used to perform a theoretical scenario analysis. This model forms a basis for reasoning about the possible trends in empty container movements such that the decision-making processes can be aided and improved.

Keywords: empty containers, system dynamics, decision support system

1. INTRODUCTION
The basic framework for the present study was introduced in Tulpule et al. (2010). This study extends the basic framework to include factors associated with the container leasing industry and the container manufacturing industry. The extended framework is used to test two theoretical scenarios in the container industry. The results of the scenario analysis are envisioned to provide insights into the primary causes leading to empty container accumulation in container surplus areas. The literature in this are traditionally focuses on trade imbalance as the major cause of empty container accumulations (Boile, 2006). Empirical data generated from the present study suggest that trade imbalance is an enabling factor while the dynamics associated with the container leasing industry are the primary reasons for empty container accumulation. These effects are further escalated by the changing preferences of the shipping companies to increasingly own containers instead of leasing them.

The problem of empty container accumulation according to Boile (2006) include trade imbalances, rate imbalances, new container prices vs. cost of inspecting and moving empties, un-timely shipment and delivery of containers, high storage fee in areas of high demand. While these factors certainly play a significant role in repositioning decisions, the third cause in the listing above has a significant impact on these decisions. This can be justified from the fact that although trade imbalance may encourage repositioning to demand areas and high storage fees may deter the same, large scale repositioning of empty container is inconceivable performed under normal circumstances if the cost of such an effort is higher than the cost of a new container in the demand area. This simple fact becomes complicated by the changing patterns of container ownership over the past few years.

The proportion of container owned directly by the shipping lines has steadily increased over the past few years (Theofanis & Boile, 2009). Shipping lines now own about 60 % of all the shipping containers while the rest is mostly owned by container leasing firms. Depending on the type of the lease that the containers are on, the shipping companies may be able to off-lease the containers in container surplus areas so as to avoid repositioning costs. Under such a scenario the leasing company becomes liable towards repositioning the container to the high demand areas. However such repositioning could become infeasible if the total cost of repositioning the empty container is more that the cost of purchasing new container in the deficit area. The shipping company has a distinct advantage of being able to reposition its own empties on its own ships without any freight costs (at least in a practical sense). This is because the ships travel largely empty on the backhaul and the trade imbalance ensures that practically no opportunity costs are involved. The leasing companies on the other hand have to pay the shipping company some freight charge to be able to reposition its container overseas. An approximate cost analysis in the later part of the paper shows that generally the shipping companies find (at least over the last decade) the repositioning option to be feasible over purchasing new container. The leasing companies, however, may or may not find repositioning feasible depending on the relative cost of repositioning versus purchasing new containers.

Since the shipping companies are liable for the containers they own, it is expected that they actively reposition them as required to ensure optimum utilization and avoid storage costs. This is not true regarding leased containers that can be possibly off-leased. With the tendency of the shipping companies to increase their ownership of the containers, such off-leased container may be replaced by purchasing new containers in the deficit area. This systematically leads to an accumulation of empty containers in the surplus areas. It can also be seen that a majority of these accumulated containers will be owned by leasing companies. This dynamic only changes in situations where the demand for empty containers is highly elevated and the container manufacturing facilities in the deficit region are unable to keep up with the demand. Under such a scenario the shipping companies in their need for empty containers and intense supply pressure of new containers opt to lease/purchase accumulated containers in the surplus region and transport then to the deficit region so as to satisfy customer demand. This situation results in a considerable drop in the container accumulation scenario.

Having introduced the background, the further paper is organized as follows; the next section includes a brief review of the relevant literature. This is followed by a brief introduction to the previously introduced model for the benefit of readers not acquainted with it. The fourth section discusses key extensions to the model developed by Tulpule, Diaz, Longo, & Cimino (2010). This is followed by developing two scenarios of interest and discussing the key results obtained by implementing the scenarios in the extended model. The paper concludes by discussing important findings and identifying the scope of future work.

2. LITERATURE REVIEW

Relevant literature pertaining to the empty container repositioning problem in general was covered in Tulpule, Diaz, Longo, & Cimino (2010). A brief summary of this literature is presented in this paragraph.

In general, empty container problems can be classified as inventory control problems (Cimino, Diaz, Longo, & Mirabelli, 2010). According to Lam, Lee, & Tang (2007) the literature dedicated to empty flows in terms of their application can be classified as operational, tactical, and strategic with a major portion of the literature inclined towards operational factors like depot location, and sizing. A comprehensive discussion the container industry in general with special emphasis on the reasons behind the accumulation of empty containers in all major ports in the US during that period has been provided in (Boile, 2006) and Theofanis & Boile (2009). The model presented in Tulpule, Diaz, Longo, & Cimino (Tulpule, Diaz, Longo, & Cimino, 2010) concerns with utilizing some of the factors identified in these studies as the basis for creating a system dynamics framework for modeling and simulating container movements. The critical point to be considered is the feasibility of the repositioning activity versus the option of purchasing new containers. In this sense, it is important to understand the costing structure behind shipping rates. An excellent analysis of the shipping fee costing and particularly the associated terminal handling charges is provided in European Commission (2009). Following is a brief account of the relevant aspects found in this paper. The shipping fee consists of three primary components namely two terminal handling charges at both the ports and a freight charge for movement over the ocean in terms of port-to-port container movement. The terminal handling charge recovers the fees that the shipping line has to pay to the terminal authorities for handling the container until it is loaded on the ship. The terminal handling charge has several cost components most of which (about 80%) are charged to the shipper in the form of the terminal handling fee. The balance, around 20%, is paid by the shipping company. Different rates may be charged for handling full versus empty containers. While the terminal handling charges are relatively stable the freight charges are the function of the supply/demand dynamics, operational costs, and fuel costs.

There is a clear difference between the shipping companies and the container leasing companies in terms of their repositioning cost structure. Assignment of freight cost to shipping company in terms of backhauling empty containers is a more or less theoretical issue and this cost is practically assumed to be zero in many cases (Konings, 2005). Another aspect that affects this relation is the relative demand for empty containers and the availability of new containers. Boile (2006) reports that excessive demand for empty containers in China around 2005 and a shortage of new containers due to limited manufacturing capacity forced the shipping liners to reposition containers form the US to China, thus, reactivating container that were off-lease for a considerable duration of time.

In summary, the literature points to the fact that container accumulation is affected by a combination of demand/supply dynamics as well as manufacturing capacity for new containers. Repositioning of empty containers is more feasible for the shipping lines as compared to the leasing companies. Also, the shipping companies may be increasingly adopting mass repositioning of empty containers in face of acute empty container shortages in demand areas. Lastly, the increasing tendency of the shipping lines to own container as reported by Theofanis & Boile (2009) adds further complexity to this system.

3. MODEL DESCRIPTION

This section briefly introduces the model that was previously introduced in Tulpule, Diaz, Longo, & Cimino (2010) which introduces a simple two port system with a trade imbalance setting. The port with a positive trade balance has the option of either importing containers from the other port or purchasing new containers. However, the preference for this decision depends on the relative cost of repositioning versus the cost of purchasing new containers. It is assumed that repositioning empty containers or purchasing of new ones is the only options for acquiring containers at the point of interest.

The model assumed an equal and fixed storage cost at both the ports and the same assumptions holds for the present analysis. Also the considerations of capacity made in the original model are no longer included. Sufficient capacity is assumed to be available at both ports to handle the container traffic. If the trade imbalance between the ports starts to change over time, an attempt is made to adjust the repositioning policy such that excessive accumulation will not occur in any of the ports. A delay of sixty days is introduced before decision makers can appreciate a significant change in trend of trade imbalance and make corrective actions to their policy.

The functionalities of this model are demonstrated using data from the Port of Los Angeles. For the sake of simplification it was assumed that the Port of Los Angeles has a single trading partner in China. The TEU statistics for the port of Los Angeles were obtained from (Port of Los Angeles, 2010). Figure 1 and 2 display the simulated and the average actual TEU of containers repositioned (out empty) from the Port of Los Angeles from 2000 to 2009 per day. As can be observed the simulated and the actual values follow similar trend and take comparable values. This provides an empirical validation for the proposed model.

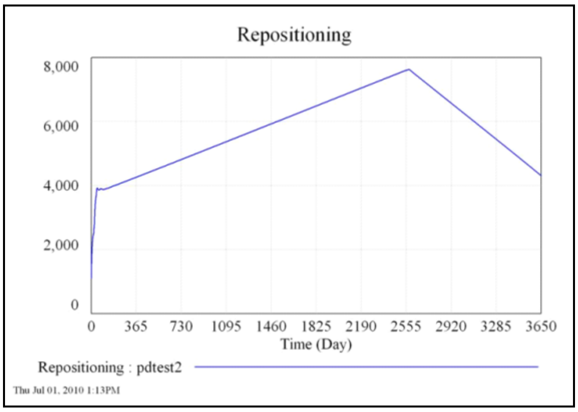

Figure 1 –Volume of repositioned TEU for port of Los Angeles

The said model is expanded to separately include representation for the 'leased' containers and is shown in Figure 3. It is known that about 60 % of the containers are owned by the shipping companies with the majority of the reminder are owned by container leasing firms (Theofanis & Boile, 2009). In the present model, the incoming containers are separately categorized as owned or leased. This is done by assuming a fixed ratio of split between owned and leased containers for containers coming into the US port. The present study assumes that 60% of the containers are owned by the shipping companies. Notice that the 'owned' portion of the containers also include leased containers that are on long term leases with the shipping company. Thus, the owned containers include all containers whose management is the liability of the shipping company. The 'leased' portion of the containers include containers that are on short term leases and which can be relinquished back to the leasing entity at the end of the trip. The empty containers (owned or leased) are used to satisfy the demand of empty containers by exporters and are consequently shipped back to the parent port (since this model has only two ports, the option of transshipment to a third port is not available).

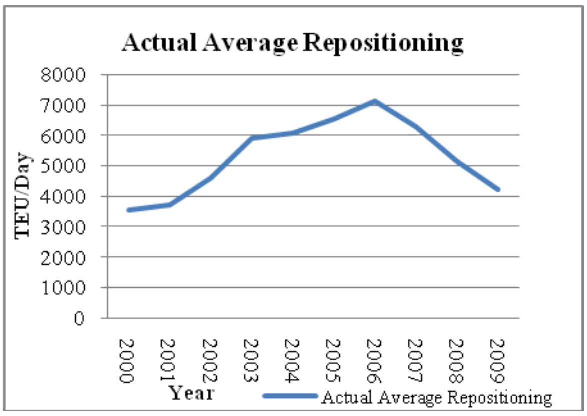

Figure 2 –Average volume of repositioned TEU for port of Los (Simulated) Angeles (Actual)

While segregation between 'owed' and 'leased' containers is included on one port, container manufacturing dynamics are included on the other port. The difference between required and the available empty containers indicates the number of containers that need to be newly manufactured. A fixed manufacturing capacity is assumed to be available. Excessive demand for newly manufactured empty containers uplifts the utilization levels of the manufacturing facility, thus, putting pressure on the container supply. This pressure is taken into account by introducing the factor 'Supply pressure.'

The utility of this factor is discussed as follows. The trade imbalance is a primary cause of empty container accumulation in ports with negative trade imbalance. Empty containers accumulate if the cost of repositioning empty containers to the deficit region is more than buying new containers in the deficit region. In this paper, the authors have asserted that trade imbalance is just an enabling cause of empties accumulation and that the factors associated with container leasing are the primary cause of accumulation.

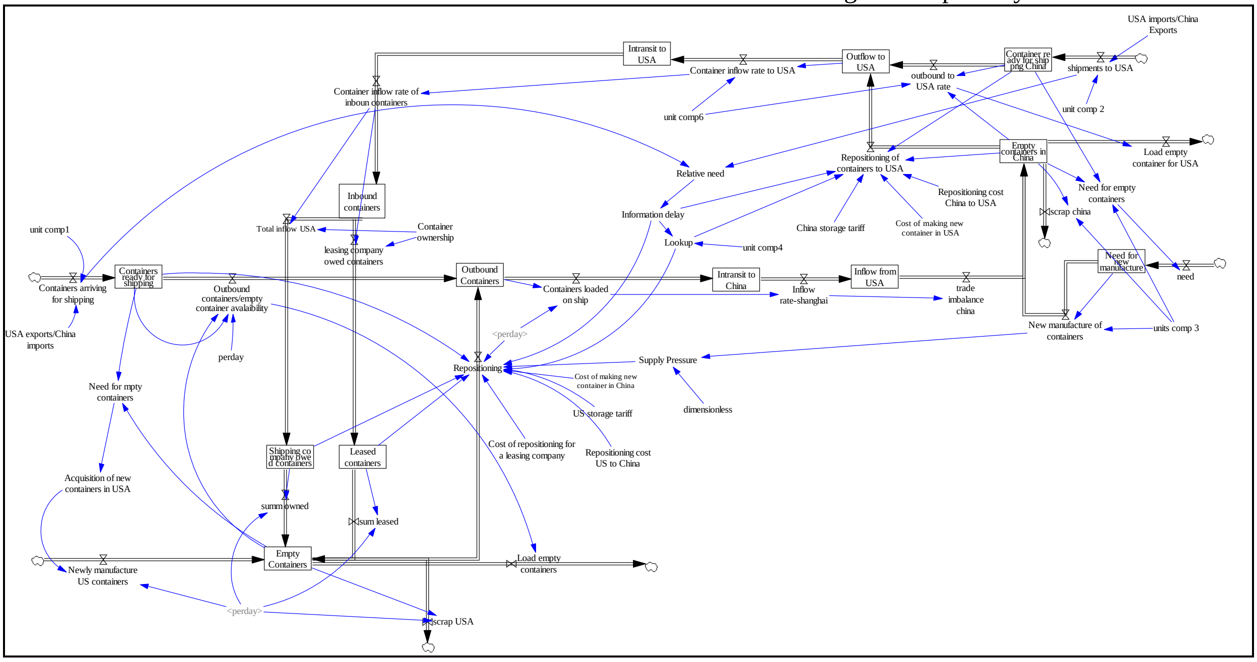

Figure 3 – Extended model for container movements

The fee charged by shipping companies to shippers for port-to-port transportation is primarily divided into three components namely a 'terminal handling charges' at both the ports and a 'freight charge' for transport over the ocean. Generally the terminal handling charge is split between the shipper and the shipping company in 80/20 ratio. To reposition an empty container, the shipping company becomes liable to pay the terminal handling charge at both the ports since it itself is the shipper.

There is no direct freight charge involved since the vessels travel largely empty in the reverse direction due to the trade imbalance and hence no significant opportunity costs is involved. However, this only is true if the container is 'owed' or on a long term lease with the shipping company.

The average terminal handling charge in 2009 at the port of Shanghai for a 20' dry container (generally any port in China) was 475 RMB with amounts to approximately 75 dollars. During the same period the terminal handling charge at the Ports in the US was 390 USD. Thus, at least in theory the total terminal handling charge that a line charges to its customers for a trans pacific movement is approximately (75+390)= 465 USD. Adding 20 % to this cost to over the liabilities of the shipping companies in terms of the terminal handling charge gives the total amount of 558 USD. (Veenstra, 2005) reports a cost of about 400 USD per empty repositioning.

As mentioned earlier, the above argument is valid only for container owned by the shipping companies. As against this the leasing companies would have to pay considerably more to have their container repositioned to deficit areas since they would also be liable to pay some ocean freight charges in addition to the charges mentioned above (Konings, 2005). Repositioning cost of the leasing companies could easily exceed 1,000 USD (Prozzi, Spurgeon, & Harrison, 2003) and are highly susceptible to demand/supply dynamics and fuel costs. Noting that the cost of a 20' dry container has never been below 1,500 USD in the last decade (Barnard, 2010), the following summary can be drawn. Firstly, repositioning is always preferable to purchasing new containers, in case where the containers are owned by shipping lines. However, this may not be true for containers that are off lease and possessed by the leasing company and depends on the relative costs of repositioning and cost of manufacturing new containers. Thus, accumulation results only if a container is off leased by the shipping company in a surplus region and the cost of repositioning the off lease container to the deficit region for the leasing company is higher than purchasing a new container in the deficit region. The only means of disposal for such containers if through the secondary market or during the periods of extreme demand for empty containers wherein the shipping companies may agree to lease or purchase those containers in the surplus region and take the cost of repositioning them to the deficit region upon themselves. The accumulation is abated by the tendency of the shipping companies to increasingly own their container fleet. Thus, containers off leased in the surplus region have likely been replaced by 'owed' containers purchased new in the deficit region.

The above discussion can be summarized as follows.

1. Shipping companies proactively reposition empty containers that they own to the deficit region since the cost of repositioning is always less than purchasing a new container (although new containers may still be purchased to satisfy increasing demand).

2. Cost of repositioning is higher for the leasing company, and thus, containers off leased in the surplus area may not be economically repositioned to the deficit areas as compared to purchasing new containers in the deficit areas.
3. The rising tendency of the shipping companies to own the containers leads to the tendency of off-leasing the container in surplus area and buying new containers in the deficit area, thus avoiding the cost of repositioning. From the first three points one could assert that empty containers owned by the shipping lines have a lesser chance of accumulation as compared to those owned by the leasing companies.
4. Extreme demand for empties and a shortage of new containers force the shipping containers to purchase or lease the containers in the surplus area and bear the repositioning cost to the deficit area, so as to be able to meet the demand for empties in the deficit area. In such a situation the surplus region should see a significant drop in accumulated containers as they are repositioned to the deficit regions.

The observations noted above are incorporated into the system dynamics model. The model is simulated and the results are used to validate if the model behavior replicates the hypothesized system behavior noted in the enumeration above.

4. SCENARIOS ANALYSIS AND RESULTS

This section would briefly introduce the model that was previously introduced

4.1. Scenario 1 - Constant export trade volume at both the ports with variable proportion of containers owed by shipping companies

Under this scenario, it is assumed that both the ports have a constant trade volume implying a constant trade imbalance. The cost of repositioning for a leasing company is same as that of a new container in the deficit area. Also, the cost of repositioning for a shipping liner is half that of the cost for a leasing company, since it is assumed that the shipping company does not incur any ocean freight charge. The following two scenarios are tested to see the effect of container ownership percentage on container accumulation and repositioning trends.

- Case 1 – Shipping companies own 60% containers
- Case 2 – Shipping companies own 100 % containers

It can be seen in the Figure 4 below a higher proportion of leased containers under the assumed circumstances leads to a higher accumulation of containers in the surplus area. These results from the fact that the shipping companies off lease the containers in the surplus areas and it is economically infeasible for the leasing companies to reposition the containers back to the deficit areas. On the other hand, containers owned by the shipping companies can be repositioned economically as the shipping companies incur lower repositioning costs. Secondly an adequate supply of new containers in the deficit area makes sure that the shipping companies can purchase or lease new containers in the deficit areas thus leading to an accumulation of empty containers owned by leasing companies in the surplus area. This observation of primarily leased containers being accumulated is reinforced in Boile (2006).

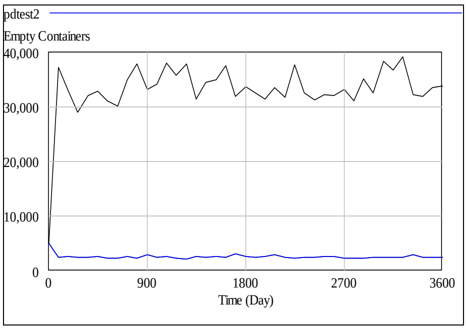

Figure 4- Container accumulation at US port, Case one – black line, Case two – blue line

It can also be seen from the Figure 5 below that in general the number of containers repositioned increases when the proportion of the containers owned by the shipping companies increases. This further reinforces our first observation of a lower accumulation rate in the same context.

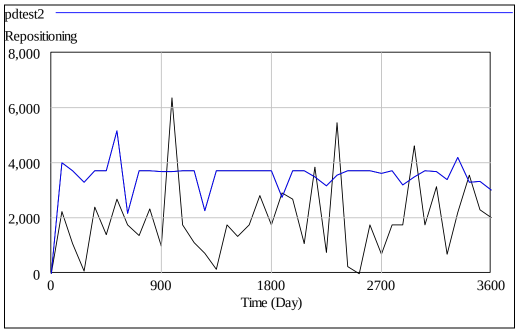

Figure 5- Container repositioning at US port, Case one – black line, Case two – blue line

4.2. Scenario 2 – Sharp increase in export trade volume at China port followed by sharp decrease, with variable proportion of containers owed by shipping companies

In the second scenario a very sharp increase in export volumes of the deficit port is assumed. The sharp rise in exports (TEU) is followed by an equally sharp drop as shown in the Figure 6 below. It is necessary to point out that such a trend is just theoretical in nature and does not reflect a real scenario. Such a trend is useful in observing how the modeled container market reacts to sharp rise and fall in demand.

Case 1 – Shipping companies own 60% containers
Case 2 – Shipping companies own 100 % containers

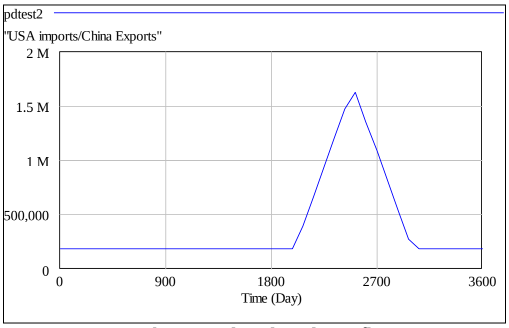

Figure 6- Theoretical trade volume fluctuation

As expected, the sharp rise in demand for empty containers exert an excessive pressure on the supply of empty containers as shown in Figure 7. As the container manufacturing facilities fail to meet the demand, the shipping companies in desperation turn to the accumulated containers owed by the leasing companies in the surplus areas. The shipping companies undertake to reposition these containers from the surplus to the deficit areas after acquiring them on lease or by purchase. This is reflected in the Figure 8 wherein a sharp drop in the accumulated leased containers is observed. Also as seen in Figure 9 the repositioning volumes of owned as well as leased containers match closely during the demand hump as opposed to the observation in the first scenario. It can also be seen from Figure 10 that a sharp fall in demand that is followed by the sharp rise leads to an excessive accumulation of empty containers in the previously deficit regions. This observation is reinforced in (Bloomberg, 2009). This is because a large number of containers repositioned to the deficit areas are no longer required which results into the observed accumulation in the previously deficit areas.

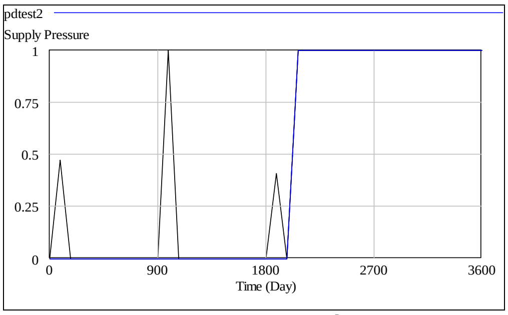

Figure 7- New container supply pressure

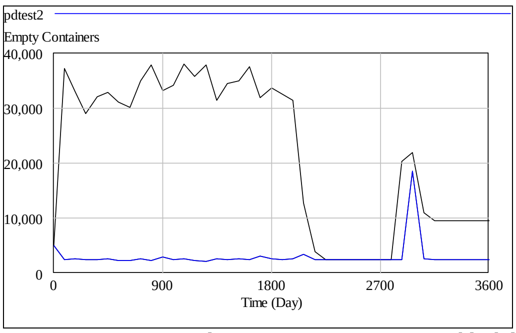

Figure 8- Container accumulation at US port, Case one – black line, Case two – blue line

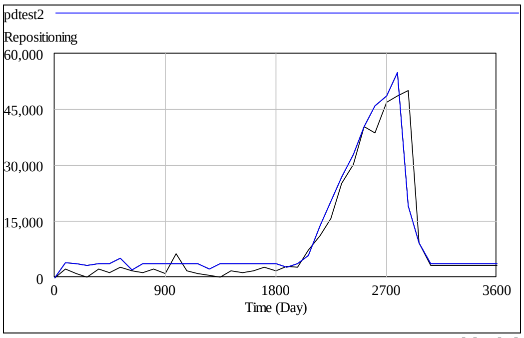

Figure 9- Container repositioning at US port, Case one – black line, Case two – blue line

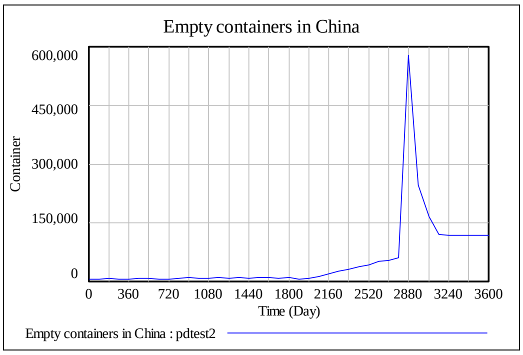

Figure10 - Empty container accumulation in the simulated Chinese port

5. CONCLUSION AND FUTURE WORK

The presents study extends the previously introduced system dynamics model (Tulpule, Diaz, Longo, & Cimino, 2010) for container movements to include container leasing dynamics and new container manufacturing capacity. It is asserted that while trade imbalance is an enabling factor, the actual underlying reason for container accumulation lies in the dynamics associated with the container leasing industry. Theoretically, speaking if all the containers were owned by the shipping lines, then no significant accumulation of the containers should be observed in either of the ports in spite of significant trade imbalance. As discussed, empty container repositioning is consistently more feasible for the shipping lines as compared to the leasing companies since the shipping lines do not have to bear any ocean freight charge, at least in a practical sense. When the demand of the empty containers exert excess pressure on the container manufacturing facilities, the shipping companies may be forced to lease accumulated containers in the surplus region and transport the back to the deficit region taking upon themselves the repositioning costs. However, the need to satisfy customer demand under heavy shortage of empty container makes this choice imperative. The increasing tendency of the shipping lines to own their containers increase pressure on the leasing companies, especially on imbalanced trade routes. A rise in the cost of steel leading to an escalation of new containers can make repositioning a more feasible option for the leasing companies. However, an equivalent rise in freight charges could offset that difference by increasing the backhaul ocean freight charges. In any case, the shipping lines are in a better position to undertake the repositioning activity as compared to the leasing companies.

On the other hand, rising trade imbalance may give the leasing companies some leverage to negotiate better backhaul charges for the empty containers as the shipping lines struggle to find export containers. It seems unlikely though, that it results in any significant gains for the leasing companies unless there is excessive demand pressure for empty containers.

The present study helps to acknowledge and quantify many of these dynamics using a modeling and simulation perspective. The scenarios presented in this paper certainly help in better understanding the factors influencing these dynamics. These results are especially relevant for the leasing companies as they provide a platform to test various scenarios in the context of various leasing options. For example, the leasing companies can and actually do alleviate the problem of repositioning by specifying the 'drop off' location on lease expiry in the container deficit region. However, in case of long term leases specifying such conditions accurately can be difficult as trade patterns keep changing. The leasing companies charge pickup and drop-off fees to the customers to cover the costs of repositioning. However, the cost of repositioning is volatile and subject to demand/supply dynamics and commodity prices which make difficult to ensure that the charged fees can cover the repositioning expenses. Above of all, the fees that can be charged and the lease conditions that can be specified are largely dependent on the leverage that the leasing companies have over the shipping companies. The increasing tendency among shipping companies to own containers act against any leverage the leasing companies have. Appropriate policies can be designed when the dynamics associated with this industry are appreciated and a rigorous scenario analysis is performed to identify and quantify risks and opportunities. The model presented in this paper aspires to support this precise effort.

The present study can be extended to include details on specific lease types such that scenarios can include various lease portfolio options. Also the two port model can be expanded to a multi port system. Primary factors like the cost of steel and oil as well as the supply demand dynamics that affect the freight rates can be explicitly included in the model.

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A SYSTEM DYNAMICS APPROACH TO MODELING THE COST ELEMENTS OF CHRONIC DISEASE MANAGEMENT INTERVENTIONS

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ABSTRACT

Medical treatment for chronic conditions forms a major portion of the US healthcare expenditure. Chronic diseases are generally associated with ailments without any permanent cure which significantly affect the health status, lifestyle, mobility and longevity of patients. A variety of chronic disease management interventions have been deployed to help patients better manage their medical condition. The main purpose of such interventions is to improve their health condition while achieving cost savings through a reduced healthcare utilization rate. While these interventions are desirable from the point of view of relevant clinical outcomes, the monetary outcomes in terms of costs and savings are uncertain. Further, most studies rely on short term savings and do not consider future healthcare costs. This study presents a system dynamics model representing the key cost factors involved in implementing a disease management intervention, and the dynamics associated with those factors. A simple goal seeking structure is embedded in the model as a simulation based optimization routine. The functionality of the model is demonstrated by means of hypothetical scenarios implemented via sensitivity analysis. The model provides useful insights into how the initial estimates of the cost of intervention and the resulting savings would change depending on the uncertainties, feedbacks and the targeted savings in the system. The model is designed to be used as a learning and decision support tool for implementing chronic disease management interventions.

Keywords: chronic disease management, ambulatory healthcare system, intervention modeling, support system

1. INTRODUCTION

Medical treatment for chronic conditions forms a major portion of the US healthcare expenditure. The increase in Medicare spending between 1987 and 2002 can be significantly attributed to patients treated for multiple chronic conditions (Thorpe & Howard, 2006). Nearly half of the US healthcare costs in 1996 accounted for five chronic conditions namely mood disorders, diabetes, heart disease, asthma and hypertension (Druss, Marcus, Olfson, Tanielian, Elinson, & Pincus, 2001). Half the female population and 40% of the male population had at least one chronic condition while 78% of the healthcare dollars were spent for treatment of chronic conditions in 1998 (Anderson & Horvath, 2004). Chronic diseases are a persistent and escalating problem with nearly 40% of adults between age of 18 to 64 years having at least one condition as compared to 34 % in 2003 (Tu & Cohen, 2009). In the same study 28% of the adults with chronic conditions reported financial problems in dealing with healthcare costs compared to 13 % with non chronic conditions.

Chronic diseases are associated with ailments without any permanent cure and which significantly affect the health status, lifestyle, mobility and longevity of the patients. Perrin, et al. (1993) suggests a two level approach that includes duration and impact when defining chronic conditions for children. Duration is referred to conditions lasting more than 3 months and classified as chronic. The impact of the condition on the child is considered in terms of healthcare utilization and any inabilities or restrictions on his/her lifestyle. O'Halloran, Miller, & Britt, 2004 provide a broader framework for defining chronic conditions wherein they identify duration, prognosis, pattern and sequelae are considered as relevant factors to be included in the definition of chronic conditions. Although no single definition of chronic conditions exits, a number of criteria are available that helps clinician a researchers classifying chronic versus non-chronic conditions. The term ‘Chronic’ is widely used in context of ailments such as Chronic obstructive pulmonary disease (COPD), Congestion Heart Failure (CHF), Asthma, Diabetes, and Cancer, though other conditions like arthritis, psychological disorders and HIV are referred to as ‘chronic’ as well.

To assist patients in managing their chronic condition, a variety of chronic disease management mechanisms have been developed. Chronic disease management is defined by Weingarten et al. (2002) as interventions designed to control or prevent chronic conditions by potentially using multiple treatment methods. These interventions include provider education, provider feedback, provider reminders, patient education, patient reminder and patient financial incentives (Weingarten, et al., 2002). Wagner, Austin, & Von Korff (1996) suggest organizing interventions within a framework called chronic care model (CCM). CCM defines a successful chronic disease healthcare system by being inclusive of six main components that include Delivery System Design, Self Management Support, Decision Support, Clinical Information Systems, Community Resources and Health Care Organization (Wagner E. H., Austin, Davis, Hindmarsh, Schaefer, & Bonomi, 2001). Interventions can be targeted at one or more of these components. Zwar (2006) shows that including few of these elements in the healthcare system leads to improvements in healthcare outcomes. The Innovative Care for Chronic Conditions (ICCC) presented in (World Health Organization, 2002) is a more universally applicable model based on the CCM. The ICCC takes a broader perspective as compared to the CCM by including the health policy at the macro level and the patients and their families at the micro level.

The literature in chronic disease management interventions targeted at various components of the healthcare system seen from this perspective is substantial and extensive. Evaluating the efficiency and effectiveness of intervention alternatives to a targeted population segment for a given condition is a relevant and remaining issue. This is essential since resources available for implementing such intervention are limited in most scenarios. This is also fundamental in achieving cost saving from launching interventions in addition to attaining improved clinical outcomes. Thus, it becomes imperative to perform a cost-benefit analysis to determine which intervention or set of interventions produce the targeted results in terms of health and monetary outcomes. Meyer & Smith (2008) suggest that the degree of success of the intervention depends on a number of factors like the particular chronic condition under consideration, patient characteristics, the type and frequency of the intervention chosen and the resultant impact on healthcare utilization patterns. Further, there seems to be no consensus on the cost elements to be considered in performing a cost-benefit or returns on investment analyses for the potentially applied interventions. For example, in the medical context the issue of whether to include future unrelated medical expenses seems open ended since most studies restrict themselves to consider only related costs (Meltzer, 1997). Unrelated future expenses are the expenses that would be incurred to treat the patient for conditions other than his original medical condition. These expenses are resultant from the extension of patient's life due to the medical intervention (Van Baal, Feenstra, Polder, Hoogenveen, & Brouwer, 2011). Thus, an intervention which may seem to be cost saving on a shorter term may prove to be otherwise in the long term. A long-term evaluation of intervention strategies is an intricate issue mired with multiple complexities and feedbacks.

This study presents a system dynamics model representing the key factors affecting the evaluation of an intervention and the dynamics associated with those factors. A simple goal-seeking structure from a system dynamics approach is embedded in the model as a simulation-based optimization routine. The functionality of the model is demonstrated with hypothetical scenarios implemented via sensitivity analysis. The model provides useful insights into how the initial estimates of the cost of intervention and the resulting saving changes depending on the uncertainties and feedbacks in the model. The model is designed to be used as a learning and decision support tool for evaluating the implementation of chronic disease management interventions.

The paper is organized as follows. In the next section a brief review of the relevant literature will be provided. This will be followed by the introduction and description of the said system dynamics model. The fourth section will present the model simulation based on theoretical scenarios and the outcomes of the same. The paper concludes with the discussion of the results and scope of future work.

2. LITERATURE REVIEW

A current issue of contention is the idea that chronic disease management interventions lead to quality improvement while achieving cost benefits. Fireman, Barlett, & Selby (2004) compare healthcare cost and quality trends among groups of adults having chronic diseases and under disease management and those not having chronic diseases. Results from this analysis suggest that although disease management interventions proved to be a useful tool, they do not produce any cost savings. Further, an increase in healthcare costs is observed at least in the shorter term. This analysis does not consider any long term related or unrelated costs, however. An extensive review of cost benefit studies in chronic disease management context was performed by Goetzel, Ozminkowski, Villagra, & Duffy (2005). They report positive savings for chronic conditions like CHF and other multiple disease conditions. Although interventions for diabetes, for example, are found to report positive savings, a need for more research is stressed. These authors assert that interventions targeted to certain chronic conditions such asthma produce mixed results while those targeted at depression report to produce negative results. Thus, it seems that interventions produce different results depending on which chronic condition they attempt to address. Meyer & Smith (2008) assert that depending on a number of factors such as the type of chronic condition, types and frequency of intervention, and the demography of the patients, it is possible to predict the success of the savings produced by the interventions. However, the numerous studies considered by Meyer & Smith (2008) assume that chronic disease management interventions deliver savings.

Fireman, Barlett, & Selby (2004) suggest that disease management interventions attain savings through the following means: first, improving quality of health through use of medications and self-care such that future complications are prevented; second, reducing overuse of healthcare by working with patients; and lastly, through productivity improvements by the way of allowing allocation of some tasks related to interventions from the physicians to other staff. However, in this suggested scheme the consideration of future related and unrelated costs due to increased life expectancy resulting from the implemented interventions is missing. The consideration of future costs has been generally limited to consideration of 'related' healthcare costs in cost effectiveness studies concerned with medical interventions (Meltzer, 1997).

Related healthcare costs refer to the costs directly concerned with the ailment at which the intervention is targeted. Van Baal, Feenstra, Polder, Hoogenveen, & Brouwer (2011) point out that if a medical intervention in the form of a heart surgery saves a patient's life, then future heart related healthcare costs for that patient is a 'related' healthcare costs. However, if the same patient is detected with diabetes after the heart surgery, then the cost of treating diabetes is an unrelated healthcare cost. The consideration of unrelated costs in evaluating intervention effectiveness studies is increasingly gaining support (Van Baal, Feenstra, Polder, Hoogenveen, & Brouwer, 2011).

Measures of performance that gauge the effects of chronic disease management interventions in certain contexts are rather limited. For example, conclusive evidence regarding the effect of chronic disease management interventions on mortality is unclear for all chronic conditions. However, a number of studies, especially in heart disease interventions, have reported an important reduction in mortality resulting from disease management interventions. Roccaforte, Demers, Baldassarre, Teo, & Yusuf (2005) report a significant reduction in mortality, among heart failure patients under disease management program as compared to those not under such a program. Garcia-Lizana & Sarria-Santamera (2007) report a reduction in mortality due to intervention for cardiovascular diseases while no improvement is reported for other chronic diseases. Hamalainen, Luurila, Kallio, & Knuts (1995) also report significant reduction in incidence of sudden deaths and mortality related to coronary disease resulting from disease management intervention. Miksch, et al. (2010) report a reduced mortality among patient enrolled under a disease management program for managing chronic diabetic conditions. Meigs, et al. (2003) conduct an analysis of web-based diabetes management interventions and claim that it has the potential to reduce patient mortality.

Due the impact of disease management interventions on mortality, the design and implementation of effective chronic diseases interventions is a need. To properly evaluate a given intervention from the cost-benefit perspective is necessary to consider future related and unrelated costs of healthcare. However, many studies seem to ignore such considerations. Few studies, such as Chan, Heidenreich, Weinstein, & Fonarow (2008) utilize a Markov model to consider such issues. The possibility that a patient will survive, hospitalize, or die is characterized by a transition probabilities matrix associated with the model. This study considers related and unrelated healthcare expenses while finding that the patients under disease management have a longer lifespan, and hence, producing higher costs to the system. The simulation of this model shows that disease management interventions for heart failures are likely to be cost-effective while incurring more cost than the base case scenario. Gohler, et al. (2008) and Miller, Randolph, Forkner, Smith, & Galbreath (2009) conducted similar studies and report comparable results. The Congressional Budget Office (2004) seems to be aligned with these suggestions when expressing that disease management programs may not be able to realize the anticipated cost savings, especially in the longer term.

Since potentially disease management programs can be cost-effective but prospectively not cost-saving, the extent of investment decisions in such programs can be controversial. Such decisions can be particularly difficult for healthcare programs in the public arena like the Medicare, wherein the administrators and the public are already weary of rising costs. Making appropriate decisions in this complex environment is possible when the stakeholders have correctly appreciated the complexities and the feedback structures within the system. The purpose of this paper is to develop a basic framework that supports such deliberations. The aforementioned complexities and feedbacks in this intricate context make system dynamics an ideal platform for such an effort. Further, system dynamics models are intuitive and can closely represent real-life factors and characteristics. Such a tool can serve as a useful scenario analysis and consensus building tool among stakeholders with conflicting viewpoints, and thus, facilitate the accomplishment of the most appropriate decisions.

3. MODEL DESCRIPTION

The objective of the model suggested in this paper is to establish the cost of intervention per patient per unit time and the cost of healthcare per visit, in such a manner that the targeted savings are achieved. The simulation model diagram is exhibited in Figure 1. The difference between the targeted savings and the actual savings denoted by 'savings pressure', drives the model towards adjusting the system parameters until the required savings are obtained and the system attains a steady state. To achieve the targeted savings the 'savings pressure' adjusts the 'cost of care pressure' and the 'cost of intervention pressure'. The magnitude of influence that the 'savings pressure' has on both of these pressures is defined by the elasticity associated with the each of these parameters. The elasticity determines the degree of change in the parameter in response to a unit change in the 'savings pressure'. The 'cost of intervention per patient' and the 'Actual cost of care per patient' are influenced by the 'cost of intervention pressure' and the 'cost of care pressure respectively'. The total cost of intervention is determined by the cost of intervention per patient, the total patient population, and the fraction of the patient population that is targeted for the intervention.

The intervention is assumed to produce a degree of improvement in the health status, which leads to a reduction in the net mortality rate. The mortality rate influences the patient population which further influences the total cost of intervention and the total cost of care. A certain pre- and post-intervention per capita healthcare utilization is assumed to estimate the total patient visits. The post intervention utilization has an aging amplification factor, 'Aging delay', associated with it. This occurs after a delay of certain time period. This factor is representative of the fact that after a reduction in per capita utilization in the short term, the per capita utilization will likely increase after certain period of time. This takes place as the patient population is further aged due to life extension resulting from the disease management intervention. Further, as the patients age they are likely to develop multiple chronic conditions which will result in further increase in utilization. Following the same logic a cost amplification factor is applied with a time delay, to compensate for the likely hike in the cost of care for treating multiple chronic conditions as compared to fewer chronic conditions at the onset.

Using the pre-intervention per capita utilization and the pre-intervention mortality rate, parameters for retrospective patient population and retrospective patient visit are determined. These parameters along with the retrospective cost of care per patient per unit time are used to estimate the total cost of healthcare in absence of the intervention. The difference between the pre- and the post-intervention healthcare costs determine the total savings in the healthcare costs as a result of the intervention. The final savings are obtained by taking the difference between the total savings in the healthcare cost and the total cost of administering the intervention. Parameters like the effectiveness of the intervention, the initial estimated cost of intervention, and cost of care or the effect of intervention on the per capita visits rate are represented by stochastic functions. These stochastic functions are embedded in the system to take into account uncertainties associated with estimating these parameters. Finally, the system stabilizes when the savings pressure is reduced to zero or to the possible extent reliant upon the values of the elasticity associated with the cost of intervention and the cost of healthcare. The trajectories of the cost of intervention and the cost of healthcare exhibit the actual resources that can be spent to achieve targeted savings.

4. SIMULATION AND RESULTS

The objective of this section is to simulate the model under different scenarios. The outcomes of these scenarios assist in developing useful insights from the system. To demonstrate its functionality, a simple hypothetical case is developed. Consider an initial population = 100, estimated cost of care post intervention=100, cost of care per visit pre intervention = 100, initial estimated cost of intervention = 10, cost of care elasticity = 0.5, cost of intervention elasticity = 0.01, health status pre-intervention = 2 (on 1-5 scale), pre-intervention per capita utilization = 3.5. Using these theoretical values, the model is simulated under specific scenarios such that its behavior can be described.

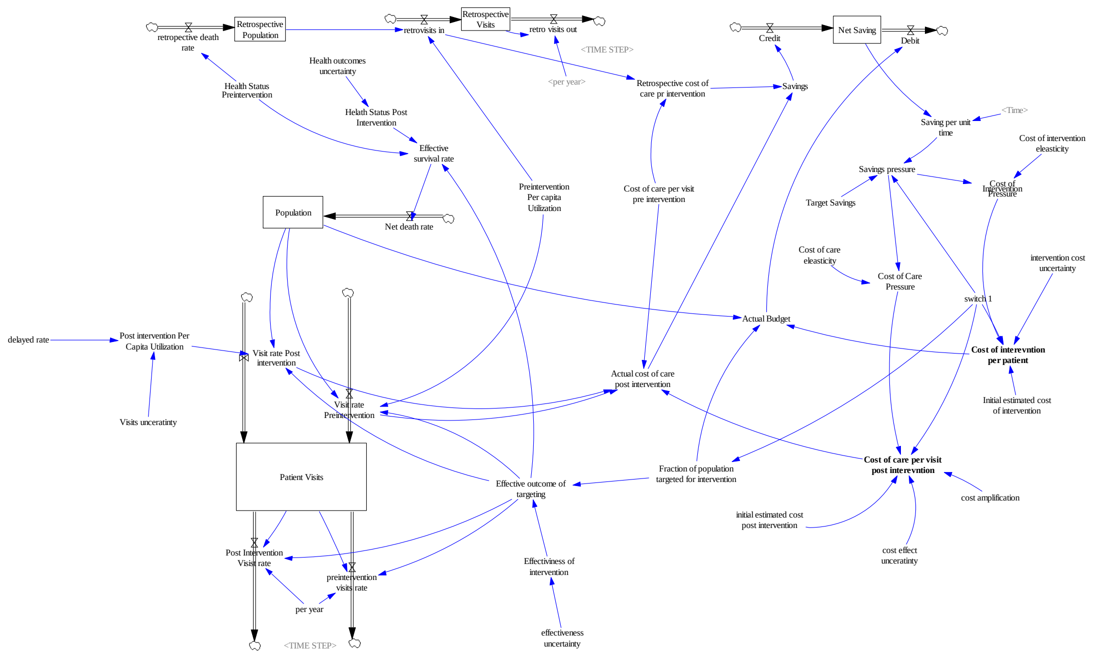

Figure 1. Simulation model for the proposed model

Scenario 1- To compare the model performance in 'intervention versus no intervention' scenario while setting the target savings to zero.

The purpose of this scenario is to see how the key system parameters behave under 'intervention' versus 'no intervention' i.e. the original system. As can be seen in Figure 2 the total visits by patients increase in both the scenarios due to increasing population. However, in the 'intervention' scenario the total visits, are initially less as compared to the 'no intervention' scenario due to the effects of the intervention. However, in the longer term the visits rate in the 'intervention' scenario exceed that of the 'no intervention' scenario as a result of aging and life extension and the increase per capita utilization at advanced age due to multiple chronic conditions.

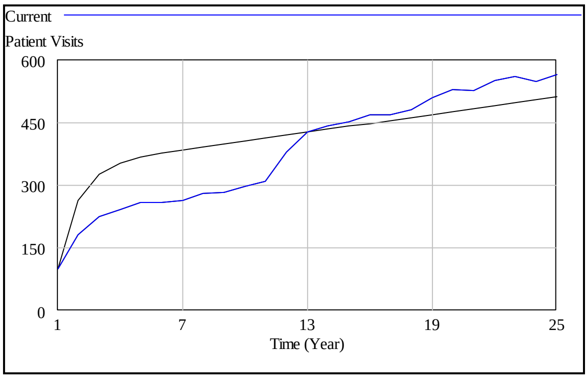

Figure 2- Total Patient Visits (blue line- intervention, black line- no intervention)

Figure 3 shows the savings accumulation in the 'intervention' versus 'no intervention' scenarios. It can be seen that 'interventions' produce higher net savings in the short term. However, the savings are eroded as the per capita utilization and the cost of utilization of the patients escalate due to aging. This result demonstrates the point of view seen earlier, that the disease management intervention may not be cost saving, especially in the longer term.

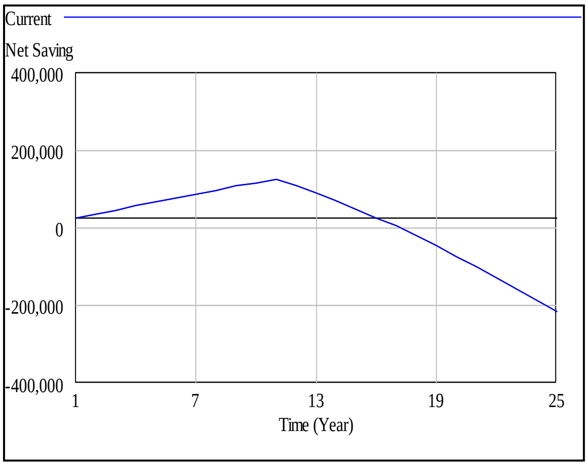

Figure 3- Net Savings (blue line- intervention, black line- no intervention)

Figure 4 shows the patient population growth in the 'intervention vs. no intervention' scenario. In the 'intervention' scenario, the population grows at a faster rate, due to decrease in the mortality rate resulting from better disease management, and therefore, increase in longevity.

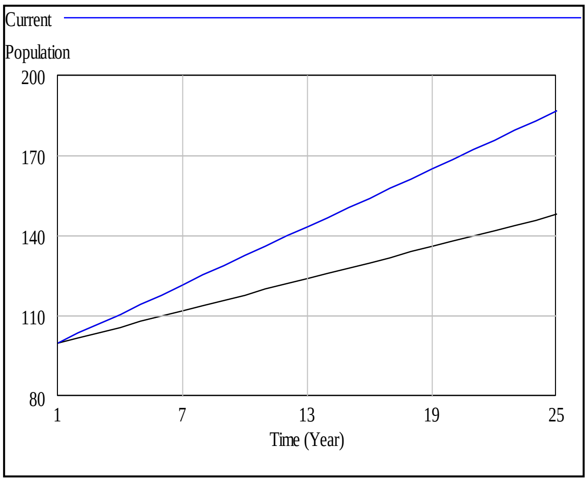

Figure 4- Population Growth (blue line- intervention, black line- no intervention)

4.1. Scenario 2- Model performance when the target savings is set versus zero target saving

This scenario serves as a demonstration of the goal seeking structure of the model. In the first case the target savings of the system are set at 25,000 dollars, while in the other case the target savings are set to zero. Figure 5 illustrates the resulting hypothetical net savings from both the cases within the scenario. When the target is set at 25,000, the goal seeking structure adjusts other components of the model to produce the higher net savings as compared to the case where no saving was targeted. However, as Figure 6 exhibits, to produce the higher savings a significant cut in the cost of care per patient is required.

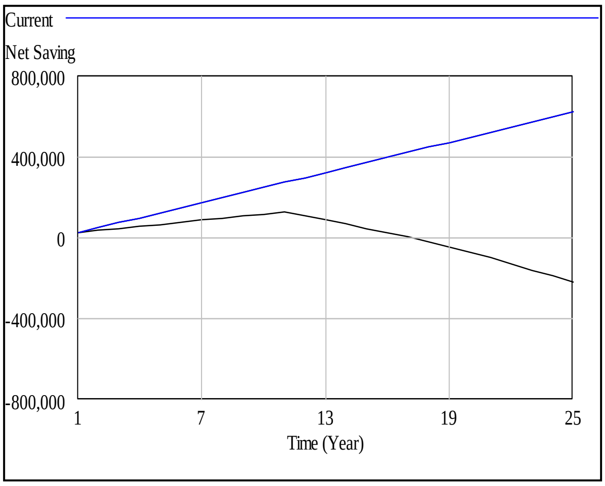

Figure 5- Net Savings (blue line- target saving, black line- no target saving)

The cost cut is not as severe in case of the cost of intervention per patient as seen in Figure 7. This is because of the low elasticity associated with the cost of intervention. Typically, the cost of intervention is found to be significantly lower than the cost of care. As a result, the net savings obtained from reducing the cost of intervention is far less than the net saving that can be obtained by reducing the cost of care. As a result the elasticity of intervention is set to be far lower than the elasticity of the cost of care.

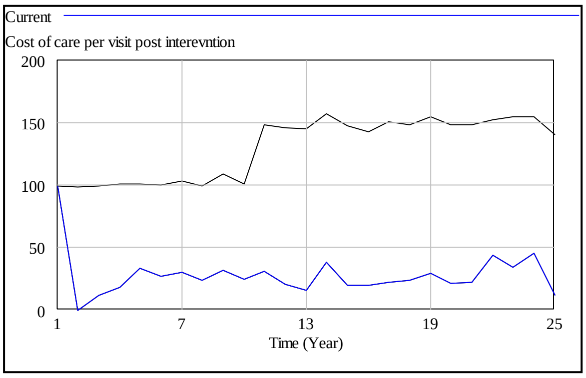

Figure 6- Cost of healthcare per visit (blue line- target saving, black line- no target saving)

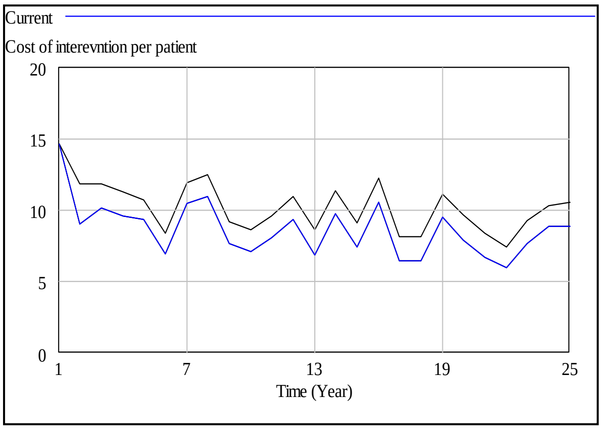

Figure 7- Cost of intervention per patient per unit time (blue line- target saving, black line- no target saving)

This scenario helps us to understand the consequences that the healthcare system would have to face if the targeted savings have to be achieved. In a more practical scene, this scenario helps us identifying the magnitude of cost efficiency that has be brought about in the healthcare system resulting of the intervention, if the targeted savings have to be realized.

5. CONCLUSIONS

The occurrence of chronic disease is widespread in the United States. Chronic diseases constitute a major portion of the healthcare expenditure which is projected to increase with the aging population. Chronic disease management has been a popular tool for mitigating some of the issues related to chronic diseases in a cost effective manner. The stress of this methodology is to create a partnership between the patients and the healthcare organization with the purpose of achieving better management of chronic conditions. This is achieved through the exercise of various disease management interventions primarily focused on patient and provider education and communication. Although the cost effectiveness of such interventions is widely acknowledged, the cost saving potential or at least the cost neutrality of such intervention is a matter of debate.

Cost evaluations of disease management interventions are complicated by a number of uncertainties in estimating the actual cost of delivering the intervention, impact of intervention of the actual utilization and the cost impact on the cost of healthcare. A number of factors like the type and the frequency of the intervention, type of chronic conditions, patient characteristics and so on determine the actual impact of the intervention on the cost and utilization of healthcare. Although inconclusive the literature suggests that certain disease management interventions can be cost saving in the short term. However, the cost saving potential of such interventions on a long term costs basis seems unfavorable. Longer term cost saving analysis based on Markov models, points to the fact that although disease management interventions are likely to be cost effective, they are unlikely to be cost saving in the long term. This is because disease management interventions lead to reduction in mortality and leads to future costs related to the disease and possibly unrelated costs of other chronic conditions that the patient may acquire as a result of acute aging.

While cost effectiveness is a welcome characteristic of such interventions, the excessive pressure of escalating healthcare costs on individuals and organization makes cost saving imperative. In such a situation the deliberating parties have to achieve a balance between harnessing the effectiveness of such interventions to produce better health outcomes while finding ways to make such efforts cost saving.

This paper has presented a system dynamics tool that takes into account the various complexities and the feedbacks comprising this system as mentioned earlier. This model presents an intuitive representation of the dynamics of the system, which would be of valuable help in analyzing various scenarios, associated with this system. Such a scenario analysis would be of value to the deliberation and decision making process mentioned earlier. The applicability of this model in such a scenario analysis was demonstrated using two hypothetical scenarios. The scenario analysis indicates that the application of intervention is likely to produce reduced utilization and savings only in the short term, which would be erased in the longer term. Also, population of aged patient is likely to increase due to reduced mortality rate as a result of the intervention. The goal seeking structure embedded in the model demonstrates the changes that the healthcare cost structure would have to undergo, to produce a certain targeted saving in healthcare cost. It is seen that a rapid reduction of healthcare costs per visit would be required to obtain the required long term savings in face of rapidly increasing utilization and escalating total costs in wake of the disease management intervention. In a practical sense, this demonstrates a positive feedback structure instigated by the intervention which increasingly makes it difficult to be cost saving in longer term. The results obtained from this scenario analysis provide useful insights and corroborate with the assertions made in the literature. This fact serves as the validation for the model behavior.

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PULL PRODUCTION POLICIES: COMPARATIVE STUDY THROUGH SIMULATIVE APPROACH

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ABSTRACT
Over the years, the JIT approach has highlighted some different types of pull production systems. Many researchers have developed control systems pull, based on a new strategy for managing production "pulled" from the market. They have proposed control policies such as: Kanban, CONWIP, Base Stock and different techniques arising from combination of two of these policies: Generalized Kanban, Extended Kanban, CONWIP-Kanban. In literature, there are several works on the analysis of each control systems, but there are few works that treat more extensive comparisons of different policies. In this study we have analyzed some different pull production policies to single-product multi-stage system to highlight similarities and differences in terms of performance, through the comparison of simulation models built with ARENA software.

Keywords: pull systems, lean manufacturing, discrete event simulation, Extended-CONWIP-Kanban System, decision support system.

1. INTRODUCTION

The events of recent years have shown some needs more and more widespread in the industrial world: the traditional business model is no longer suitable to the actual context in which companies are increasingly subjected to a fierce competition. Therefore we have to rethink the business model: it has to be able to perceive and manage change. Therefore, many researchers have developed control systems pull, based on a new strategy for managing production "pulled" from the market (i.e., the actual customers demand). These systems are against with the more traditional push-type systems (such as MRP), in which the production is "pushed" from forecasts of customer demand.

During the years, experts have developed and proposed several policies based on pull control logic from the model universally known as Lean Thinking. In particular, in literature they have proposed control policies such as: Kanban, CONWIP, Base Stock. We can also speak about different techniques arising from combination of two of these policies: Generalized Kanban, Extended Kanban, CONWIP-Kanban.

Finally, it is recently developed, the technique called Extended-CONWIP-Kanban, by a combination of the three basic policies. The main goal of lean management is to reduce and eliminate the "muda": only in this way we help to streamline the production system (less inventory, scrap, etc..).

In literature, there are many works on the analysis of each control systems, but there are few works that perform more extensive comparisons of different policies. It is difficult to identify and to analyze performance's parameters that quantify the goodness of these techniques: the difficulty lies in assessing which control system can give better performance depending on the type of production. This paper aims to analyze and compare the pull-type control policies in a multi-stage production system, highlighting differences and similarities of control actions in each policy.

2. PULL PRODUCTION CONTROL SYSTEMS

The pull control system is based on real events demand, rather than on its forecasts. The demand for each station in downstream is sent to the upper station on basis of the current consumption of the downstream station, since the demand for finished products required by consumers. So, in a pull control system, production is allowed by current demand and upstream station produces only what is needed to meet the demand of the downstream phase, which is controlled by the effective demand of end customers (Murino, Naviglio and Romano 2010).

Recently, many manufacturers have used the lean production as a strategy to increase their global competitiveness. Since the '80s, in fact, the Just-In-Time (JIT) approach has triggered the emergence of several "pull production systems": they emphasize the importance of production control systems that react to real demand, rather than to forecasts of future demand. In literature, there are a large number of variants of pull production systems (Lage, Filho 2010) that can be traced back to the pull techniques represented by the Kanban, Base Stock and CONWIP. From their combination some different hybrid systems derive. The Generalized Kanban system mixes Kanban and Base Stock policies , as well as the Extended Kanban policy. CONWIP-Kanban System mixes, however, the Kanban and CONWIP controls, while all the three basic logic define the Extended-CONWIP-Kanban system. These control policies have been described for a generic multi-stage production system, where each phase has been modeled as a production system characterized by a production process and an output buffer.

2.1. The Kanban control system (KCS)

The Kanban control system (KCS) is the most widespread pull control system: the information on the demand are transferred from downstream station to upstream station through the kanban cards. They allow synchronization between the release of parts to the downstream station and the transfer of demand to the upstream station. Then, the control kanban depends on one parameter per each phase, the number of k_i kanban at each i stage. This parameter limits the number of units in each stage of production.

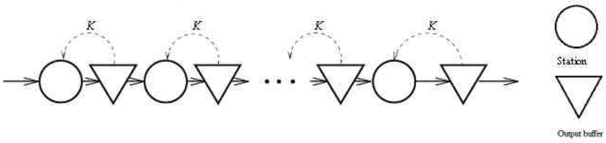


Figure 1: The Kanban control system

2.2. The CONWIP control system (CCS)

The CONWIP control system (CCS), however, limits the total number of parts inside the production system, using only one type of card that follows the pieces through the system. The production control is performed only at beginning of the production and the information about the demand are transferred only between the last and the first phase. Therefore, CONWIP control results from a single parameter for the complete system: the number of CONWIP cards C (Framinan, Gonzalez and Ruiz-Use, 2006).

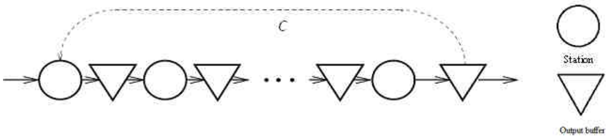


Figure 2: The CONWIP control system

2.3. The Base Stock control system (BSCS)

In the Base Stock control system (BSCS), however, are not physically present cards which allow the production: the information on the demand are sent to each stage as soon as available. The levels of WIP in each stage are unlimited, because every request that arrives to the system authorizes the release of new item. This request provides a safety stock level in any buffer system, defined as basic s_i stock level, which is the control parameter for any phase of this system (Du and Larsen, 2010).

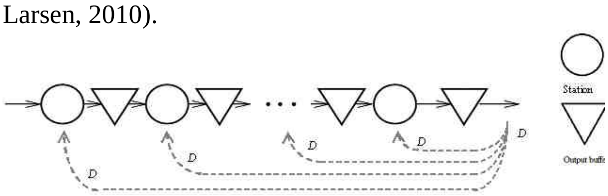


Figure 3: The Base Stock control system

2.4. The CONWIP-Kanban control system (CKCS)

In the hybrid CONWIP-Kanban control system (CKCS), the cards CONWIP limit the level of WIP in the full system, while the number of kanban available in each stage controls the inventory level. The information on demand are transferred to upstream station by a kanban signal and they are transferred to the first stage by the CONWIP signal. The CONWIP-Kanban system depends on one parameter for each phase (i.e. the number of kanban k_i) and it depends on one parameter for the entire system (i.e. the number of CONWIP cards C).

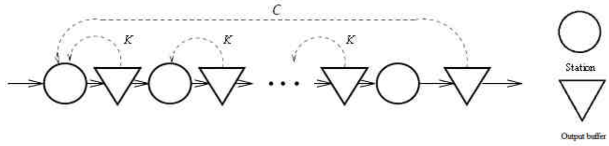


Figure 4: The CONWIP-Kanban control system

2.5. The Generalized Kanban control system (GKCS)

In Generalized Kanban control system (GKCS) the kanban cards are used as production licenses and the maximum number of parts in the output buffer of each stage is fixed by the base stock level. The demand, outside the system, is forwarded from upstream station to downstream station through all different stages, but the transfer of this information is not fully synchronized with the transfer of items to the next step: therefore the information flow matches only partially to kanban. This system results from two control parameters for each phase, the k_i kanban number and s_i base stock level.

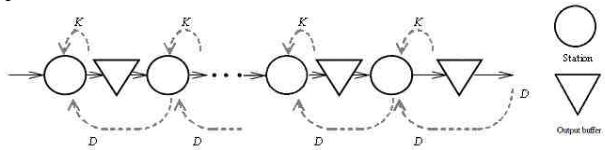


Figure 5: The Generalized Kanban control system

2.6. The Extended Kanban control system (EKCS)

The Extended Kanban control system (EKCS) as the GKCS, mixes the Kanban and Base Stock controls. In this case the information about the demand shall be forwarded immediately to each workstation, while the pieces are moving together with kanban: the transfer of information on demand and transfer of kanban are completely unmatched (Chaouiya, Liberopoulos and Dallery 2000). The Extended Kanban system is therefore characterized by two parameters control for each workstation: the k_i kanban number and s_i base stock level. EKCS imposes a constraint on the parameters: $k_i > s_i$ for each phase, so to have at each stage a s limited number of free kanban not attached to the finished pieces in the buffers (Dallery and Liberopoulos, 2000).

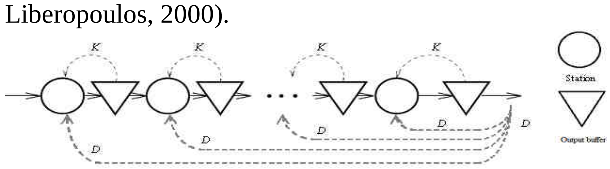


Figure 6: The Extended Kanban control system

2.7. The Extended-CONWIP-Kanban control system (ECKCS)

Finally, the Extended-CONWIP-Kanban System (ECKCS) mixes the features of the three pull logic. The information about the demand are immediately transferred to the different phases when those arrives to the system. The total level of WIP in the system is limited by the number of CONWIP cards, while the release of item in each phase is approved by the kanban cards. Also in this system the flow of information is completely unmatched to the transfer cards. This system results from two control parameters per phase (the k_i kanban number and s_i base stock level) and one parameter for the entire system (i.e. the number of CONWIP cards C), $C \geq \Sigma i\ s_i$, i = 1, ..., N-1, in order to have in the first phase a number of CONWIP s cards free not attached to the finished pieces in the buffer.

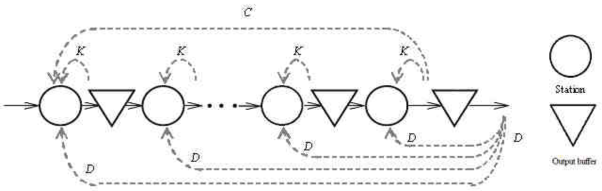


Figure 7: The Extended-CONWIP-Kanban System

3. LITERATURE REWIEW

In literature, many studies analyze the strategies of pull production control (Khojasteh Ghamari 2008), but only a few studies compare the several techniques, among them only few papers compare - all together - pull production control policies. This is due in part to the different contexts in which it was assumed to analyze the several control policies. This doesn't allow a simple and direct comparative study among the different techniques (Gallo, Guerra and Guizzi 2009).

The hybrid policy CONWIP-Kanban is compared with the basic policies CONWIP and Kanban, but also with the Base Stock (Bonvik et al., 1996). The several logics are compared in a system consisting of four stages in series, simulating the behavior of different systems with steady and variable demand: the hybrid control policy reduces the inventory level of the system by 10-20% compared to Kanban policy with the same level of service, while the performance of the Base Stock and CONWIP are intermediate between the two previous results. Geraghty and Heavey (2003) have, however, compared the optimal control policy for hybrid push / pull proposed by Hodgson and Wang (1991) with the hybrid control policy CONWIP-Kanban proposed Bonvik et al. (1996), showing that, under certain conditions, the two logics are equivalent. Indeed, simulation tests gave the same results in terms of average WIP, service level, holding and backlog costs. Also the studies related to hybrid systems Kanban / Base Stock, or Generalized Kanban Control and Extended Kanban Control policies, show better results than each policies basic (Karaesmen and Dallery, 1998).

Recent comparative studies among hybrid control policies show, finally, that the Extended-CONWIP-Kanban policy is better than all other policies based on the pull logic (basic and hybrid) because it mixes all the advantages resulting from several techniques (Lavoie, Gharbi and Kenne, 2010). It's been obtained, by simulation techniques, the better results in terms of performance (trade-off between service level and inventory level) and in terms of stability of solutions to changing conditions both within and outside the system. Boonlertvanich (2005) has simulated the different pull systems in three different scenarios, starting from a basic case, characterized by a variability of demand and process time. These parameters are expressed in terms of variation of the Mean Time To Failure (MTTF) and Mean Time To Repair (MTTR). He has evaluated the performance of these systems when the parameters changes.

In all examined cases, the performance of hybrid policies (CONWIP-Kanban, GKCS, EKCS, ECKCS) are better than the basic logic to reach a high level of service at the lowest levels of stocks.

Similar results are also obtained by Xu and Miao (2009), when the demand and processing times change. In particular, the pull policy is compared with an MRP system: once again the ECKCS policy gives us the best results in terms of WIP, while inventory levels are obviously higher for the MRP system. The purpose of this study is to compare the different pull production systems through a simulation approach. Thus we can help companies choose the best policy according to the characteristics and priorities, which the company decides to pursue.

4. PRODUCTION MODEL AND BASE HYPOTHESIS

We have considered sequential multistage systems: the first stage is fed from the raw materials buffer while each subsequent station is fed from the output buffer of its upstream stage.

The assumptions underlying the construction of our models can be summarized as follows:

- the system has five stages, each modeled as a single station;
- a single type of finished product is considered (there are not set-up times);
- the net system demand is deterministic and it occurs every eight hours;
- the unmet demand in a certain day is postponed to the following days;
- the system is operated for 240 days a year with an 8-hour shift per day (= 1920 hours/year);
- the machine failures are not considered;
- the transfer time is negligible;
- the kanban size is set at one
- there is infinite availability of raw material.

To highlight the differences between the different production control systems, we have defined some performance indicators. In particular, the models have been compared using four benchmarks:

- the service level: the degree at which customer requirements are met;
- the average WIP (the average number of parts in the system);
- the average delay of orders (hours);
- the system total cost considering backlog costs and holding costs.

The above described systems have been modeled using ARENA software, which supports the modeling of different scenarios using a discrete event simulation approach. The ARENA models of the seven systems are showed in the figures 8, 9, 10, 11, 12, 13 and 14.

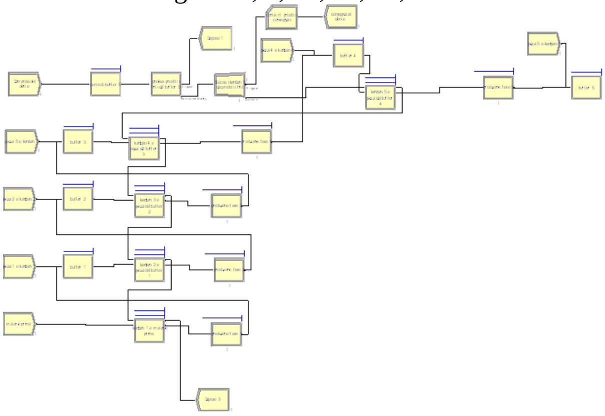


Figure 8: The ARENA model of KCS

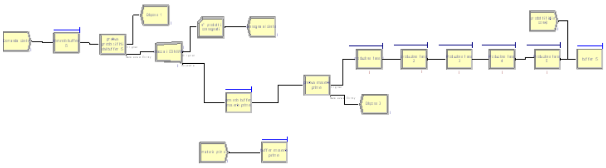


Figure 9: The ARENA model of CCS

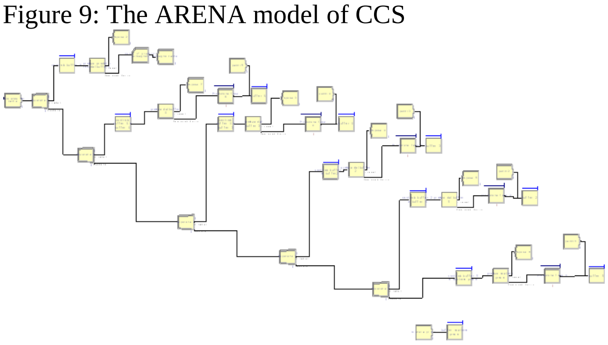


Figure 10: The ARENA model of BSCS

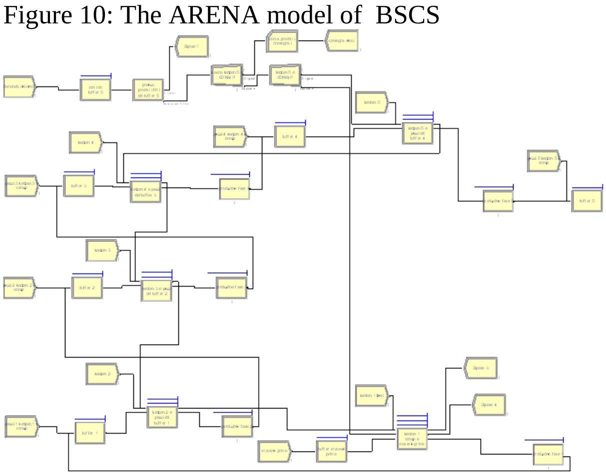


Figure 11: The ARENA model of CKCS

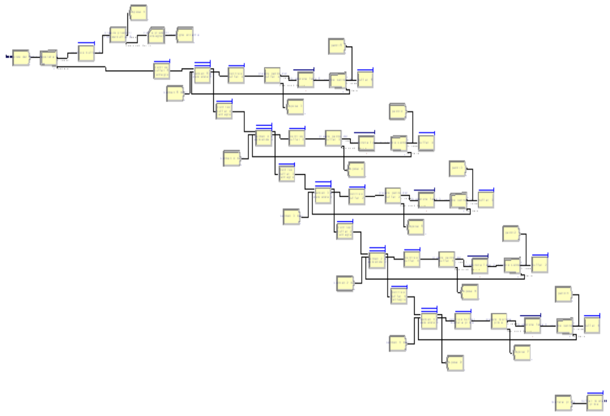


Figure 12: The ARENA model of GKCS

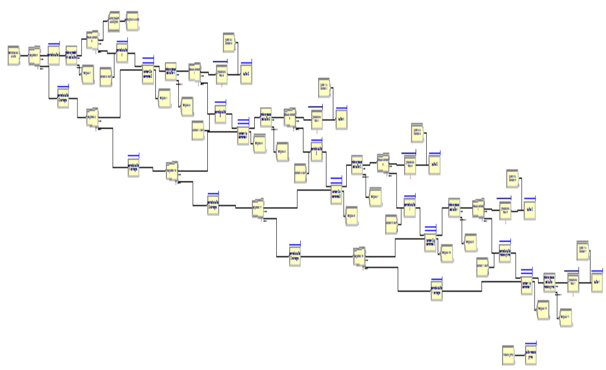


Figure 13: The ARENA model of EKCS

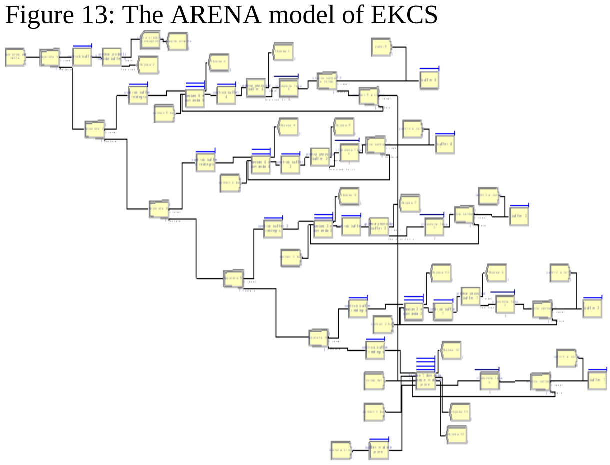


Figure 14: The ARENA model of ECKCS

5. MODELS PARAMETERS DEFINITION AND VERIFICATION

For a proper comparison between the different control policies, it has been necessary to identify the most appropriate range of values for their control parameters. We decided to use for each model those control parameters values that guarantee a fairly high service level. Identifying these ranges has showed to be easier for systems characterized by a single parameter (*basic systems*) rather than for those characterized by multiple, and in some cases interlinked, parameters (*hybrid systems*).

In the basic systems, the range of each parameter has been chosen considering the values most frequently used in literature. In the hybrid system, where there is no link between the control parameters, namely CONWIP-Kanban and Generalized Kanban, we have considered the same range of values used for basic systems, and considering all the possible combinations of parameters' values. In the Extended-Kanban Systems and Extended-CONWIP-Kanban Systems, instead, the constraints between the various parameters have to be taken into account. In the EKCS model we have decided to vary the basic stock level in the range considered in the BSCS model and, for each of these values, we have varied the number of kanban always in the same interval and respecting the relationship between the parameters' values. In the Extended-CONWIP-Kanban model the number of kanban and the base stock level, among which there is no relationship, have been varied in the same intervals considered for the basic control policies, while for the variation range of the CONWIP level the relationship between C and s must be taken into account: as the base stock level varies, the variation ranges for C have been chosen of the same width and respecting the aforesaid constraint. We have analyzed the simulation results constructing some experimental curves, for each model, reporting the trend of the benchmark parameter to the change of the various control parameters. For systems depending on more than one control parameter, we decided to evaluate, initially, the trend of benchmarks as each control parameter varies individually, and then considering the joint variation by constructing a family of curves.

In KCS model as the number of kanban cards for each stage increases, the WIP in each stage and, consequently, the WIP of the system increases too (figure 15.a). As the number of parts circulating in the system grows, of course, the probability and the speed of the system to meet the demand, which translates in an increased service level (figure 15.b) and in a reduced average delay of orders (figure 15.c). The rising total cost is due to the increasing holding cost (figure 15.d).

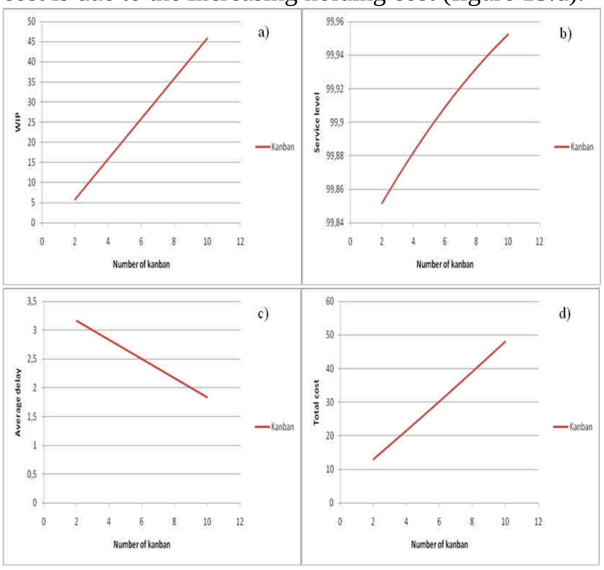


Figure 15: Performance parameters variation with respect to the kanban number in the KCS model

Also in the CONWIP system, the average WIP increases with the number of kanban available in the system (figure 16.a), but the service level increases rapidly only at the beginning: for high values of C, in fact, increases only the number of parts into the input buffers of the system (figure 16.b). Consistent with this result, the average delay of orders has a very fast downward trend first and then much slower (figure 16.c). The total cost is initially influenced by the backlog cost and then for higher values of C by the holding cost (figure 16.d).

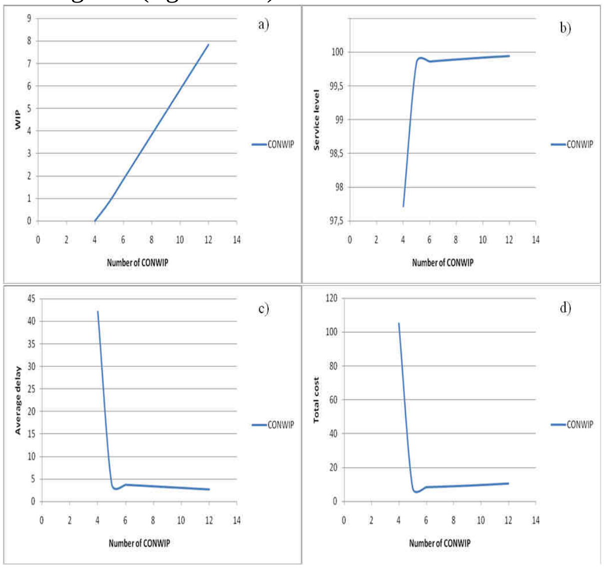


Figure 16: Performance parameters variation with respect to the kanban number in the Conwip model

In BSCS model the increase of s increases the number of parts in each buffer and, consequently, the average WIP of the system (figure 17.a). The availability of a greater number of finished parts pushes toward ever greater service level values, and allows to meet customer demand more quickly (figure 17.b). The total cost is more influenced by the holding cost than by the backlog cost (figure 17.d).

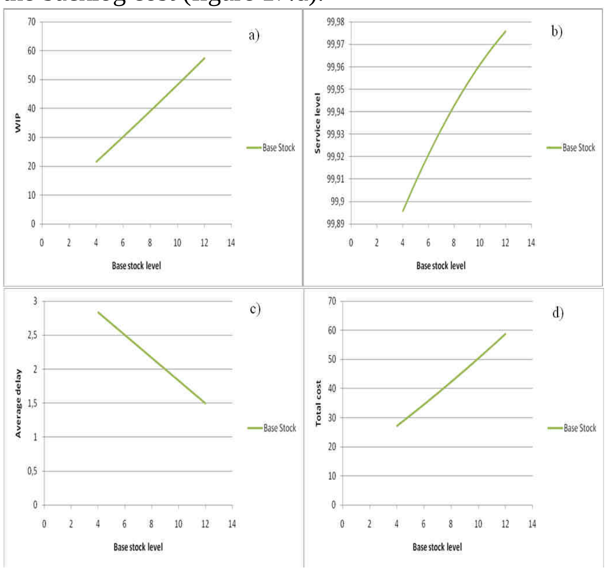


Figure 17: Performance parameters variation with respect to the base stock level in the BSCS model

In the CONWIP-Kanban model as k increases the average WIP is at first slightly increasing and then remains constant, since it is possible to increase the number of units at each stage only up to the limit imposed by the CONWIP control (figure 18.a). By increasing of C the service level increases very rapidly initially and then remain constant at higher values of the parameter C, at which we have only a greater number of parts in the input buffers (figure 18.b). By varying k, the service level initially grows slowly and then remain constant, consistent with constrained changes in WIP. Considering the joint variation of C and k, we obtain curves that start from the same point, but delivering an increasing service level: as C increases it is possible to use a larger number of kanban cards (figure 18.c). In the same way, also delivery delays decrease (figure 18.d). As C increases, the total cost is at first more sensitive to the backlog cost, and then to the holding cost (figure 18.e). Considering also the variation of k, the curve is at first slightly decreasing due to the positive effect of reduced backlog, and then it remains stable. The growth of C moves the curve upward due to the increasing holding cost (figure 18.f).

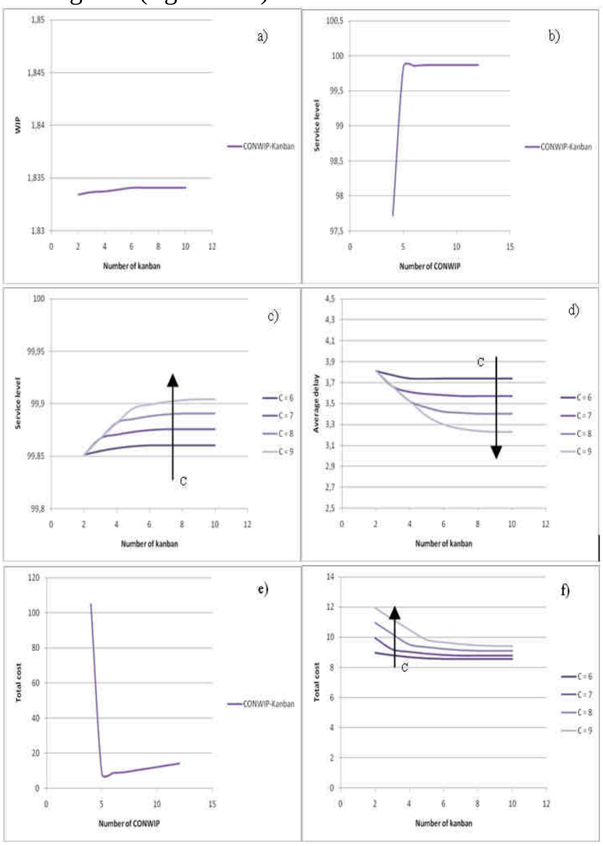


Figure 18: Performance parameters variation with respect to the kanban and Conwip kanban number in the CKCS model

In the GKCS model the average WIP increases both to the rise in k and s, a faster increase occurs in the second case because of the greater amount of finished parts in the various output buffers (figures 19.a and 19.b). The service level increases with s, but it is independent of the number of kanban (figure 19.c), and, consequently, also the delay in deliveries is independent of k (figure 19.d). The total cost is more influenced by the holding cost considering both k and s: the upward trend in both cases has different slopes, consistent with different growth rates of WIP (figures 19.e and 19.f).

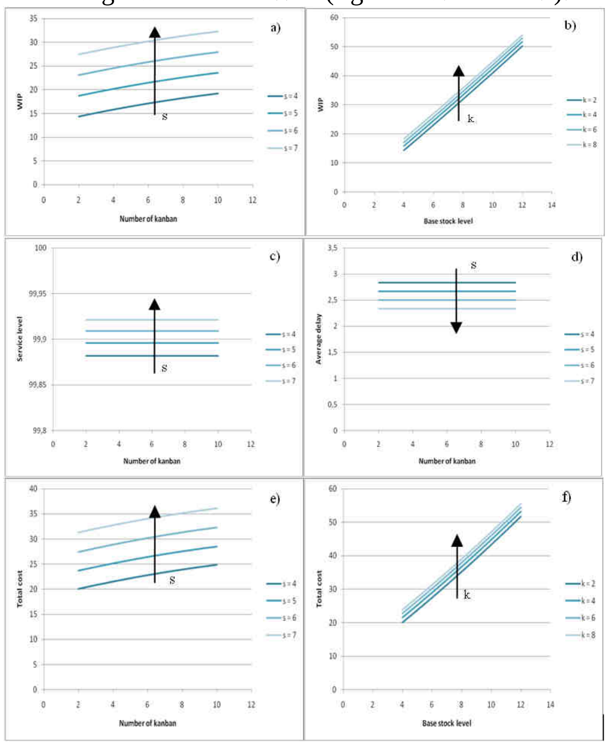
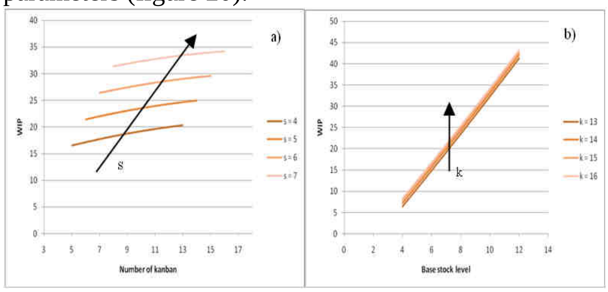


Figure 19: Performance parameters variation with respect to the kanban number and the base stock level in the GCKS model

In the EKCS model, the trend of benchmarks parameters is similar to previous model, with different values of the control parameters, consistent with the model's logic that allows to release downstream the parts more quickly decoupling completely the demand and the kanban cycle. Moreover, the curves having s as parameter move to the right with increasing s in accordance with the relationship between the control parameters (figure 20).



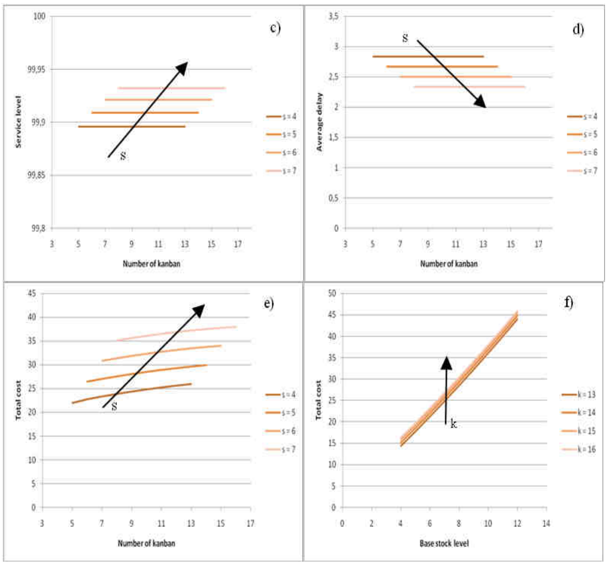
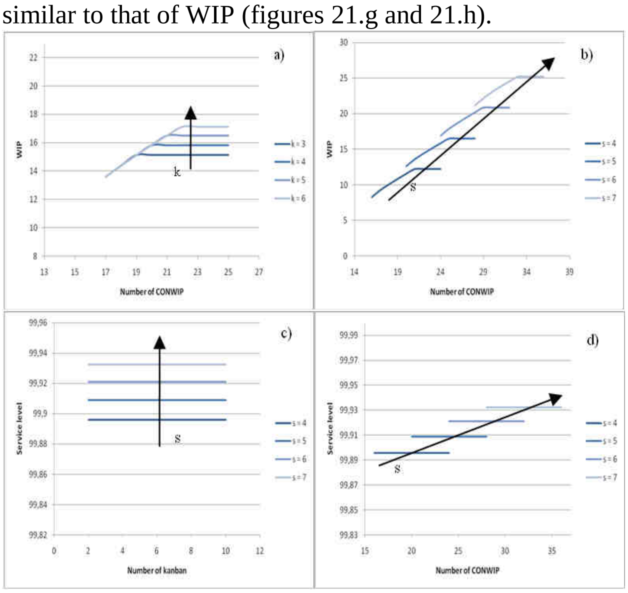


Figure 20: Performance parameters variation with respect to the kanban number and the base stock level in the EKCS model

Considering the ECKCS model, the average WIP as a function of C has a different trend with s or k raising. In the first case the curve moves upward, because of the increase of finished parts in the output buffers, and to the right in respect of the constraint between the parameters (figure 21.a). In the second case, all curves start from the same point, but grow up to higher values of WIP with k increasing (figure 21.b). Again the service level depends only on s: so if s increases, the service level lines move upward, and to the right in the case of C varying (figures 21.c and 21.d). The average delay, of course, has a behavior opposite to that observed for the service level (figures 21.e and 21.f), while the total cost is mainly impacted by the holding cost that produces a trend of the curves similar to that of WIP (figures 21.g and 21.h).



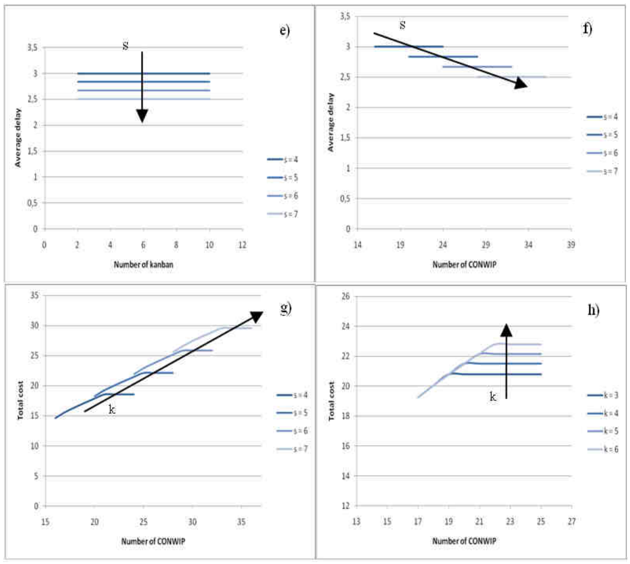


Figure 21: Performance parameters variation with respect to the kanban number, the conwip kanban number and the base stock level in the EKCS model

6. COMPARISON OF THE CONSIDERED PULL CONTROL POLICIES

Identified the ranges of variability for the parameters of each model, it is possible to compare their performance considering two specific scenarios. In the first scenario we evaluate how the various model react to changes in final demand, in the second one the systems' response to sudden changes in production times. In both cases, we have considered a just in time procurement policy to meet the daily demand.

In the first case, demand has been increased up to 30 % from an initial rate of 20 parts per day . All models manage well changes in demand up to 20%. The models that deliver the highest service level are the Base Stock, the Extended kanban and the Extended-CONWIP-Kanban. A slightly lower service level is delivered by the Kanban systems, the Generalized Kanban and the CONWIP-Kanban, while the lowest service level is delivered by the CONWIP system.

It is necessary, however, to associate these results in terms of service level to the corresponding performance in terms of total cost. Among the three first models, at the same service level, the lowest total cost is reached by the ECKCS model. In the second set of models, the CKCS one produces the lowest total cost. The basic CONWIP system, instead, while reaching the lowest total cost among all the considered policies, delivers, however, the lowest service level. So the CONWIP-Kanban and the Extended CONWIP Kanban models globally react better to the change in demand (figure 22).

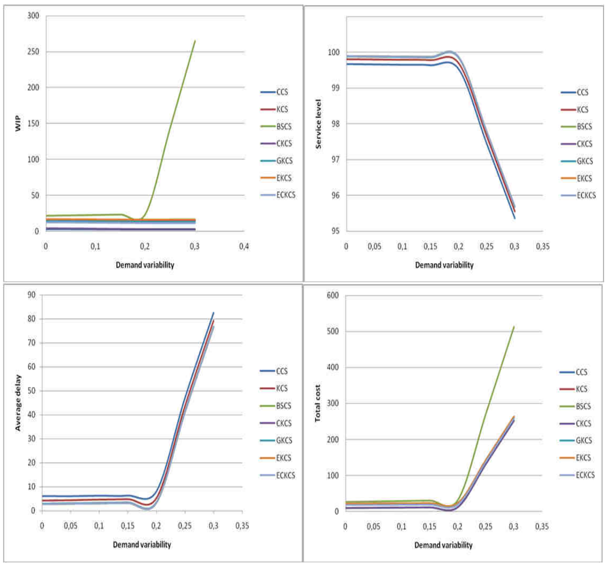


Figure 22: Comparison of the performance parameters for the various pull production models with the demand varying

In the second scenario, the production time has been increased up to 50% from an initial value of 20 minutes. Again, all systems respond well to changes in production time for increments lower than 20%. Even in this scenario the systems ensuring the highest service level are the Base Stock, the Extended Kanban and the Extended-CONWIP-Kanban, the last one getting the lowest total cost. A slightly lower service level is reached by the Kanban, the Generalized Kanban and the CONWIP-Kanban system: with the last one getting the lowest total cost. Again, the CONWIP model gets the lowest total cost but with the lowest service level. So the Extended-CONWIP-Kanban and the CONWIP-Kanban system respond better than the others also to variations in production times (figure 23).

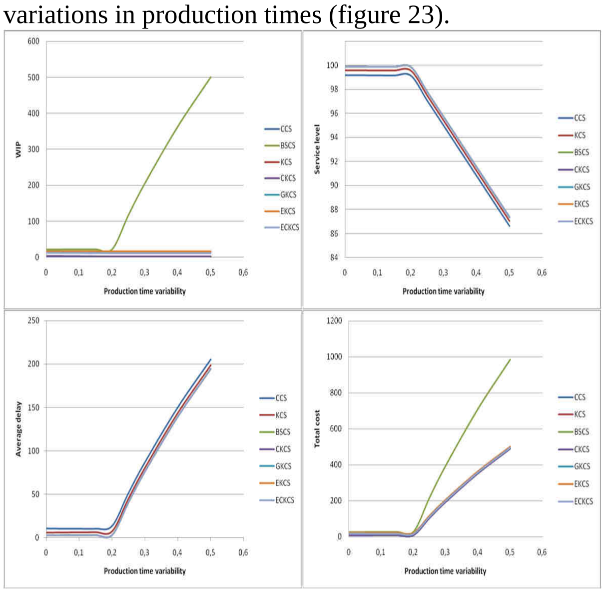


Figure 23: Comparison of the performance parameters for the various pull models with the production time varying

7. CONCLUSIONS

In general, all simulation runs have led to results consistent with the logic of the control policies. All models are more responsive to changes in production time that a change in demand, but in both cases the models that perform better are the CKCS and the ECKCS system. This is also reflected in the results proposed by various authors in literature, so the simplifying assumptions underlying the models do not undermine the validity of the models themselves. These models can be considered a valid instrument to support strategic business decisions to maximize efficiency. In fact, reducing production wastes lowers the cost and the environmental impact. However, the ECK policy, despite its superiority, is rather difficult to implement being a combination of the three basic control mechanisms. Therefore, the decision on the right control policy to implement has to be guided by its characteristics and by the priorities that the company decides to pursue. Possible future developments of this work could be to evaluate these policies in other scenarios: modeling, for example, assembly and/or multi-product systems with stochastic data, in order to make these models more adaptable to various production realities and ever more flexible in responding to fluctuations that inevitably characterize the production context.

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APPLICATION OF TRAMO-SEATS AUTOMATIC PROCEDURE FOR FORECASTING SPORADIC AND IRREGULAR DEMAND PATTERNS WITH SEASONALITY

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ABSTRACT
Managing sporadic and irregular demand patterns represents a relevant issue in several industrial contexts. Two main aspects have to be underlined due to their prominence: the former is the problem of forecasting future demand profiles, and the latter choosing and determining the best re-order policy to be applied, in accordance with information gained during the forecasting step. In this paper the former issue is discussed, by focusing on the management of items with sporadic and irregular demand patterns that also present a seasonality component. TRAMO-SEATS is a versatile procedure that allows quick identification of the best SARIMA forecasting model from an available set. Results obtained by its implementation are compared with those obtained by the Croston (1972) and Syntetos-Boylan (2005) methods, which represent two modified versions of simple exponential smoothing, introduced in literature for forecasting mean demand size per period specifically in case of irregular and sporadic demand profiles. In particular, two items are analysed, with the aim of demonstrating that when the strict hypothesis required by Croston's and Syntetos-Boylan's approaches fails, alternative forecasting methods could be required. TRAMO-SEATS represents a promising and user-friendly option.

Keywords: irregular and sporadic demand patterns, TRAMO-SEATS software, Croston's and Syntetos-Boylan's forecasting methods.

1. INTRODUCTION
Managing irregular and sporadic demand patterns is a relevant issue in several real industrial contexts, in terms of both their supply management and the application of different forecasting methods. In this paper, only the latter issue is handled, by comparing alternative forecasting methods which are briefly explained below here. Specifically, items affected by seasonality are studied.

The paper is organized as described in the following. A synthesis of the main contributions from literature is reported in section 2. The forecasting methods applied and compared in this paper are briefly explained in section 3, while section 4 describes some experimental data. Specifically, given a brief introduction of the steps followed (in section 4.1), data preliminary analysis is discussed in section 4.2. Section 4.3 reports the results of the experimentation and finally some interesting results and guidance for practitioners are given in section 5.

2. LITERATURE
Since the issue of demand forecasting is extremely wide-ranging, this section aims to summarise main contributions from literature on the forecasting methods applied only in the case of irregular and sporadic demand patterns. In particular, it focuses on the application in this context of Croston (1972) and Syntetos-Boylan's (2005) approaches, along with a tool named TRAMO-SEATS (Gómez and Maravall 1996) which uses a SARIMA-based automatic procedure both for identifying models that fit better with the time series and for forecasting future demand values.

Croston (1972) published a pioneering work concerning the forecast of irregular and sporadic demand. Starting from single exponential smoothing, Croston observes that it attains inappropriate results when applied to intermittent demand patterns, that is to say when demand does not occur in frequent time periods. Computing both the expected size of non-null demand occurrences and the expected interval between such occurrences is the insight provided by Croston in order to achieve the estimator of mean demand per period. In particular, Croston considers customers' order series with demand occurrences generated by a Bernoulli process and with demand sizes (when non-null) following a normal distribution. Then, Croston applies a single exponential smoothing separately to non-null demand sizes and inter-demand intervals. Finally he combines them to obtain such an estimator.

Several modifications and experimental analysis of Croston' approach have been successively proposed in literature (Rao 1973; Johnston and Boylan 1996;

Syntetos and Boylan 2005). In particular, Syntetos and Boylan firstly (2001) explain the detection of a mistake in Croston's mathematical derivation of the expected estimate of demand per time period and then (2005) they introduce a factor equal to (1- α/2) applied to Croston's original estimator of mean demand, with α equal to the smoothing parameter used for updating the inter-demand intervals, in order to obtain a theoretically unbiased estimator. The derivation of the new estimator is based on Croston's assumptions of stationary, identically, independently distributed series of demand sizes and demand intervals, geometrically distributed inter-demand intervals and normally distributed demand sizes.

The SARIMA (Seasonal Autoregressive Integrated Moving Average) model, which is discussed in section 3, represents a appreciable robust approach due to its applicability to a wide variety of operative conditions. For a more detailed discussion on the application of SARIMA models see Jarrett (1991) and Bowerman and O'Connel (1993). However, it seems to require the close attention of time series analysts and considerable computing resources (Maravall 2006). Thus, although the SARIMA model has been neglected for same years due to its complexity, in particular in real-world applications, several statistics software have been developed in order to make it automatically applicable. Contextually, alternative methodologies for seasonal adjustment of time series are introduced (see for example Burman 1980, Hilmer and Tiao 1982). In particular, the TRAMO-SEATS (TS) tool allows the automatic application of the SARIMA model without requiring considerable computing resources, thus improving its implementation in real-world environments.

In synthesis, on one hand several authors investigate the possibility of improving the applicability of SARIMA-based methods by reducing their computational efforts in a wide range of operative conditions, while on the other hand *ad hoc* forecasting methods for irregular and sporadic demand patterns have yet to be improved. Nevertheless their comparison in the case of irregular and sporadic demand patterns, especially with trend and/or seasonal components, still remains a field that needs to be widely investigated.

Hence, comparing the forecasting performances obtained both by automatic software based on the SARIMA model (TS) and by forecasting methods *ad hoc* for irregular and sporadic demand patterns is the aim of this paper, without resorting to the initial research of trend and/or seasonal components of the time series. In fact, the advantage of the automatic software TS is that it can be used without any specific knowledge of time series analysis, and thus it represents a useful operative tool in a practical perspective.

3. METHODS APPLIED

In this section, a brief analytic explanation of the forecasting methods applied below is proposed.

For a more detailed discussion about them, see Makridakis *et al*. (1997).

3.1. Croston's method - CR

Croston (1972) proposes a method that takes account of both demand size and inter-arrival time between demand, which are assumed to have constant means and variances for modelling purposes, and to be mutually independent. Demand is assumed to occur as a Bernoulli process. Croston's method indicates the following forecasting steps: single exponential method evaluation, only when demand occurs, both for the smoothed demand size at the end of the review time period t (Z_t), and the smoothed interval between non-null demands (P_t), using the same smoothing constant value. Thus, the equations are as follows:

$$Z_t = \alpha Y_t + (1-\alpha)Z_{t-1} \quad (1)$$

$$P_t = \alpha G_t + (1-\alpha)P_{t-1} \quad (2)$$

where G_t is the actual value of the time between consecutive transactions at the time t, and α is the smoothing parameter.

If no demand occurs, then the smoothed estimates remain exactly unchanged. Otherwise, if demand occurs the estimates are updated. If demand occurs in every time period, Croston's estimator is identical to SES (Single Exponential Smoothing) in each time period.

The forecast of demand per period ($\bar{F}_{t+1}$) at the end of time period t is given by:

$$\bar{F}_{t+1} = \frac{Z_t}{P_t} \quad (3)$$

3.2. Syntetos-Boylan's Approximation - SBA

An error in Croston's mathematical derivation of expected demand size is reported by Syntetos and Boylan (2001), who propose a revision to approximately correct Croston's demand estimates: the SBA method.

Several variations have been applied to Croston's method since its introduction in 1972, but SBA is considered to be the most effective by several authors.

The forecast of demand per period ($\bar{F}_{t+1}$) at the end of time period t is given by:

$$\overline{F}_{t+1} = \frac{\left(1-\frac{\alpha}{2}\right)Z_t}{P_t} \quad (4)$$

Note that equation 4 is similar to equation 3, except for the presence of a corrective factor ($1-\frac{\alpha}{2}$) depending on the smoothing parameter α . In fact, both Z_t and P_t have the same meaning as those in equation 3.

3.3. Seasonal Auto-Regressive Integrated Moving Average – SARIMA

This is a group of methods which consist of two parts: an autoregressive (AR) part and a moving average (MA) part. In order to define the SARIMA model, which is the more generic forecasting method belonging to this group, each of its constituent components is introduced.

An autoregressive forecasting model of the order of *p*, AR(*p*), has the form:

$$F_t = \rho_1 Y_{t-1} + \rho_2 Y_{t-2} + \ldots + \rho_p Y_{t-p} + \varepsilon_t \quad (5)$$

where ε_t is a residual term that represents random events that are not explained by the model, while ρ_i is a coefficient related to time period *i*.

A moving average forecasting model uses lagged values of the forecast error to improve the current forecast. A first-order moving average term uses the most recent forecast error, a second-order term uses the forecast error from the two most recent periods, and so on. A moving average forecasting model of the order of *q*, MA(*q*), has the form:

$$F_t - \varepsilon_t + \vartheta_1 \varepsilon_{t-1} + \vartheta_2 \varepsilon_{t-2} + \cdots + \vartheta_q \varepsilon_{t-q} \quad (6)$$

where ε_i and ϑ_i are respectively the residual term and the coefficient related to time period *i*.

When the time series is stationary (the average and variance do not change over time), then an ARMA(*p,q*) can be applied in the following form:

$$F_t = \rho_1 Y_{t-1} + \rho_2 Y_{t-2} + \cdots + \rho_p Y_{t-p} + \varepsilon_t + \vartheta_1 \varepsilon_{t-1} \quad (7)$$

AR and MA are combined: *p* is the degree of AR and *q* is the degree of MA.

An autoregressive integrated moving average (ARIMA) model is a generalization of an autoregressive moving average (ARMA) model. It is applied in some cases where data shows evidence of non-stationarity, where an initial differencing step (corresponding to the "integrated" part of the model) can be applied to remove the non-stationarity. When the “integrated” part of the model is removed, then the process is the same as ARMA. The model is referred to as an ARIMA(*p,d,q*) model where *p*, *d* and *q* are integers greater than or equal to zero and refer respectively to the order of the autoregressive, integrated, and moving average parts of the model. When one of the terms is zero, it is usual to drop AR, I or MA. For example, an I(1) model is ARIMA(0,1,0), and a MA(1) model is ARIMA(0,0,1).

SARIMA(*p,d,q*) x $(P,D,Q)_s$ is used in case of seasonality of the order *s*. The procedure is the same as ARIMA but in this case there are three other degrees: *P*, *D* and *Q*; they have the same meaning as *p*, *d*, *q* but they are only applied to the seasonal data in the periods *t*, *t-s*, *t-2s*,..., where *s* is the seasonality length.

In synthesis, the seven parameters (*p*, *q*, *d*, *P*, *D*, *Q*, *s*) uniquely define each SARIMA model that suitably fits the original time series. Box and Jenkins (1976) formalise the complete procedure to be applied to identify the model, avoiding over-fitting occurrences (the need to test too many parameters). Many techniques and methods have been suggested to add mathematical rigour to the search process, including Akaike’s criterion (1974) or Schwarz’s criterion (1978), which penalise models based on their number of parameters. In any case, since nowadays statistical commercial software allows the user to test several SARIMA models very quickly, the identification of the model can only be based on its forecasting performances (Gamberini *et al.* 2010).

In this paper, the TS software is used to both identify the proper SARIMA model and to generate forecasts. It is composed of two modules, TRAMO (Time Series Regression with ARIMA Noise, Missing Observations and Outliers) and SEATS (Signal Extraction in ARIMA Time Series) respectively. The former, after eliminating deterministic effects from the time series (e.g. fixed holidays such as Easter, anomalous values and so on), automatically identifies and estimates the ARIMA model, applying the same tools listed in the Box-Jenkins procedure (e.g. sample autocorrelation ACF and partial autocorrelation PACF, Akaike’s criterion, Schwarz’s criterion, maximum likelihood estimation, and so on). The latter, using the results obtained by TRAMO, achieves the decomposition of the time series in its non-observable components, such as cycle-trend, seasonal component and irregular component. In synthesis, the aggregation of TRAMO and SEATS allows the identification of the final SARIMA model and thus it represents a full software package for the analysis, decomposition and forecasting of the time series. For a more detailed discussion about such a tool, the reader can refer to Pollock (2002) and Maravall (2006).

4. CASE STUDY

Below, data analysed in a case study is described. Specifically, with the presentation of the steps followed during experimentation, the data collected is commented on, introducing the results obtained.

4.1 Framework of the experimentation

The steps followed in the experimentation are presented below:

- Selection of two time series, characterised by irregularity and sporadicity, along with seasonality. In particular, analysed items do not satisfy the hypothesis required by CR and SBA approaches.
- For each time series, application of CR and SBA methods and utilisation of TS software, with the aim of achieving forecasts for the different number of months ahead (1, 3, 6, 12).
- Comparison of the aforementioned forecasting methods in terms of different accuracy measures.

Several accuracy measures are presented in literature to compare the performances of forecasting methods. For a more detailed discussion about them, see Makridakis (1993).

Define T as the number of forecasted time periods, F_t as the forecasted demand size in time period t, A as the mean demand size occurring in the forecasted time periods and D_t as the real demand size occurring in time period t, for $t = 1,..., T$. In accordance with guidelines reported in Regattieri *et al.* (2005), the following accuracy measures are adopted (equations 8, 9, 10):

- *MAD/A:* Represents the Mean Absolute Deviation (*MAD*) divided by the average demand size. By describing the incidence of the mean absolute forecasting error in the mean existing demand, this index allows the performance of forecasting approaches on time series to be evaluated with very different mean values, as introduced by Regattieri *et al.* (2005).

$$MAD / A = \sum_{t=1}^{T} \frac{|F_t - D_t|}{T} \Big/ A \qquad (8)$$

- *MSE/A²:* Represents the arithmetic Mean of the sum of the Squares of the forecasting Errors (*MSE*), divided by the squared average demand size. Low values of MSE/A^2 address the adoption of forecasting approaches with a high incidence of low errors between true values and estimated ones. Otherwise, high MSE/A^2 indicates that high errors sometimes occur. Specifically, the ratio with A^2 is proposed again in order to compare values obtained in series characterised by consistent differences in the mean demand size.

$$MSE / A^2 = \sum_{t=1}^{T} \frac{(F_t - D_t)^2}{T} \Big/ A^2 \qquad (9)$$

4.2 Preliminary analysis of data

Two monthly time series, i.e. Item1 and Item2, are collected from a real manufacturing environment, with a length of one hundred and twenty time periods (time series length of ten years).

Item 1 and Item 2 are characterised by irregularity and sporadicity. The former concerns the variability of the demand sizes, while the latter is related to the presence of frequent time periods in which demand does not occur. Therefore, two coefficients are computed (*CV* and *ADI*) in accordance with the definitions reported in Willemain (1994). Specifically, *CV* represents the coefficient of variation of non-null demands, while *ADI* represents the average number of time periods between two successive non-null demands. Hence *CV* and *ADI* establish the mark respectively of demand sizes' irregularity and of the sporadicity of demand pattern. Alternatively, in accordance with definitions reported in Syntetos (2001), CV^2 can be computed, that is the squared version of *CV*. Table 1 reports the values of *ADI* and *CV* along with the average demand size for both time series.

Furthermore, following the guideline introduced by Croston (1972), the demand is split into its two subcomponents, i.e. the demand sizes and the intervals between non-null demands. Then, the best distribution functions (*ddp*) that fit each of the series of subcomponents obtained are attained by using the software AutoFit®. It indicates a list of the best fitting distribution functions, presenting them in descending order of preference. In table 1 both *ddp* functions (i.e. *ddp* describing the series of non-null demand size and *ddp* describing the series of intervals between non-null demand sizes) are reported for each time series.

Finally, selected series present trend and seasonal components in the demand patterns, as shown in the bottom row of table 1.

Table 1: Statistical analysis of selected time series

	Item1	Item2
Average demand size	3.43	2.83
ADI	1.35	1.50
CV	0.74	0.68
ddp demand sizes	Inv. Gauss.	Cauchy
ddp intervals	Chi-squared	Chi-squared
Further characteristics	Trend and seasonality	Trend and seasonality

4.3 Experimental results

Even if, as often occurs in industrial practice, selected items do not satisfy the hypothesis of CR and SBA forecasting approaches, they are selected for predicting future values of the demand patterns, in accordance with preceding experimentations reported by the authors themselves. Subsequently, the TS tool is adopted, in order to compare the results obtained.

The application of CR and SBA methods is preceded by the choice of smoothing parameters. In an intermittent demand context, low smoothing constant values are recommended in literature. Smoothing constant values in the range of 0.05 - 0.2 are viewed as realistic

(Croston 1972; Willemain *et al*. 1994; Johnston and Boylan 1996). In this case study, as well as in Syntetos and Boylan (2005), four values are simulated: 0.05, 0.10, 0.15, and 0.20. Finally, the choice of smoothing parameters is based exclusively on the forecasting performance.

Table 2 and table 3 respectively report the forecasting errors obtained by the three aforementioned methods for the two selected items. For each accuracy measure evaluated and for each number of time periods, the lower forecasting error is underlined. Note that forecasting performance tends to improve for each forecasting method when the number of time periods ahead is increased. Figure 1 depicts the histograms of the forecasting errors for Item1 and Item2, in terms of both MAD/A and MSE/A^2

Despite how little data has been tested, some guidelines can be extrapolated. Firstly, the SBA method outperforms the CR method six times out of eight, and thus it appears to be an improvement in respect of Croston's method, even if the theoretical assumptions required for their implementation are violated. Moreover, whilst SBA reaches good performance in item 1 forecasting, TS achieves satisfactory results by analysing item 2, where consistent improvements are registered, especially when the number of forecasting time periods tends to increase (i.e. 6 months and 12 months).

Hence, further research is addressed in order to publish consistent experimentation comparing SBA and promising TS in real life series, representing a wide range of real-life occurrences.

5. CONCLUSIONS

This paper focuses on the comparison of alternative forecasting methods in case of irregular and sporadic demand patterns with seasonal components. Despite the great amount of contributions from literature on forecasting methods, this field needs further investigation due to its high criticality.

In particular, three alternative forecasting methods are compared, i.e. Croston's and Syntetos-Boylan' approaches and an automatic procedure called TRAMO-SEATS that is based on the best SARIMA model identification and application for forecasting aims. While the former methods represent *ad hoc* forecasting methods for irregular and sporadic demand patterns, the latter is a statistics software based on SARIMA modelling, which is robust and a forecasting method for general purposes.

Gamberini *et al*. (2010) obtain significant results in applying the SARIMA method in case of irregular and sporadic demand patterns with trend and/or seasonal components. In this paper a further investigation about the effectiveness of such a method is proposed. In particular, TRAMO-SEATS represents an automatic procedure for both identifying and applying the best SARIMA method found, and therefore it can be usefully applied in real industrial environments with satisfactory results.

Further research focuses on the implementation of wide experimentation for exploring TS potentials in the field of forecasting irregular and sporadic demand patterns with seasonality. Specifically, TS appears promising, since in the proposed case study it achieves results comparable with those attained by SBA, while coupling low implementation time, given its automatic behaviour and capability of jointly testing a wide range of SARIMA.

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Table 2: Results achieved in terms of MAD/A

	1 month			3 months			6 months			12 months		
	CR	SBA	TS	CR	SBA	TS	CR	SBA	TS	CR	SBA	TS
Item1	0.90	0.88	1.03	0.65	0.72	0.89	0.72	0.72	0.89	0.17	0.05	0.07
Item2	0.65	0.64	0.65	0.36	0.34	0.35	0.35	0.27	0.15	0.35	0.27	0.05

Table 3: Results achieved in terms of MSE/A^2

	1 month			3 months			6 months			12 months		
	CR	SBA	TS	CR	SBA	TS	CR	SBA	TS	CR	SBA	TS
Item1	1.03	1.01	1.68	0.65	0.63	0.88	0.58	0.57	0.80	0.03	0.003	0.005
Item2	0.62	0.56	0.57	0.21	0.19	0.15	0.13	0.11	0.025	0.13	0.07	0.003

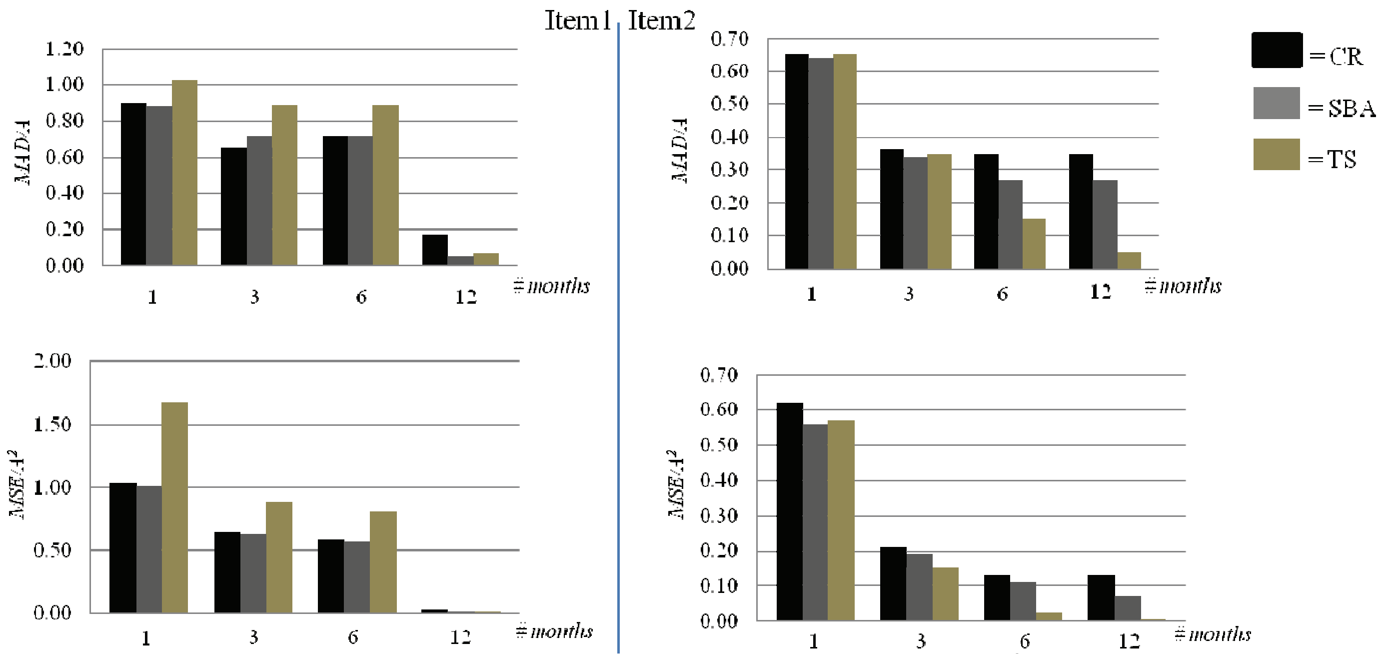

Figure 1: Forecasting errors in terms of MAD/A and MSE/A^2

SUPPLY CHAIN DYNAMICS: SIMULATION-BASED TRAINING AND EDUCATION

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ABSTRACT

The paper discusses use of simulation-based business games for training and education in the area of supply chain management. It starts with a state-of-the art review of extant application of simulation games used for training and education in supply chain management, followed by description of a recently developed ECLIPS game. It has been developed within a European project for providing an insight into various aspects of supply chain management, with possibilities to analyze different supply chain structures and control mechanisms. In particular, application of the ECLIPS game to comparison of different supply chain inventory management policies, including non-cyclic and cyclic ones, is provided. For that particular situation, game rules and playing process are explained, as well as sample results obtained by participants are presented and interpreted.

Keywords: simulation-based training and education, simulation business games, supply chain management.

1. INTRODUCTION

Currently simulation-based training and education methods have proved their efficiency in different areas ranging from a military sphere to health care, as they result in greater retention, deeper understanding, higher levels of engagement, and better transfer of knowledge to the job. In particular, simulation-based business games (or shortly "simulation games") are widely used for training managerial, technical, and problem-solving skills, based on the experiential learning principles. Simulation games significantly increase the motivation and interest level of trainees.

In the field of supply chain management, simulation games have been used for over 50 years. Nowadays this sphere is developing rapidly, as new methods and approaches appear for solving actual problems, for example, the one discussed in Merkuryev et al. (2007, 2008). Introducing of new approaches to supply chain management usually causes a necessity for their exhaustive explanation and illustration. For this purpose, new simulation games are often developed. Moreover, the use of modern information and telecommunication technologies also contributes to the development of new games and improving existing ones than could significantly increase the number of potential users, as well as enhances their efficiency.

2. LITERATURE REVIEW

Nowadays many simulation games that focus on supply chain management are available. The most well-known is the Beer Game (Sterman, 1989). It has been developed in the 1960s at the Massachusetts Institute of Technology to demonstrate the bullwhip effect and clarify the advantages of taking an integrated approach to the managing of a supply chain. The Beer Game allows players to simulate the working of a single product distribution supply chain in which each player manages the inventory of a retailer, wholesaler, distributor, or manufacturer. Initially the game was developed as a board game. As an example of its realization, the LOGDIS game developed by Cim_Cil Technology Transfer Center (www.cimcil.be) can be mentioned. Later on a computerized version was developed (Simchi-Levi et al., 1998). The most recent versions are played with computers through the Internet, for example, the one described by (Jacobs, 2000) or another one described by Sparling (2002). These Internet based implementations have the advantage of considerably reducing time required to play the game. Some modifications of the classic Beer Game are proposed by Chen and Samroengraja (2000) - the material and information flows in a production-distribution channel serving a stationary market where the customer demands in different periods are independent and identically distributed. Despite these updates, the Beer Game has a strong focus on the bullwhip effect and its casual factors, i.e., inadequate information sharing across the supply chain, however there are many other aspects that can be considered and illustrated through simulation games.

For example, an Internet based supply chain management game (Zhou L. et. al, 2008) is extended from the Beer Game and provides an Internet supply chain challenge business scenario simulation (ISCS) with a Management Information System built in to support decision making. In other words, ISCS is an on-line multi user information system which links every player together using the Internet technology with capability to test and evaluate comprehensive SCM strategies, e.g., capacity planning and inventory management, production planning, purchasing strategies, supply chain collaboration and integration strategies and others. The game needs a minimum of seven players. There are five types of products considered in the game.

To model a specific supply chain application, the Blood Supply Game (Mustafee and Katasaliaki, 2010) has been developed. It can be used to illustrate supply chain management principles in a special make-to-stock environment with perishable products with limited collection/production. In particular, the game simulates the process of blood collection, production, testing, distribution, hospital stocking, and usage by patients where participant plays a distributor role. It is played by individuals on a PC with Microsoft Excel exploiting VBA environment.

For teaching service-oriented supply chain management principles, the Mortgage Service Game (Anderson and Morrice, 2000) has been developed. It is a computer-based simulation game that can be used to illustrate supply chain management principles in a make-to-order environment as that kind of supply chain typically cannot hold inventory and can only manage backlogs through capacity adjustments. The bullwhip effect is considered in this game. The game can be played in teams or by individual where players manage only one stage of the supply chain.

The Supply Chain Game (Feng and Ma, 2008) has been developed at the Kellogg School of Management at Northwest University by prof. Chopra and prof. Afeche. It is an Internet-based supply network simulator. Here the supply chain structure is not strictly defined; participants are responsible for demand forecasting, inventory control, production planning and scheduling, network design, and logistics; only one product is considered.

SBELP is a supply chain simulator developed at King Fahd University of Petroleum and Minerals (Siddiqui et.al. 2008) that simulates an international supply chain network used to deliver electronic equipment. Here the player acts as a manufacturer who takes decisions that impact the performance of the whole supply chain. In order to investigate the Bullwhip effect three scenarios have to be played: (1) the traditional chain – no information from other echelons is shared, (2) the value of information – all information on flow of material downstream and flow of orders upstream is available, and (3) the true market – customer demand is stochastic.

The RSS-POD Supply Chain Management Game (Chan E.W. et.al, 2009) developed by RAND Health Center for Domestic and International Health Security is a Microsoft Excel-based game that allows players to practice in inventory management. It can be played by individuals or in small groups. Players perform the role of inventory manager at a receipt, storing, and staging (RSS) facility and must allocate inventory among multiple points of dispensing (PODs), with the goal of distributing countermeasures to as many people as possible. The exercise consists of three rounds of playing called modules, in which the player is progressively given more information for managing inventory. These three modules are played through the same time period, so that after all three modules have been completed, performance comparisons can be made across the modules. In the final module, players are provided with a simple mathematical algorithm to make distribution decisions that is a version of a standard periodic-review, "order-up-to" inventory policy. The distribution network consists of one warehouse and ten PODs. Only one product is considered in the game.

The Trading Agent Competition – Supply Chain Management game (TAC/SCM, 2007) has been designed jointly by a team of researchers from the e-Supply Chain Management Lab at Carnegie Mellon University and the Swedish Institute of Computer Science (SICS). Here agents are simulations of small manufacturers, who must compete with each other for both supplies and customers, and manage inventories and production facilities. The game represents of a broad range of supply chain situations. It is challenging in that it requires agents to concurrently compete in multiple markets (markets for different components on the supply side and markets for different products on the customer side) with interdependencies and incomplete information. It allows agents to strategize (e.g. specializing in particular types of products, stocking up components that are in low supply). To succeed, agents will have to demonstrate their ability to react to variations in customer demand and availability of supplies, as well as adapt to the strategies adopted by other competing agents. While the game is well known among researchers, in fact it is not suitable for teaching purposes.

A team of researchers from Delft University and from the Robert H. Smith School of Business at the University of Maryland has developed The Global Supply Chain Game (Corsi et.al., 2006). A specific instance of the game is called "Distributor Game". It focuses on a distribution process in a global real-time supply chain. It replicates the traits of a modern supply chain, which requires multi-tasking in a dynamic 24/7, real-time and event-driven environment in which global supply chain leaders must function that makes it different from other static turn-based games. The supply chain structure simulated within the game is non-linear. The decision-making processes of the distributors are controlled by human players while other echelons can be represented by computer-controlled actors. Four different products are considered in the game.

The comparison of key attributes of the described games is provided in Table 1. It can be concluded that most games have a fixed structure of the simulated supply chain that limits their use for training company personnel within its own supply chain as well as only a few games have focus on inventory control strategies. The recently developed ECLIPS game covers these issues. The detailed description of this game is

Table1: Comparison of Key Attributes of the Reviewed Supply Chain Games

	Beer Game	ISCS	Blood Supply Game	Mortgage Service Game	Supply Chain Game	SBELP: supply chain simulation	RSS-POD Supply Chain Management Game	Trading Agent Competition	Global Supply Chain Game -Distributor Game	ECLIPS
Turn-based (T) or continuous time(C)	T	T	T	T	T	T	T	n/a	C	T
Software assisted	Y*	Y	Y	Y	Y	Y	Y	Y	Y	N
Web-based	Y*	Y	N	N	Y	N	N	Y	Y	N
Players per team	1-4	7	1	1-5	3-5	1	1-5	n/a	2	4
Echelon focus within supply chain: Distributor (D), Factory (F)	All	All	D	D	F	F	D	F	D	All
Demand: pre-planned (P) or random (R)	P	R	R	P	R	P/R	R	R	R	R
Number of products	1	5	1	1	1	1	1	16	4	1
Supply chain structure: fixed (1) or flexible (2)	1	1	1	1	2	1	1	1	1	2
Inventory control strategies: continuous (C), periodic (P) or not considered (No)	No	n/a	No	No	C	No	P	No	No	C, P

*****some versions of the game

presented in the following sections of the paper.

There are also simulation games that cover a much wider range of issues that this article does not intend to cover. For example in (Merkuryeva et al., 2009) the number of simulation games on general logistics management are described, while in (Van der Zee and Slomp, 2009) the use of simulation games for training operations management concepts is discussed.

3. DESCRIPTION OF THE ECLIPS GAME

The ECLIPS simulation game has been developed within a European project "Extended Collaborative Integrated Life Cycle Supply Chain Planning System" (ECLIPS) under the 6th Framework Programme of the European Commission (Merkuryev et al., 2007). It focuses on multi-echelon supply chain networks. A typical managerial problem in a multi-echelon system is to decrease total costs by coordinating orders across the supply chain, while providing a certain service level. The game helps in understanding organization and functioning of a multi-echelon supply chain based on cyclic planning.

3.1. Playing process

In the ECLIPS game, the playing process usually consists of playing a number of rounds (or periods). Each round consists of the following steps (which are executed from the end-customer to raw material supplier, echelon by echelon):

1. Tossing the <u>demand die</u> that determines end customer(s) demand;
2. <u>Delivery</u> of the demand by each retailer (if possible);
3. Filling in the "customer demand" and "delivery" columns in the respective transaction form;
4. Echelon by echelon <u>delivery by transport</u>;
5. For each retailer: decision if <u>orders</u> should be send out to the nearest upstream warehouse;
6. <u>Delivery</u> of the demand by respective warehouse (if possible);
7. Echelon by echelon <u>delivery by transport</u>;
8. Decision if orders should be sent out to the nearest upstream warehouse. If an upstream warehouse is absent, production can be triggered;
9. Filling in the "customer demand" and "delivery" columns in the respective transaction form;
10. The <u>raw material and production echelon</u> has an alternating function each period: one period it can be triggered for new production, next period it moves its production one echelon ahead in the chain;
11. Filling in the "customer demand" and "delivery" columns in the respective transaction form.

Ideally, more than three complete cycles have to be played to make conclusions. The required minimum number of periods in a game can be calculated with a following formula: *play_periods* = *echelons* * 3.

The total number of playing rounds is not communicated to the players to avoid endgames. To avoid players guessing the number of periods, the scoring sheets contain entries for more periods than the number that will be played.

If the game is played with more than one player, players are assigned to one or more inventory points. A possible further area of research is to assign different performance targets to the different players.

At the end of the game, summary statistics are calculated based on performance metrics recorded during the game (see Tables 3 and 4).

The following four performance metrics have been identified as being useful:

1. Demand: the sum of the demand at every retailer that is equal to the sum of the dices thrown.
2. Delivered products: the sum of the items delivered by retailers that is equal to the sum of the products that are placed in the trolleys.
3. Orders: how many orders have been issued during that round? An order is issued when a warehouse ships goods (by land, air, sea). Orders can be sent out by wholesalers or retailers.
4. New production: the sum of the newly requested production at raw material and production units.

To analyse and compare different inventory management policies, the following performance metrics have to be calculated at the end of the game:

- *Service level:*

$$SL = \frac{\sum_{t=1}^{n} P_t}{\sum_{t=1}^{n} D_t} * 100,\% \tag{1}$$

P_t – satisfied end customer demand at period t;
D_t – end customer demand at period t;
n – total number of played periods.

- *Average cost:*

$$AC = \frac{\sum_{t=1}^{n} (TQ_t * C_h + O_t * C_o + NP_t * C_n)}{n} \tag{2}$$

TQ_t –product items in chain at period t;
C_h – inventory holding per period;
O_t – total number of orders at period t;
C_o – order fixed cost;
NP_t – number of produced units at period t;
C_n – production cost per unit.

- *Average inventory:*

$$AQ = \frac{\sum_{t=1}^{n} (TQ_{t-1} - P_t + NP_t)}{n} \tag{3}$$

TQ_0 – initial stock of products within the entire supply chain.

As a side remark, it should be noted that, ideally, scoring should not take in account the part of the game where players "discover" the game mechanics. This can be done by scoring only over the number of periods minus the number of supply chain stages in the game.

The second side remark is that assembly games require a different scoring table. Each inventory-point has to be taken into account. Multi-sourcing games do not suffer from this drawback.

3.2. Different game modes to be played

Four ways of playing the game are provided.

1. Supply Chain Discovery: This play mode is suitable as a first introduction into multi-echelon supply chain inventory management. Player objectives are to attain a 95% service level at the lowest cost. Concepts that are suitable for identification are: general mechanisms of supply chains, bullwhip effect, introduction to ordering policies.
2. Ordering policies (ECLIPS mode): This play mode illustrates concepts of the multi-echelon supply chain cyclic planning developed within the ECLIPS project. Different ordering policies are played during the game, namely, non-cyclic, cyclic non-synchronised and cyclic synchronised policies. Concepts that are suitable for identification are: detailed operation of different ordering policies and their best practices.
3. Supply chain design: After playing with an existing supply chain, capacity constraints are introduced, the network is altered. The effects of changing the supply chain network become visible. Concepts that are suitable for identification are: mechanisms of supply chain management and supply chain design.
4. Risk Management: An assembly network is set up. Customer demand is kept as constant. Once the network and playing policies are stabilised, one of the suppliers is removed. Then the demand has to be satisfied by the remaining suppliers. Concepts that are suitable for identification are: supply chain risk management and risk mitigation strategies.

3.3. Symbols used during the game

Different supply chains can be modelled by using placemats with different symbols (as described in Merkuryev et al., 2009).

Only one product is used in the game. Because product large quantities can traverse the supply chain, colour codes are used to designate different quantities (see Table 2).

Table 2: Colour Codes for Different Product Quantities

Products	Explication
	One unit of product
	Five units of product
	Twenty-five units of product

Demand occurs at a "retailer" and is generated by tossing either a:

- octahedron dice with sides 0,1,1,2,2,2,3,13 or
- cube dice with sides 0,1,1,2,2,9 or 0,1,1,2,3,11.

For some games, demand can be constant or variable being read from a table each period.

Fulfilled demand is put in the “trolley” symbol. Unfulfilled demand is lost. No backlogging is allowed during the game. Depending on the game, a penalty for lost sales might be given.

3.4. Networks used during plays

The authors have tested different networks during the development phase. They felt some networks were more appropriate to illustrate some specific problems than others.

Linear supply chain is represented in Fig. 1. It can be used in the ECLIPS mode of the Each warehouse starts with an inventory of 20 products and retailer starts with an inventory of 30 products. Demand is dynamic and stochastic. The chain should be played for at least 30 periods.

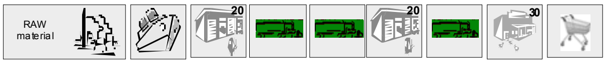

Figure 1: Three-echelon Supply Chain

In the Discovery mode the distribution network presented in Fig. 2 can be used. It consists of two subsequent distribution steps (see Fig. 2). The black lines in figure indicate the possible ways to supply products to three end-customers (labelled from one to three). The initial stock of products is placed on the respective card; it is indicated in the figure below with numbers. Demand is dynamic and stochastic. The network should be played for at least 30 periods.

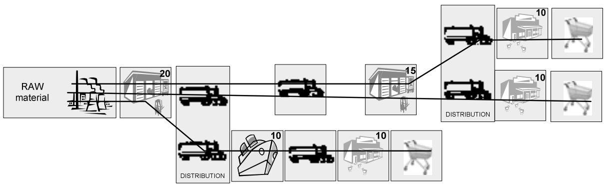

Figure 2: Three-echelon Distribution Network

Small assembly chain consists of one assembly step which is intertwined with long transports and only one customer (see Fig. 3).

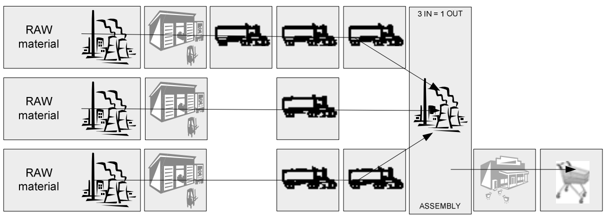

Figure 3: Small Assembly Chain

Large assembly chain consists of three subsequent assembly steps which are intertwined with long transports and only one customer (see Fig. 4). If a risk management game is played, the assembly step in the 2nd echelon could be replaced with a multi-sourcing.

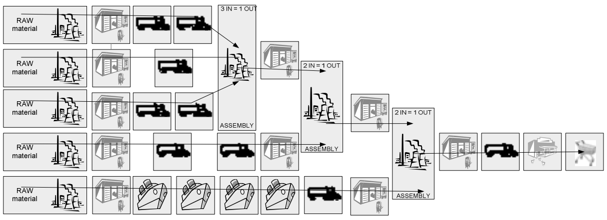

Figure 4: Large Assembly Chain

4. GAME TESTING RESULTS

At Riga Technical University (RTU) Department of Modelling and Simulation, the ECLIPS game is played since 2008. This chapter describes an example of typical results of the game obtained by master level students within the course ‘Supply Chain Management’.

The following educational scheme and agenda of the day were proposed for playing the game at RTU:

1. Introducing the game –general rules (20’);
2. Playing the Discovery mode as an introduction into multi-echelon supply chain management (40’);
3. Analysing the results of the Discovery mode (10’);
4. Playing the ECLIPS mode as getting insight into the following replenishment policies and their best practices (40’):
   a. Non-cyclic, or continuous review policy (ROP);
   b. Cyclic, or periodic review policy (POR):
      - Cyclic non-synchronised,
      - Cyclic synchronised;
5. Analysing the results of the ECLIPS mode (10’);
6. Making general conclusions (10’).

4.1. General guidelines

The following are general guidelines of playing the game at RTU:

1. Supply chain networks are physically simulated in the game.
2. For each game mode, a specific multi-echelon supply chain network is designed, i.e. a distribution network with 3 echelons and 5 nodes (see Fig. 2) for the Discovery mode, and a three-echelon 3 nodes linear chain (see Fig.1) for the ECLIPS mode. Each element of the supply chain is represented by a card. The meanings of cards are explained in (Merkuryev et.al, 2009).
3. Possible roles of players are defined as:
   i. Retailer (R),
   ii. Distribution Centre (DC),
   iii. Factory Warehouse (FW).
4. Players’ objective is defined as follows: to attain a 95% service level at the lowest cost.
5. The following costs are considered:
   i. inventory holding cost - 1 EUR per period per unit,

ii. fixed order cost - 10 EUR per order,
iii. production cost that is equal to 3 EUR per unit.

6. Customer demand is dynamic and stochastic.
7. Only one product is used in the game.
8. Production can be triggered every 2 weeks in the Discovery mode, and it is instantaneous in the ECLIPS mode, so the manufacturer can produce when needed.
9. Information about the end customer demand, inventories at each stock point and placed orders in the network is visible for all players.
10. The number of periods in the game play is defined by 15 periods for the Discovery mode and by so called "long run", i.e. 100 periods, for the ECLIPS mode. Here, 1 period corresponds to 1 week of a real life.

4.2. Gameplay

The recommended number of players for each supply chain network is defined by 3 in each team. Several teams supported by game moderators could play simultaneously.

Each player is assigned to a particular inventory point(s); e.g., in the Discovery mode:

- Player 1: R1, R2, R3 (retailers Nr. 1, 2, 3);
- Player 2: DC (distribution centre);
- Player 3: FW (production site with an inventory point).

Cards are placed on the table for a specific supply chain network layout defined in section 3.4.

Special forms developed for each player role, i.e. R, DC and FW in the network (see Tables 3 and 4) were used by players in order to fix all transactions made during the game sessions.

Table 3: Transaction Form for R and DC

Inventory Carrying Cost	Order Cost
1	10

Period	Stock at the begining of period	Customer Demand	Delivered	Stock at the end of period	Order
1					
2					
3					
4					
...					
...					
14					
15					

To generate the end-customer demand, a cube dice with sides 0-1-1-2-2-9 was used (see Fig. 5).

Figure 5: A Die for the Game

If the respective network contains more than one end customer, a dice is tossed several times to simulate demand for each end customer.

Table 4: Transaction Form for FW

Inventory Carrying Cost	Order Cost	Production Cost
1	10	3

Period	Stock at the begining of period	Customer Demand	Delivered	Stock at the end of period	New production
1					
2					
3					
4					
...					
...					
14					
15					

At the end of each game mode, the following tasks are performed:

1. Making cost calculation, i.e. total costs for each echelon and for the whole company (for this purpose special Excel templates of transaction forms are provided).
2. Drawing graphics based on processing data in Excel transaction forms to analyse:
   a. company service level;
   b. company inventory level;
   c. company total costs;
   d. demand variation through the network (only for the Discovery mode);
3. Explaining a decision strategy (only for the Discovery mode).

4.3. Results of the game

In the Discovery mode, 15 playing rounds were performed. As defined in the general guidelines, players' objective is defined as follows: minimising the company total costs while attaining a service level of 95%.

Let us note that lead times in the network are set at 1 period between retailer 1, retailer 2 and distribution centre as well as between distribution centre and factory warehouse, and at 3 periods between retailer 3 and factory warehouse (see Fig. 2). Initial inventories are set at 10 pieces for retailers, 15 pieces for distribution centre and 20 pieces for factory warehouse as well as 10 pieces are in transit between factory warehouse and retailer 3.

An example of the completed transaction form by DC player is presented in Table 5 below. All data recorded by the game players in the transaction forms are summarised in the Excel template sheet "Summary results" and used to calculate "Debriefing" results presented in Table 6 below. These results include company performance metrics such as total costs, service level, new production, etc.

In the debriefing session, the analysis of the company service level, inventory level, total costs and demand variation (see Fig. 6, 7, 8 and 9) leads to the following main conclusions.

Table 5: Example of Completed Transaction Form

Inventory Carying Cost	Order Cost
1	10

Period	Stock at the begining of period	Customer Demand	Delivered	Stock at the end of period	Order
1	10	2	2	8	0
2	8	9	8	0	1
3	0	0	0	0	0
4	12	1	1	11	0
5	11	2	2	9	0
6	9	1	1	8	0
7	8	1	1	7	0
8	7	1	1	6	0
9	6	1	1	5	1
10	5	9	5	0	1
11	5	1	1	4	0
12	9	0	0	9	0
13	9	9	9	0	1
14	0	2	0	0	0
15	5	1	1	4	0

As it follows from Fig. 6, the game objective was not fully met. After period T9, the service level dropped below 95%.

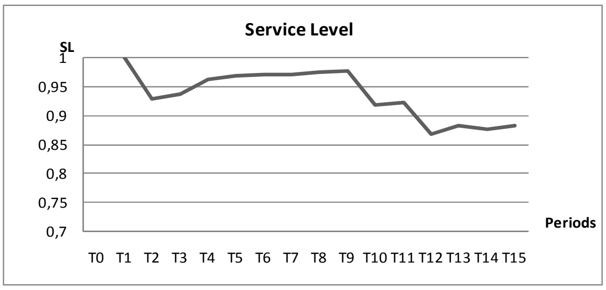

Figure 6: Company Service Level

Inventory initially raised, then dropped below starting levels (see Fig. 7). This could be explained by a company decision to decrease a safety stock level in order to minimise the company total costs. Due to this reason, as follows from Fig. 8, costs were reduced after period T6. However, since the decisions were made intuitively, it caused the decrease of the service level already after two periods (see Fig. 6). This is due to the lead time of 2 periods between stock points. This result could have been partially expected, because the time to travel completely through the network is 8 periods and players did not have enough time to overpass arisen problem. Moreover, as follows from Fig. 9 the demand variation increases in the network upstream echelons.

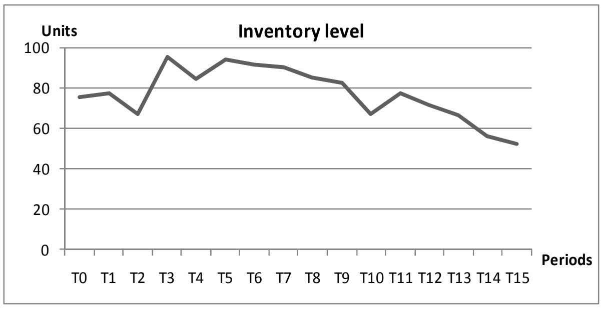

Figure 7: Company Inventory Level

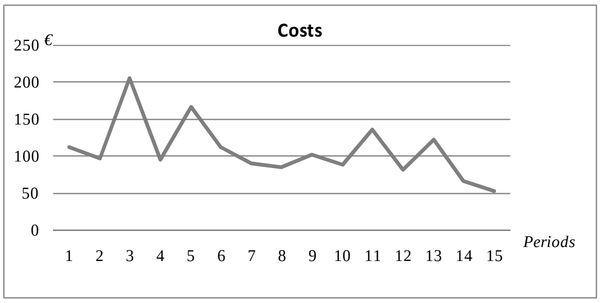

Figure 8: Company Costs

As a result, the company's strategy was not successful and it is necessary to introduce some inventory management techniques that could help to calculate a safety stock level that ensures service level of 95% and avoid the bullwhip effect.

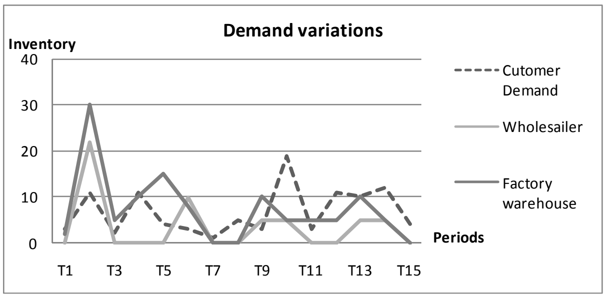

Figure 9: Demand Variations

The results of the Discovery mode were discussed in debriefing and acknowledged the material to be learned in the next game session.

The ECLIPS mode of the game practically demonstrates the theoretical aspects of using different reordering policies. A non-cyclic (reorder point driven referred to as ROP) policy is compared with a cyclic policy (referred to as POR).

Table 6: Results of the Discovery Mode

	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	Sum	Average	FR
WIP	75	77	67	95	84	94	91	90	85	82	67	77	71	66	56	52		76,9	
SL		100,0%	92,9%	93,8%	96,3%	96,8%	97,1%	97,1%	97,5%	97,7%	91,9%	92,3%	86,8%	88,4%	87,8%	88,2%			88,2%
Cost pp		112	97	205	94	166	111	90	85	102	87	136	81	121	66	52		107,0	
Cutomer Demand		3	11	2	11	4	3	1	5	3	19	3	11	10	12	4	102	6,8	
Delivered		3	10	2	11	4	3	1	5	3	15	3	6	10	10	4	90	6,0	
Orders		2	3	2	1	3	2	0	0	2	2	2	1	4	1	0	25	1,7	
New Production		5	0	30	0	14	0	0	0	0	0	13	0	5	0	0	67	4,5	

Hard and soft benefits of using the latter have been indicated. The hard benefit is an inventory reduction that can be witnessed during the game (see Fig. 10). As the most evident soft benefit, easy decision implementation and control can be mentioned.

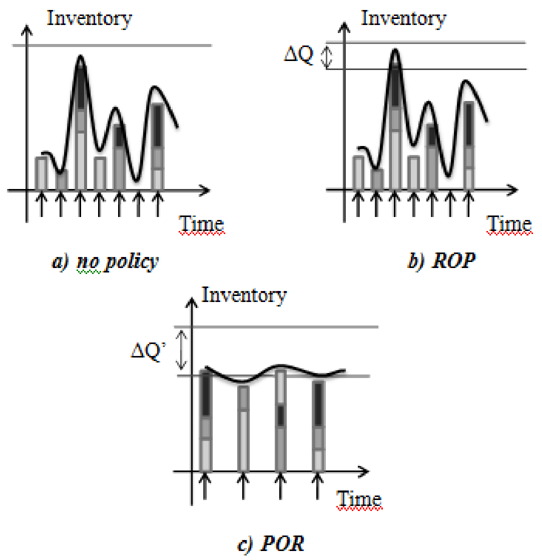

Figure 10: Inventory Reduction Potential

For testing purposes, a "long run" of 110 periods was performed for each of the three replenishment policies:

- non-cyclic,
- cyclic non-synchronised and
- cyclic synchronised.

For regular plays, only 30 playing rounds have to be performed. As defined in the general guidelines, players follow the objective defined in the Discovery mode.

Let us note that lead times in the network are set at 1 period between retailer and distribution centre, 2 periods between other stock points and 1 period between raw material and production and the nearest downstream warehouse (see Fig. 1). Initial inventories are set at 30 pieces for retailer and 20 pieces for distribution centre and factory warehouse. The following policies are played in the game:

- non-cyclic policy with lot size 7 and reorder point equal to 8, 14 and 22 for retailer, distributor and factory warehouse, respectively;
- cyclic non-synchronised policy with cycles of 3 days and order-up levels of 21, 25, 25 for retailer, distributor and factory warehouse, respectively, that order at the same time;
- cyclic synchronised with cycles of 3 days and order-up levels of 21, 25, 25 for retailer, distributor and factory warehouse, respectively, that order when the previous stage has been supplied.

All calculations are made according to respective formulas described in (Simchi-Levi et al., 2003).

While testing, all results from transaction forms completed by players were aggregated and processed by the game moderator in the Excel template sheet "Summary results" and used to calculate and analysed "Debriefing" results presented in Table 6 and Fig. 11, 12, 13 and 14. These results include company performance indicators such as average inventory level and average costs, etc. For regular playing, players calculated the company performance indicators and draw graphics by their own.

The customer demand simulated in the game is shown in Fig. 11. As follows from Fig. 12, all replenishment policies allow keeping service level up to 95%.

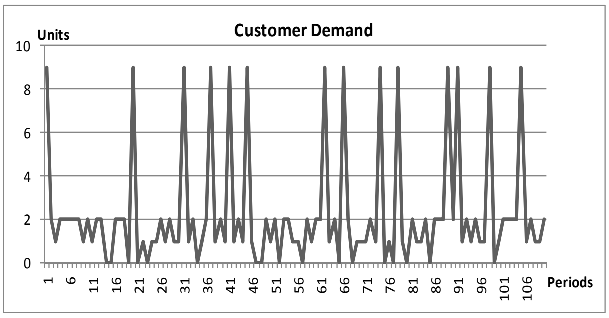

Figure 11: Customer Demand

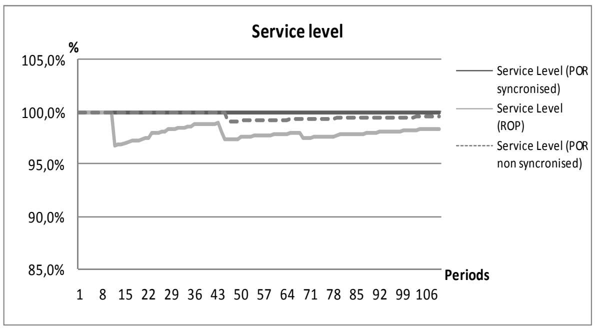

Figure 12: Service Level

However, by comparing average costs (see Table 7), one can conclude that implementation of the cyclic policy reduced the company average costs and average inventory level, in comparison with the non-cyclic policy (see Fig. 13 and 14). Moreover, implementing the synchronised cyclic policy can improve the results even more.

Table 7: Results of Different Replenishment Strategies

	ROP	POR non-synchronised	POR synchronised
Service Level	99%	98%	100%
Average Costs	86,47	85,41	81,03
Average Inventory	71,15	68,74	64,46

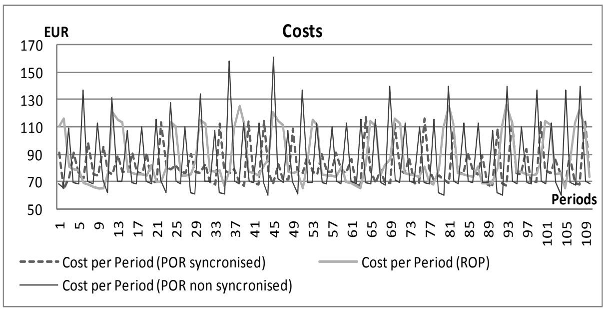

Figure 13: Total Costs

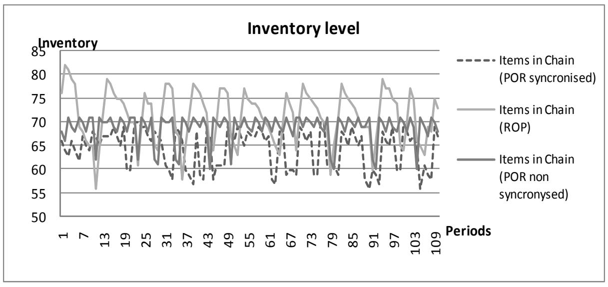

Figure 14: Inventory Level

Finally, it could be concluded that through playing the game participants learn about typical problems that arise in supply chain inventory management and what benefits the company could gain by implementing the cyclic replenishment policies.

5. CONCLUSIONS

The performed review of supply chain simulation-based business games allows indicating the main development trends of such training and educational tools. In particular, modern simulation games are tended to cover a wide range of supply chain management issues, instead of concentrating on a single phenomenon.

The discussed experiences approve the statement that demonstration of different events and decisions in supply chain through simulation games is a powerful and effective way to teach them.

The described ECLIPS game demonstrates ability to support understanding general concepts of supply chain management. In particular, the game was used to introduce ordering policies aimed to improve supply chain performance, proving their efficiency and demonstrating implementation benefits. The game creates awareness of modern inventory management policies in supply chains of different structures, demonstrating efficiency of collaboration between supply chain partners.

The development of a computer-aided supporting tool for the ECLIPS game is currently in progress. It is aimed at providing special templates for testing different supply chain networks and supporting processing of game results.

ACKNOWLEDGEMENT

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MODELING AND SIMULATION AS SUPPORT FOR DECISIONS MAKING IN PETROCHEMICAL MARINE LOGISTICS

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Abstract
The paper proposes a simulation model to support decision in marine logistics; the application field is related to petrochemical industry where different production sites need exchange intermediate products by marine lines; the MARLON model and the use of this simulation approach is described and new applications based on distributed use of these innovative decision support system are proposed and demonstrated; in fact an experimental analysis on a case study is proposed as example of the potential provided by MARLON in improving logistics marine solutions within this field;

INTRODUCTION

The market globalization, the arising of new markets like China and Latin America that permit the access to new resources with low pricing policies and the economical world crisis that make a decrementation of the demand in most of western countries causes continuously and very fast changing in world economy. In all the industrial field logistics, and related costs are a relevant importance especially in maritime logistics. For the previous reason and in the scenario characterized by continuously and very fast changes companies must be careful in taking decision involving their supply chain and their logistics solutions; due to the complexity of the real environment simulation is one of the powerful approach to support the DSS (Decision Support Sustem) of that enterprises. The proposed research is focused on petrochemical logistics with special attention to marine operations; the authors present an innovative approach based on Modeling & Simulation (M&S) technique to support decision maker in problem solving related to maritime logistics, especially in fleets management and sequencing of ship missions over a wide set of chemical plants (Bruzzone et al., 2004). The advantages by using simulation for supporting DSS (in order to optimize resource management, time and costs) are highlighted in the paper. The simulation model developed by the authors allows to analyze complex problems affected by stochastic factors and to evaluate alternative solutions related to logistics network management within petrochemical industries. The simulator proposed in this research is defined MARLON (MARitime LOgistic Network). This simulation model is designed in order to support decisions makers, considering stochastic variables (such as weather condition during the navigation, variability in production rates, failures, demand changes etc) that have influence on the whole supply chain; navigation time, load/unload operations time as well as ship fees and missions costs are in fact critical factors to identify optimal solutions over scenarios.

MARINE LOGISTICS

Due to the necessity both to improve customers service, get benefits of global evolving markets and manage the variations in goods flows it is evident the importance of marine logistics and the strategic issue related to the management of related supply chains.

In almost all the industrial sector the importance of that aspect grows very quickly and consequently grows the interest of companies, also petrochemical companies, in R&D (Research and Development) devoted to improve the efficiency and effectiveness of their Supply Chain (Christopher, M., 1998).
The paper, in fact, focuses on the development of a simulation model devoted to provide petrochemical industries with an effective decision support system (DSS) for maritime logistics of liquid bulks (i.e. chemical intermediate products).
The transportation of chemical bulks is often performed by ship in high percentage; despite its flexibility and convenience this transportation solution is affected by a large number of technical (port infrastructure, site tanks) and commercial (contracts, fees…) constraints.
Due to these reasons different major leading companies in this sector are investing in R&D (Research and Development) for improving their logistics networks and their supply chain effectiveness.

CRITICAL ISSUES IN MARINE LOGISTICS

As anticipated the Maritime Transportation is an important way for goods transportation and recently it is increasingly characterized by innovative solutions and technologies to improve customers service and to satisfy their increasing needs. For the transportation of bulk chemical liquids (i.e. petrol) maritime transportation is a very competitive way respect other solutions and sometime even compared to pipelines due to particular advantages in terms of flexibility, safety regulations and laws.
In fact the logistics solution to be chosen for Chemical Bulk depends mainly by two aspects: quantity to be transported and distance to be covered.
This kind of product are made by continuous chemical processes into Chemical Plants; anyway, to avoid stock out and/or stop of production the raw materials supply needs to be managed with particular care.
The percentage of bulk liquid transported every year is the about the 30% of the total weight of materials shipped world-wide. The use of shipping to transport liquid bulk is performed mainly when: is necessary to transport non compatible products, is necessary to cover wide distance; and in addition maritime transportation guarantees more flexibility, independence from territory morphology.
Due to the high number of components, Maritime Network is a very complex System including harbors, ports and intermodal connections and infrastructures (pumps, tanks, docks and plants) and it is characterized by several stochastic variables that make complex flows and resources management.
Some critical point are:

- Legislative constraints about quantities, not allowed products, not allowed areas for navigation
- Compatibility of Transported Products, from a space point of view (it is not possible to mix into the same tank two different products) and time point of view (i.e. tank cleaning operations to transport a different product)
- Stochastic factors: models able to fit this real complex environment should take care of the stochastic factors. In this case for marine side there are ship fees, weather and sea conditions that influence navigation time and load and unload operations or presence of other ships that could slow down port operations; therefore demand behavior, product prices evolution and production site productivity represent other major context for stochastic factors

Due to high complexity of the systems reproduce is necessary to consider some additional parameters:

- Distance to be covered
- Sequence of port in complex missions (that’s very critical during the planning phase because)
- Transported material quantities that influence the time of navigation and of the operations in the port.
- Availability of the ships used for transportation
- Type of ship
- Ship Capability

Safety issue due to the characteristics of the liquid transported are critical and have a large impact on almost all the item involved in the transportation (i.e. plants and infrastructures are designed in order to respect all fire laws).
One of the main goal of companies is to is to maintain active the process and guarantee the production by supplying right quantities at the right time and in the right way and by reducing costs with a correct fleet configuration and an efficient planning and scheduling of paths and missions.
The high variability in ship fees over different contract times

M&S BENEFITS IN PETROCHEMICAL LOGISTIC NETWORK

There are several ways to optimise Marine Chemical Bulk Transportation, and due to the not-linear nature of this problem and to the strong mutual influence of variables and the presence of many important stochastic elements it is usually necessary to introduce simulation models as decision support system.

In fact in order to reduce costs and increase the plant production, especially considering that chemical plants are generally operative 24 hours/day, 7 days/week, is necessary an appropriate logistics management system able to react dynamically to market changes (i.e. product prices and ship fees).
Obviously the prohibitive costs of production stops due to the continuous nature of these processes and the strongly economic involvement of even operating chemical plants out of their optimal operative range it becomes very critical to guarantee a robust logistics solutions; this in fact is connected not only to the direct costs, but even to technical problems (i.e. damage to the reactors, long time for the start up); so it is evident that this kind of process requires a reliable and regular flow of supplying and also a available storage for chemical reaction products; therefore it's very critical to design appropriate inventory management systems to guarantee the process continuity (Longo et al. 2009).

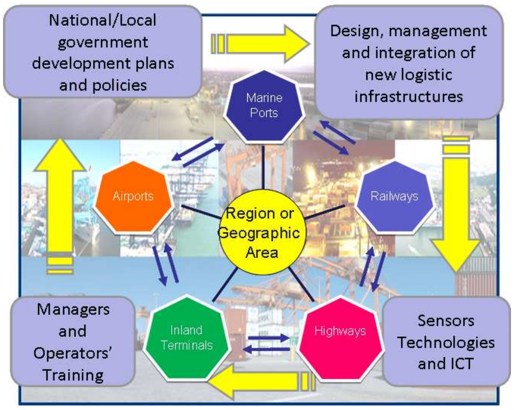


Figure 1. Logistic Network Model

The following aspects characterize the logistic networks in petrochemical field:
- Integration of Complex Systems
- Different Operations in different nodes
- Analytical approaches rarely succeed in properly identifying optimal solutions
- M&S (Modeling & Simulation) is necessary due to the Complexity and Interactions among the networks.
- Variables and Stochastic factors interact and dynamically evolve in time, space in the entire network

Figure 1 shows the benefits provided by using simulation as support to different functions in a marine logistic network:

- Managers and operators training:
  - Training made by quantitative models and innovative approaches.
  - Special high education processes on complex systems life cycle management
  - Personnel evaluation and Recruitment procedures based on realistic, immersive and challenging scenarios
- Government laws and policies:
  - Improvement and evaluation of actual supply chain efficiency and competitiveness
  - Impacts of normative and laws
  - Costs/revenues analysis
  - Point of contact between public and private logistics
- Sensors Technologies and ICT
  - Evaluation of available Sensors and IT solutions
  - Definition of Technical requirements
  - Evaluation of data/information management solutions and ICT tools
- Design, management and integration of new logistic infrastructures
  - Optimization of Demand Production Flows
  - Improvements of marine terminal infrastructures
  - Optimal Reallocation for production site tank infrastructures
  - Enhancement of marine ports services
  - Analysis of Logistics & Transportation scenario
  - Positioning optimization for production sites

As anticipated this research is focused by the authors mainly for marine logistics petrochemical industry:

- Sizing and Fleet management (Sea Logistics)
  - Optimization of Ship Fleet and contracts
  - Scheduling of Ship Operations and extra port activities
- Analysis of Investments on Plants related to their facilities and related marine infrastructures
- The possibility to interact, aided by the integration of the simulator and the web for the all the people involved in the project simulating different scenarios during videoconferences to support the decision making (Information Logistic)
- Management of Ancillary Logistics and Transportation (personnel transportation, support material logistics, Definition of Infrastructure and solutions, Management Optimization Tools)

In fact the author developed the MARLON simulator (www.mastsrl.eu/solutions/marlon) in order to support:
- Evaluation of Ship Costs:
  - Navigation Fuel
  - Port Fuel
  - Ship Daily Costs
  - Extra Costs
  - Total Costs per Mission

- Total Fleet Costs
- Evaluation of Sites Costs for overstock and stock-out occurrences
- Analysis of Current Flows Management
- Analysis of Alternative Scenarios

MARLON: MARITIME LOGISTICS NETWORK

The complex system to be reproduced and analyzed suggest to use simulation; in fact the model developed by the authors consider the maritime supply chain and their components including petrochemical plants, tank infrastructures, port infrastructures and fleets. The complexity of the models grows considering the commercial constraints, added to the technical one mentioned above; in fact different type of contracts and very dynamic market evolution requires to develop a simulator able to support decisions leading to optimal, but robust solutions.
The authors propose to approach the simulation of the maritime logistics processes based on object oriented design and analysis (OODA) by identifying and defining each single element as an object characterized by its attributes and methods.
The authors referred to discrete event stochastic simulation paradigms to develop the related models.
The result is an innovative simulation system defined MARLON (Maritime Logistics Network), that allows to model all the entities and processes related to the marine logistics; MARLON could be customized for different goods, in this paper it is proposed the application to liquid bulks for petrochemical industries; obviously the simulator allows to estimate costs and savings both in term of value and risk; in fact this simulator benefits of previous researches carried out by the authors (i.e. Charme Sequencer 2.0, MALOSI Simulator) focusing just on specific aspects of maritime logistics and chemical productions (Bruzzone, Serindat, Bertoni 2002).
In order to identify critical aspect that affect marine logistics, the authors propose the application of analysis techniques such as DOE (Design of Experiments) methodology and sensitivity analysis.
In addition the author are still integrating the current functionality of the model with advanced optimization solutions in order to investigate new improved intelligent optimization approaches in this field.
MARLON is a simulator able to demonstrate the enhanced advantages provided by using simulation in this framework; in fact by using MARLON it becomes possible to analyze complex scenarios and support the company decision making process with quantitative results and detailed risk analysis.

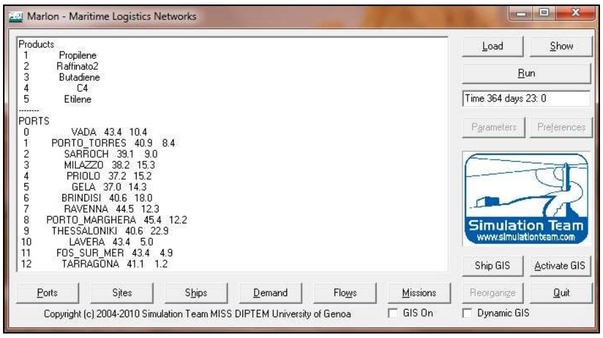


Figure 2. Marlon Simulator

The MARLON conceptual models were implemented in a discrete event stochastic simulator integrated with Google Earth APIs (MARLON).
In fact a basic use of these simulation models is related to fleet management; graphic interface is useful to navigate over the different lines and facilities and to quickly understand the implications of different solutions.
In addition to fleet management a great benefit of MARLON is the possibility to support a complex optimization process in bulk liquids marine logistics considering both costs and performances; the process is to proceed in the definition of the logistics by optimizing first of all the clustering of the chemical flows to be manage, then to identify optimal solutions in term of missions and related ports sequence; at this point it becomes possible to optimize tactical missions in term of fleet characteristics and contracts (Bruzzone et al. 2002)..
All these processes should be carried out interacting dynamically with the MARLON simulator by an automatic smart optimizer and/or by the decision makers.
The authors suggest to proceed by a combined approach that mix automatic optimization based on an intelligent solution dynamically connected with the simulator and expert test on the simulator; this approach allows to reuse logistics solutions proposed directly by the decision makers and to refine them progressively.

Figure 3. MARLON Ports GUI

The following objects are includes in MARLON simulator:

- *Ports* characterized by:
  - ID
  - Port Name
  - Coordinates
  - Input and Output Times
  - Docks Pumps Flows
  - Number of Docks
  - Docks Status
  - Prices for Ship Characteristics

- *Links* characterized by:
  - ID
  - Departure Port
  - Arrival Port
  - Distance
  - Reference Speed
  - Time (Average and Standard Devition)
  - Extra Cost (i.e. passage in a Canal)
  - Path Element

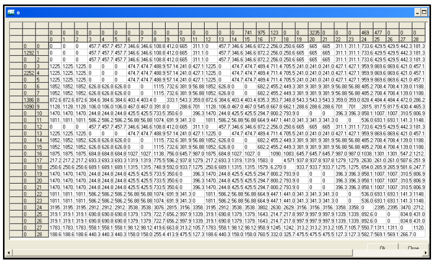
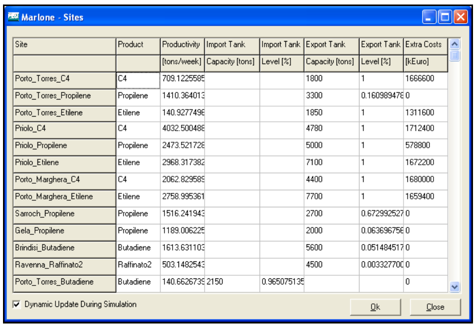


Figure 4. MARLON Links GUI

- *Missions* characterized by:
  - ID Mission
  - Flows
  - Sites Sequence
  - Ships allocated
- *Paths* characterized by:
  - ID
  - Path Element Name
  - Coordinates
- *Sites* characterized by:
  - ID
  - Port-Product
  - ID Port
  - Stop Cost
  - Shortage Cost
  - Minimum Weekly Production
  - Maximum Capacity
  - Product Types
  - Import / Export Products
  - Import / Export Tanks
  - Weekly Production Slots
  - Weekly Production Volumes (in term of statistical distributions)



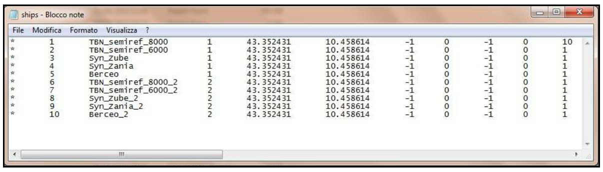
Marlone - Sites

Site	Product	Productivity	Import Tank	Import Tank	Export Tank	Export Tank	Extra Costs
		[tons/week]	Capacity [tons]	Level [%]	Capacity [tons]	Level [%]	[kEuro]
Porto_Torres_C4	C4	709.1225585			1800	1	1666600
Porto_Torres_Propilene	Propilene	1410.364013			3300	0.160989478	0
Porto_Torres_Etilene	Etilene	140.9277496			1850	1	1311600
Priolo_C4	C4	4032.500488			4780	1	1712400
Priolo_Propilene	Propilene	2473.521728			5000	1	578800
Priolo_Etilene	Etilene	2968.317382			7100	1	1672200
Porto_Marghera_C4	C4	2062.829589			4400	1	1680000
Porto_Marghera_Etilene	Etilene	2758.995361			7700	1	1659400
Sarroch_Propilene	Propilene	1516.241943			2700	0.672992527	0
Gela_Propilene	Propilene	1189.006225			2000	0.063696756	0
Brindisi_Butadiene	Butadiene	1613.631103			5600	0.051484517	0
Ravenna_Raffinato2	Raffinato2	503.1482543			4500	0.003327700	0
Porto_Torres_Butadiene	Butadiene	140.6626739	2150	0.965075135			0

Dynamic Update During Simulation
Ok
Close

Figure 5. MARLON Sites GUI

- *Ship* characterized by the following attributes:
  - ID
  - Name
  - Type
  - Geographical Coordinates
  - Operational Status
  - Operational Time
  - Fuel Navigation Cost (for unit of distance/time)
  - Fuel Port Cost (for unit of time)
  - Ship Daily Cost
  - Navigation Speed
  - Draft
  - Number of holds
  - Capacity e Characteristics of each hold
  - Loads Carried
  - Data of Current Mission
  - Ports and Docks Sequence
  - On Board Pumps Flow



ships - Blocco note

File Modifica Formato Visualizza ?

*	1	TBN_semiref_8000	1	43.352431	10.458614	-1	0	-1	0	10
*	2	TBN_semiref_6000	1	43.352431	10.458614	-1	0	-1	0	1
*	3	Syn_Zube	1	43.352431	10.458614	-1	0	-1	0	1
*	4	Syn_Zania	1	43.352431	10.458614	-1	0	-1	0	1
*	5	Berceo	1	43.352431	10.458614	-1	0	-1	0	1
*	6	TBN_semiref_8000_2	2	43.352431	10.458614	-1	0	-1	0	1
*	7	TBN_semiref_6000_2	2	43.352431	10.458614	-1	0	-1	0	1
*	8	Syn_Zube_2	2	43.352431	10.458614	-1	0	-1	0	1
*	9	Syn_Zania_2	2	43.352431	10.458614	-1	0	-1	0	1
*	10	Berceo_2	2	43.352431	10.458614	-1	0	-1	0	1

Figure 6. Ship Object

Figure 7. MARLON Paths

- *Tank* characterized by:
  - ID
  - Port-Product
  - ID Product and Characteristics
  - Capacity, Minimum and Maximum Levels
  - Conversion Time and Costs
  - Current Level

- *Products* characterized by:
  - ID Product
  - Product Name
  - Characteristics
  - Compatibility Constraints

- *Flows* characterized by:
  - ID Flow
  - Flow Name
  - ID Product
  - ID Departure Port
  - ID Arrival Port
  - Quantity (t/week)

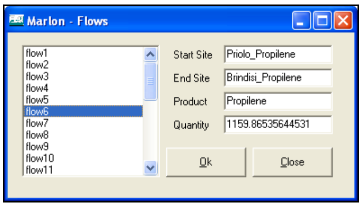


Figure 3. MARLON Flows GUI

Processing all the information resumed above MARLON Simulator identify the best fleet configuration by an heuristic computation procedure; the results obtained are synthesized and presented to the users through reports and animations, while details of each solution are available on demand.
This simulation model is able to simulate the following phenomena:

- Ship Fee Variation
- Product Market Prices Changes
- Production Cost behaviour
- Chemical Facility behaviour
- Navigation Time (including delays and time advances)
- Nautical Operations Time and Port Operations
- Tactical Missions Management by considering n Ports and m flows
- Level of Saturation of Vectors
- Evaluation of different sequencing alternatives
- Evaluation of different grouping alternatives
- Evaluation of Tactical Mission Costs
- Import/Export Operations related to the load type and to volumes
- Waiting time in Rada and Port Costs Evaluation including Controstallie
- Ships missions cycles

The geographic network is defined by links, therefore links in two directions can be different in term of distance and costs (i.e. channel fees); the user is entitled to define probability distributions for the different phenomena (i.e. Beta distribution or Gaussian distribution)
MARLON variables and parameters are easy accessible by users for changes the characteristic of the simulated scenario.
The update the MARLON DBASE is provided with a user-friendly GUI (Graphical Users Interface), by clicking on the apposite buttons it is possible to access input files or output report.
Several additional functions are allowed for flows management:

- *Load* for Input Files Data load and refresh
- *Show* for updating text and graphical areas
- *Run* to start up simulation

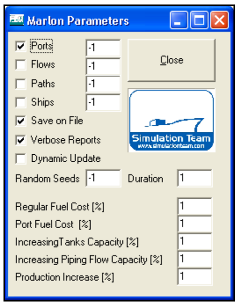


Figure 4. MARLON Parameters

For an high-end user is available also a parameters task button allows to manage simulation parameters such as:

- *Icons Types* to be visualized on Google Earth
- *Random seeds*
- *Duration*
- *Costs Coefficient* (i.e. port fuel cost)
- *Capacity Coefficient* of tanks or piping

The integration of MARLON with Google Earth APIs allows to activate GIS functions for the visualization of ships location and movements (determined by simulated coordinates) step by step:

- *Ship GIS* to visualize ships on Google map
- *Activate GIS* to activate GIS localization

Figure 5. View of some MARLON Ports

The results of the simulation runs are available for being analyzed by users in different ways: quick monitoring of flows, products, costs, profits and times during the simulation as well as by most accurate post processing analysis of the simulation output including cost trends evaluation for each site (i.e. including extra costs due to overstock and stock-out) and for each ship (i.e. fuel costs for navigation and port operations).

The major benefits related to the use of MARLON simulator are:

- Support the Optimization of the fleet configuration and port sequences during a ship mission made by the decision makers
- Support distributed decision making sharing information over the web among people located in different geographic areas; this allows to organise meetings and training sessions to evaluate different scenarios and solutions
- Improve the cooperation among different divisions of the same company, for example to put in contact logistics with commercial units or production sites generating a collaborative working environment with the benefit of a common simulation based framework for integrated quantitative analysis

Interoperability and integration with other modules is one of the innovative features of the DSS based on simulator (Bruzzone 2007). This feature is so useful, for instance, during meetings for tactical and strategic decisions on logistics and production (investments and budget) or videoconference to evaluate scheduling decision and critical operations. The experimentation was carried out using smart interactive whiteboards and dynamicallyb integration of MARLON with interactive GIS such as Google Earth.

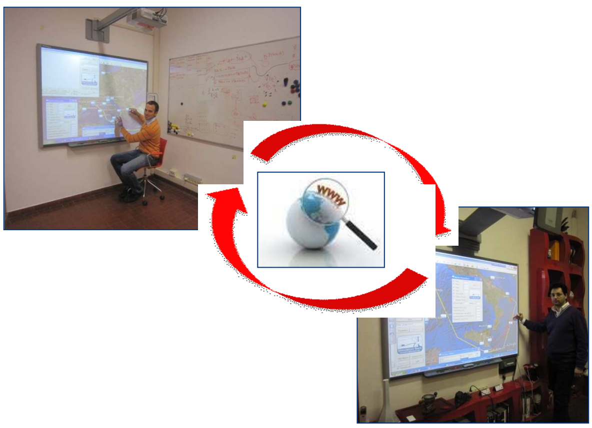


Figure 6. MARLON for "information logistics" during a distributed meeting over the web

The integration of MARLON with two modules: an optimizer and a sequencer allow to make more complete analysis and to propose new optimal solution or to refine existing ones. The best port sequence in a marine mission involving multiple picks and drops should be identify by an optimisation module due to the high number of variable; some previous research allowed to refine these algorithms and a demonstrator was developed by the authors for supporting implementation in industrial DSS (Charme Sequencer 2.0), these missions, obviously must satisfy the following constraints: required flows, technical commercial and operative constraints and available fleet.

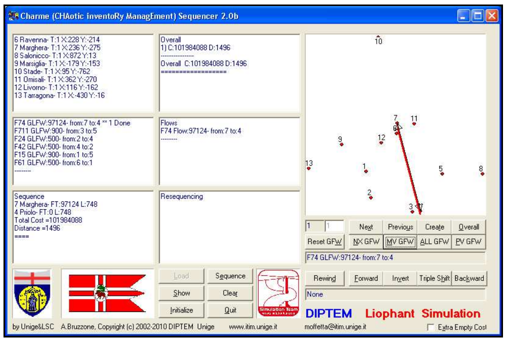


Figure 7. Charme Sequencer Module

This module allow to simulate:

- Ship's Saturation Levels
- Times and Costs for Port Operations
- Times and Costs of Navigation
- Times and Costs for Logistics Activities
- Ship fees

This additional module allow also the identification, definition and optimization of ship missions:

- Evaluation of different alternatives for Flows Grouping (Flows Clustering)
- Evaluation of different alternatives for Ports Sequencing (Ships Missions)
- Evaluation of cluster based Mission Costs

The second additional module is a sequencer that allows to optimise the vessels to be attributed to a mission from available fleet; the related algorithms was originally developed MALOSI models (Ship & Tank) to support industrial DSS in this area; these algorithms allows to identify risk and opportunities as well as optimal solutions in term of Ships management and Tank Infrastructures over stochastic complex scenarios. The outputs of MALOSI Ship 2.0 models includes the Optimal Ship Configuration able to satisfy the required flow of materials for a Mission

In similar way the outputs of MALOSI Tank 2.0 includes the best Import and Export Tank Infrastructures for a cluster of chemical plants/ports

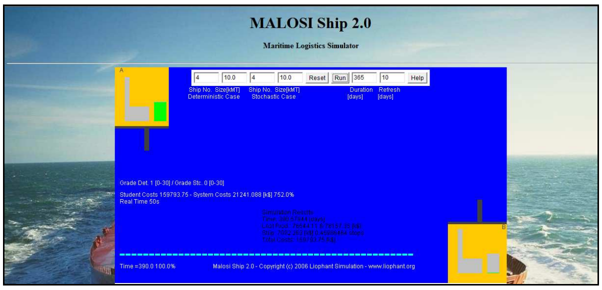


Figure 8. MALOSI Module

By using MSpE (Mean Square pure Error) and ANOVA (Analysis of Variance) techniques the authors successfully complete the MARLON VV&T (validation, verification and test) phase.

The next paragraph shows the obtained results over a case study extracted by a real industrial problem with some alternation on the original data due to their confidential nature.

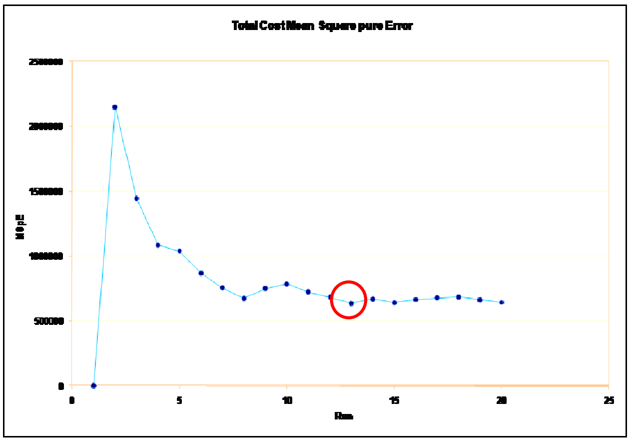


Figure 9. MSpE referred to Simulations runs

EXPERIMENTATION EXAMPLE

As mentioned before the scenario reproduced was very complex, stochastic factors and the non-linearity of the system need to be studied with care.

In order to analyze the stochastic influence on processes and to identify critical and significant parameters in terms of influence on the target functions (i.e. fleet total costs) the authors defined a detailed and careful experimental analysis.

Using Mean Square Pure Error methodology (MSpE) the authors performed statistical analysis in order to evaluate the experimental error and to measure the influence of stochastic variables onto the output target functions.

The use of that particular methodology allows to identify the correct simulation duration and, through the calculation of the confidence band, to know the fidelity of simulation output.

In this paper it is proposed the target function related to Ship Total Costs corresponding to fleet management costs; this KPI (Key Performance Index) includes the following eleemnts:

- Navigation Cost for each distance/time unit
- Operational Costs for each time unit
- Port Operations Class Cost
- Load Unit Cost
- Ship Mission Cost for each route and contract
- Lay-days, demurrage, etc.
- Penalties

In Figure 14 the MSpE analysis is proposed as well as the evolution of the Experimental Error referred to the simulation runs, as enhanced in that picture the stability of the Error is reached after 13 runs that represent the optimal number of replications over the same logistics solutions to properly take care of the influence of stochastic factors; this measure allows to estimate the tolerance of simulation results over the different target functions. The MSpE analysis is repeated for the following target function:

- Ships Total Costs
- Fuel Total Cost
- Ports Total Cost

in order to analyze the Experimental Error evolution respect the simulation time for identify the minimum simulation duration that allows to obtain reliable results.

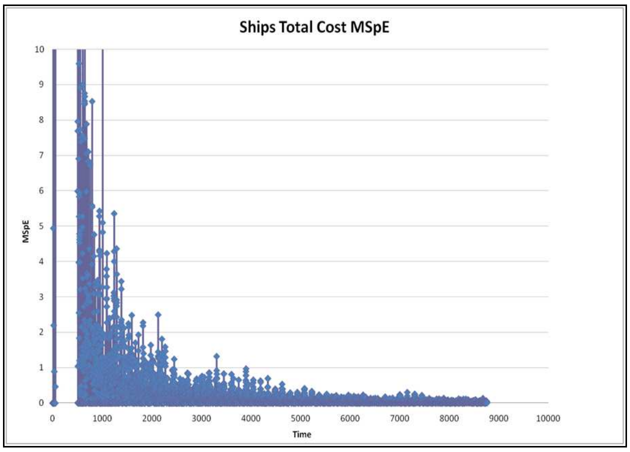


Figure 10. Ship Total Cost MSpE

Melting the results obtained, in terms of optimal run for each target function, is possible to determine the Correct Minimal Run Time by appliying the following relation:

CMRT = max(RTstc; RTftc; RTptc)

where:

RTstc = Run Time Ship Total Cost
RTftc = Run Time Fuel Total Cost
RTptc = Run Time Port Total Cost

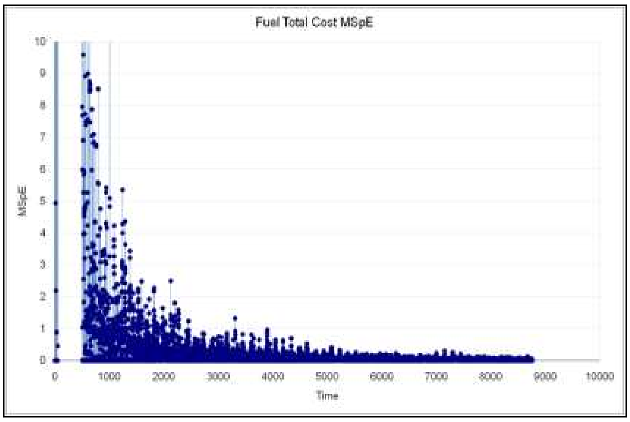


Figure 11. Fuel Total Cost MSpE

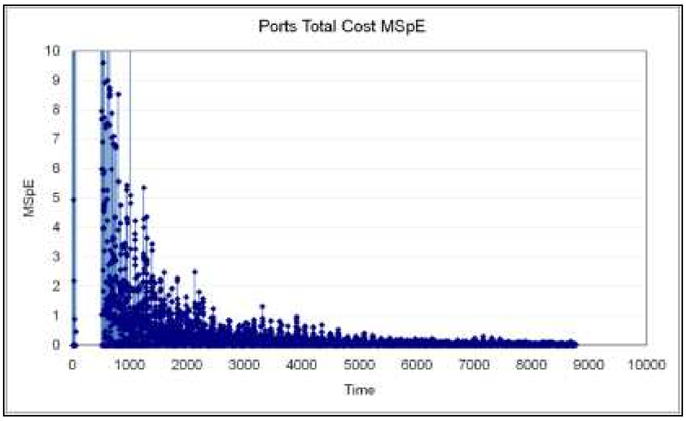


Figure 12. Ports Total Cost MSpE

The whole simulator is quite stable. As a matter of fact, it has been tested and validated and it reaches stability just after 20 simulated days (CMRT); so it means that MALOSI over the specific scenario under analysis it is able to support decision dealing within expected results over three weeks with very high degree of precision.
In order to analyze the impact of the input factors (and their interactions) on target functions the authors applied the sensitivity analysis techniques.

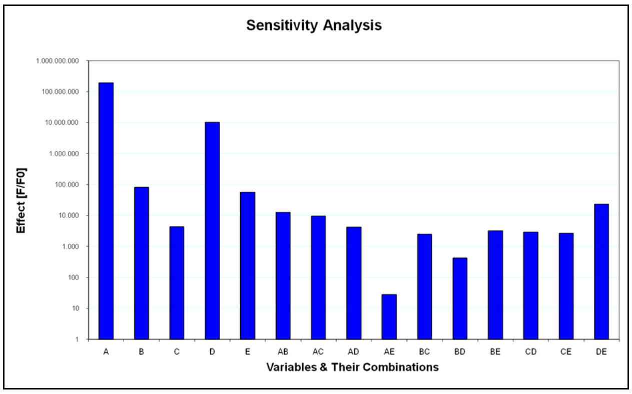


Figure 13. Sensitivity Analysis Results

In particular it is applied a Central Composite Design in order to complete this analysis reducing the efforts to estimate the stochastic factor influence; results are reported in the diagram below:
The graph shows the impact of the following input variable on the "Ship Total Cost" target function:
a) Production
b) Cost of Regular Fuel
c) Capacity of Tank
d) Cost of Port Fuel
e) Flow Capacity of Piping

The results are obviously strictly related to the variable ranges chosen and to the scenario used; in fact due to the non-linear nature of the problem the sensitivity could result very different changing this aspect; for instance in the proposed case the fleet is fixed and the range of variability of costs are estimated based on experts evaluation; despite very synthetic result proposed, it is interesting to note that this analysis allows not only to estimate the influence of the main input but even their interactions that obviously resulted by high due to the high level of complexity of this problem.

CONCLUSIONS

This research highlights the benefit of using simulation models to support analysis and decision making in complex logistics systems.
Focusing the study on maritime logistic fields the authors developed a simulator, MARLON, as support for marine supply chain management; the simulator is able to deal with fleet management and optimization and with evaluation of infrastructures and management policies over different scenarios. MARLON include innovative features such as interoperability with other modules; for instance MARLON is integrated through dynamic connection with the other modules (CHARME and MALOSI) for supporting optimization; another interesting features investigated in this research is the use of MARLON as distributed DSS for distributed teams working over the web; from this point of view the use of interactive smartboard and the integration with GIS (Google Earth) provide good results during the experimentation. At this stage MARLON is effectively implemented and the preliminary tests on real cases result very promizing. The experimental analysis confirms that the model is stable and reliable, and propose a methodology to effectively use as integrated systems for supporting decision makers in defining and managing marine logistics and fleet configuration within petrochemical industries.

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SIMULATION, ANALYSIS AND OPTIMIZATION OF CONTAINER TERMINALS PROCESSES

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ABSTRACT

The freight logistics includes all the processes which are needed to supply industry, retail and wholesale and the end customers with goods. Such processes generate a flow of goods that, in the global supply chain, mainly relies on the activities carried out within worldwide container terminals. In this paper, the authors present a simulation model of a real container terminal. The simulation model is jointly used with optimization techniques (genetic algorithms) to carry out a range allocation optimization on berth assignment to incoming ships and number of tractors for each quay crane with the aim of minimizing the average time spent by each ship in the port area (decreasing, as consequence, costs and increasing service level provided to final customers).

Keywords: container terminals, supply chain node, simulation, optimization, genetic algorithms

1. INTRODUCTION

According to the TRANSvisions report of the EU (TRANSvisions, 2009), the freight transportations in Europe (in terms of tonnes-km) are expected to increase by 1.7% per year (until 2030). Today, it is estimated that 80% of Europe trade is carried by sea, and that short sea shipping accounts for 40% of freight transport. With over 400 million passengers that annually pass through European ports (EU-27 main ports) and more than 169.8 millions of tonnes transported by using containers (see table 1), maritime transport has a direct impact on the EU GDP as well as on the quality of life of many European people.

In addition, during the last years the growth of international goods trades has increased the demand for maritime transportation services; by the end of 2008, however, this sector has begun to suffer the consequences of the financial crisis (see figure 1), even if activities in European ports have continued their gradual recovery from the global economic downturn, with an increase of 1.6% in the 3rd quarter of 2010 compared to the 2nd quarter of 2010 (Maritime transport of goods - quarterly data, 2011). Data in table 1 also shows that the growth rate on the same quarter of 2009 is about 11.5% while the annual growth rate is about 5.7%.

Table 1: Quarterly data for European ports
Source: Maritime transport of goods - quarterly data (2011)

Type of cargo	2007 Q3	2008 Q3	2009 Q3	2009 Q4	2010 Q1	2010 Q2	2010 Q3 Gross weight of goods (in Mio tonnes)	2010 Q3 Growth rate on previous quarter	2010 Q3 Growth rate on same quarter of previous year	2010 Q3 "Annual" growth rate
	Gross weight of goods (in Mio tonnes)									
Total	956.2	956.5	841.3	844.8	848.4	869.9	883.6	+1.6%	+5.0%	+0.9%
Liquid bulk goods	373.3	372.2	351.0	349.7	358.9	344.7	361.0	+4.7%	+2.8%	-1.8%
Dry bulk goods	234.0	240.7	196.0	199.4	197.4	207.1	205.7	-0.7%	+4.9%	+1.3%
Large containers	175.3	177.1	152.3	156.8	152.7	164.6	169.8	+3.2%	+11.5%	+5.7%
Ro-Ro mobile units	110.8	106.6	97.5	89.9	89.7	98.1	95.6	-2.5%	-1.9%	-1.3%
Other general cargo nes	62.8	60.0	44.5	49.1	49.8	56.4	51.5	-7.1%	+15.7%	+9.0%
Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-	-

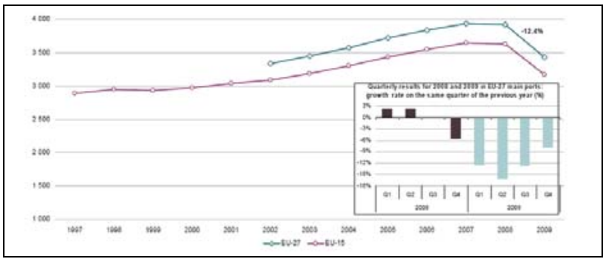

Figure 1: Gross weight of seaborne goods handled in all ports (in million tonnes). *Source: Maritime ports freight and passenger statistics (2010)*

In such a context and with the renovating competitive pressure, both Northern European ports and ports of the Mediterranean area are demonstrating an aggressive behavior in terms of quality and service level provided to the final customers, with the aim of increasing ports receptivity, improving efficiency, reducing times and costs for container handling operations (trying to meet the main requirement dictated by the shipping lines companies: minimization of the time spent by the ships in the port).

Actually, container terminals management is a quite complicated issue in which theories and analytical models, proposed over the years by researchers, very often have not tackled correctly the design and management problems (above all in terms of results applicability). A typical container terminal environment is usually characterized by multiple operations that run concurrently, such as quay cranes loading and unloading operations, containers handling operations between the berth and the yard area, containers handling operations within the yard area (also including trucks loading and unloading operations), rail services management and containers inspections operations. Usually, such complexity requires to use an approach able to recreate the system considered without restrictive or simplifying assumptions. In this context the authors have extensively used Modeling & Simulation (M&S) both as decision support system (i.e. for container terminal resources management), for operators training and for security enhancement and containers inspection procedures analysis (some of the research proposed by authors over the years are presented in the next section).

In this paper, the authors propose a simulation model of a container terminal located in the upper Tyrrhenian sea. The simulation model is jointly used with optimization techniques (genetic algorithms) to carry out a range allocation optimization on berth assignment to incoming ships and number of tractors for each quay crane with the aim of minimizing the average time spent by each ship in the port area (decreasing, as a consequence, costs and increasing service level provided to final customers).

The paper is organized as follows: section 2 briefly surveys related works, section 3 presents the container terminal and the simulation model, section 4 proposes simulation results and analysis and finally conclusions summarizes the main findings and research activities still on going.

2. RELATED WORKS

M&S approach plays an important role as problem solving methodology and enabling technology for investigating the behaviour of supply chain nodes (Longo & Mirabelli, 2008; De Sensi et al., 2008) and it is usually very effective for design and management of container terminal operations. As already mentioned before, M&S has been used in the logistics and maritime area both to support decision – i.e. for container terminal design and resources management as well as for security issues (above all after 9/11) – and as one of the most effective methodology for port personnel training at any level (i.e. quay crane operators, yard equipment operators, drivers, port managers, etc.). Even in Education, M&S has proven its capability to transmit sharp concepts and support the full comprehension of complex systems (such as marine ports, see for instance Bruzzone et al., 2007; Longo, 2007).

The survey of the research works, proposed by other researchers in the last 20 years, shows that, even with a common M&S denominator, there is heterogeneity among the scientific approaches due to the different models, techniques and methods used for facing decision support problems and training in container terminals (as proven by the analysis of the following references).

Simulation model are often used to analyze or predict the performance of existing container terminals as done by Yun and Choi (1999) and Shabayek and Yeung (2002). In this case, aspects such as simulation model Verification, Validation and Accreditation (VV&A, Balci, 1998) become even more critical because they strongly affect the extent to which simulation can predict the performance of the real container terminals.

Simulation is also jointly used with optimization techniques in order to solve multi-objective optimisation problems involving multiple stochastic variables (in this case, the optimization problem involves contrasting and competing objectives and requires the definition of multiple performance measures). Approaches used see the combination of simulation with both advanced statistic methodology (i.e. Analysis of Variance, Response Surface Methodology, etc.) and artificial intelligence techniques. Examples of research works that deal with optimization problems in container terminals can be found in Gambardella et al. (2001), Kia et al. (2002), Moorthy and Teo (2006), Lee et al. (2007), Lau and Zhao (2008). Among others, the following are still the most challenging optimization problems in container terminals: resources allocation and scheduling of loading and unloading operations (both on the berth and in the yard area), containers allocation in the yard area and the berth allocation problem to a set of incoming vessels. In many cases, artificial intelligence techniques used include genetic algorithms and ants theory.

M&S is also used to support container terminal design and for investment decisions (Bielli et al., 2006; Alattar et al., 2006; Ottjes et al., 2006). In this case, the main aim is to increase both the service level provided to the final customer (by reducing the total time spent by each vessel in the port and the queue of the incoming vessels) and the vessels traffic. The design of multi-terminal systems for containers handling that share limited resources is another challenging problem in which simulation has been profitably used.

The authors of this paper have extensively used Modeling & Simulation (M&S) in the past. Longo et al. (2006) develop a container terminal simulation model; the simulation model is equipped with an advanced graphic user interface to generate different conditions (regarding all the port main operations) an output section to monitor multiple performance measures. The simulation model is used to identify the most important parameters that affect the total number of stored containers. In Longo (2007), an integrated model (made up by five different simulation models) is proposed and used to educate student to analyze complex systems such as container terminals. In Bruzzone et al. (2010) an overview of the architecture of the TRAINPORTS simulators (developed by using the High Level Architecture, HLA) is proposed. The TRAINPORTS simulators include multiple federates (i.e. Straddle Carriers, Quay Cranes, Reach stackers, Trucks, etc.) and can be used to support marine workers training providing the sensation to be in a real container terminal environment. In Longo (2010), simulation is jointly used with advanced design of experiments techniques and response surface methodology for the design and integration of the security procedures (specifically, container inspection activities) in the container terminal operations. Effective operational policies and practices to improve the containers flow management toward the inspection area are proposed, as well as the impact of container inspection operations on the container terminal efficiency is investigated. This approach is further extended in Longo (2011) where an advanced 3D simulation framework for investigating and analyzing the security problem within marine ports environment is proposed with the aim of finding out security gaps and redesigning the most critical security procedures and infrastructures.

3. THE CONTAINER TERMINAL SCENARIO AND THE SIMULATION MODEL

The authors consider a real container terminal, located in the upper Tyrrhenian Sea, with a current capacity up to 1.5 million of TEUs per year and trades, to date, amounted to around 1 million of TEUs. The direct access to sea allows easy maneuvering for different types of ships; the 1.500 m of berth and the 15 m deep water allow the simultaneous docking of multiple container and ro-ro ships. The yard area includes more than 12000 ground slots (up to 900.000 squares meters) with a dedicated rail service (multiple tracks, capacity up to 120 trains per week). The container handling equipment includes 10 portainers post-panamax for ships loading and unloading operations (from 40 to 50 tonnages), 50 tractors (for connection between the docking area and the yard area), 23 Rubber Tired Gantry (for container movements in the yard area) and 3 Rail Mounted Gantry (up to 45 tonnages) for trains loading and unloading operations.

3.1. The STEP Simulation Model

The simulation model of the container terminal (called STEP, *Simulation and analysis of container TErminal Processes*) recreates the main operations of the container terminal and it is in four different parts. Each part recreates specific processes and activities of the container terminal.

Figure 2 shows the flow chart recreating ships arrival and departure operations, as well as ships loading and unloading operations. Without enter in the flow chart details, note that, for each berth module, a specific class recreates containers unloading and loading operations; in addition the object positioned just before the six parallel classes implements all the logics for berth assignment to each incoming ship.

Similarly figure 3 shows trains arrival and departure and trains unloading and loading operations (flow chart in the upper part of figure 3). Two specific classes recreate the 8 different rail tracks. The lower part of figure 4 shows the trucks arrival and departure operations and the trucks unloading and loading operations.

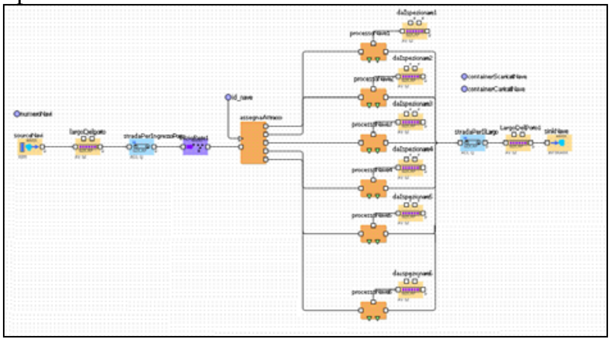

Figure 2: Ships arrival/departure and unloading/loading operations

It should be noted that trucks flow chart has a double "Y" shape. In correspondence of the first "Y", trucks are subdivided in empty and full; in correspondence of the second "Y", unloading/loading options are modelled (i.e. a full truck after the container unloading operation must load another container before leaving or must leave the port empty, etc.).

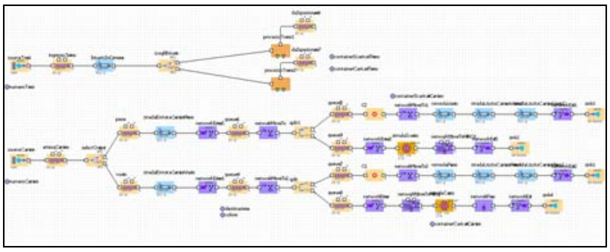

Figure 3: Trains arrival/departure and unloading/loading operations; trucks arrival/departure and unloading/loading operations

Finally, figure 4 shows the containers inspection operations. The containers inspection phase is made up by several and different operations. First of all, by using a scanning equipment a digital image of the container is created (i.e. by using gamma ray). The image analysis aims at discovering container anomalies. In addition to image analysis, physical check, visual check and radiation inspections are usually carried out. In case of anomalies detection, the container is subjected to further and more detailed inspections (Longo 2010).

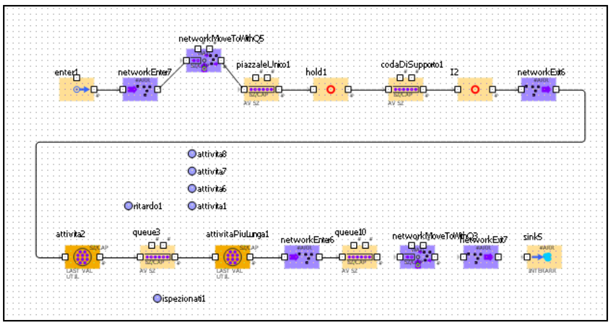

Figure 4: Security procedures and containers inspection operations.

3.2. Simulation Model Animation, Graphic User Interface and Simulation Output Section

The development of the simulation model animation is based on the network concept. A network is made up of departure and arrival points (represented by rectangles) and trajectories that connect departure and arrival points. The simulation model animation includes 4 different networks:

- the ships network that is used by ships for entering and exiting the port;
- the yard network that is used by tractors, rubber tired gantries and trucks (for containers movements in the yard, between the yard and the berth, between the yard and the rail service and between the yard and the area outside the port);
- the trains network (used by trains for entering and exiting the port and by rail mounted gantries);
- the security inspection network that is used for moving containers between the yard area and the security area where inspection procedures are executed.

The animation networks described above are shown in figure 5.

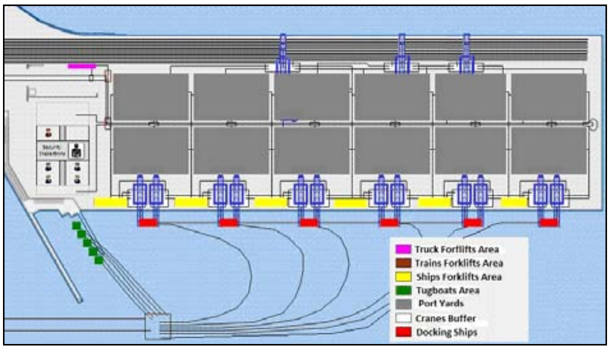

Figure 5: Simulation Model Animation Networks

The simulation model is finally equipped with a graphic user interface and a simulation output section. The following parameters values can be easily changed by using the sliders provided by the graphic user interface:

- the minimum and the maximum number of container to be unloaded/loaded from/to a ship
- the inter-arrival time between two consecutive ships (also eventually providing a ships arrival list);
- the speed of the tractors;
- the speed of the tugboats;
- the minimum and the maximum number of container to be unloaded/loaded from/to a train
- the inter-arrival time between two consecutive trains (also eventually providing a trains arrival list);
- the inter-arrival time between two consecutive trucks (also eventually providing a trains arrival list);
- the number of tractors used to serve quay cranes;
- the number of tractors used to serve rail mounted gantries;
- the number of tractors used to serve the inspection area.

The simulation output section shows the main simulation results including mean utilization level of quay cranes and rail mounted gantries, total number of ships, trains and trucks arrived in the terminal, number of containers unloaded/loaded from/to ships, trains and trucks, total number of handled containers and total number of inspected containers. Figure 6 shows the model during a simulation run execution (figure 6 also depicts the input and output sections).

4. ANALYSIS AND RESULTS

The STEP simulation model is used to investigate different operative scenarios in terms of resources allocation. In particular, after some preliminary analysis the authors used the STEP simulator jointly with Genetic Algorithms to carry out a multiple optimization on berth assignment to incoming ships and number of tractors serving each quay crane over a fixed time horizon with the aim of minimizing the average time spent by ships in the port area. Such time depends on multiple factors and the complexity of the overall system requires to use *ad hoc* simulation models and optimization techniques to come up with feasible and optimal solutions. In fact, the total time spent by each ship in the port depends on the storage area chosen for the containers unloaded from the ship as well as from the position of the containers that must be loaded on the ship. Another important factor affecting the total time spent in the port is the number of available resources used to serve the ship (i.e. number of quay cranes simultaneously working on the same ship, number of tractors/trailers to move container from the berth to the yard area and vice-versa). The optimization proposed in this paper considers a 33 days time frame, 30 incoming vessels of different dimensions and different number of containers to unloaded/loaded; the optimization simultaneously takes into account the berth assignment to each incoming ship and the number of tractors for each quay crane.

The objective function (to be minimized) is the average time spent by ships in the port area and Genetic Algorithms (GAs) are used to find out the optimal berth assignment scheduling and the optimal number of tractors/trailers to be assigned to each quay crane. Our experimental analysis considers roughly one month of real data (33 days) that include the information needed to simulate all the terminal container activities (unloading/loading times, containers position in the yard, available cranes/tractors, etc.). A sample of this data is reported in table 2 in terms of ships arrival time,

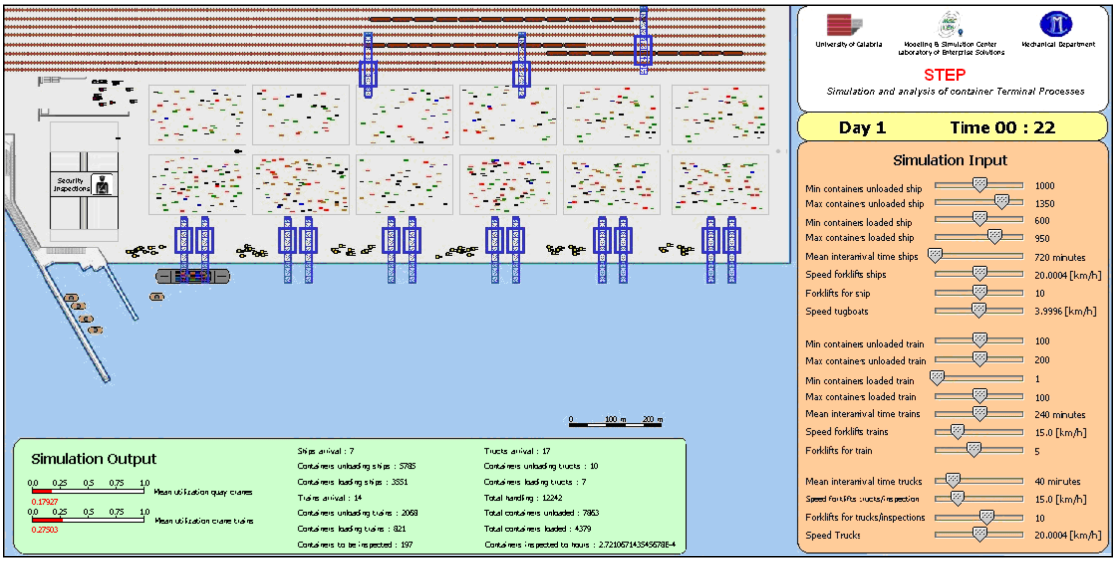

Figure 6: the STEP simulation model during an execution of a simulation run

number of containers to be unloaded and number of containers to be loaded. The total workplan consists of 30 vessels and about 173,473 TEU movements.

4.1. Preliminary analysis and simulation model validation

As mentioned above, some preliminary analyses have been carried out to validate the simulation model. According available data, the Container Terminal handles roughly 1 million of TEU per year. In order to validate the simulation model, the following factors have been changed and the behavior of the simulated terminal has been analyzed: (i) ships inter-arrival times; (ii) number of tractors; (iii) quay cranes efficiency (in terms of loading/unloading times). To come up with reliable results, each preliminary scenario has been replicated three times (the length of the simulation run is 1 year) and simulation results have been averaged out as shown figure 7 and figure 8.
Figure 7 shows the behavior of the simulated container terminal (in terms of number of TEU movements over 1 year) when the ships inter-arrival time is changed according to a Poisson process between 4 hours and 18 hours and the number of available tractors (for container movements from the berth to the yard and vice-versa is kept constant, 40 tractors). The upper curve in figure 7 corresponds to the high efficiency case for quay cranes, while the lower curve corresponds to the low efficiency case.
Similarly, the figure 8 shows the behavior of the simulated container terminal when the ships inter-arrival time is changed according to a Poisson process between 4 hours and 18 hours and the number of available tractors is 50. Again, both the quay cranes high efficiency and low efficiency cases are reported.

Note that both the inter-arrival time and the number of available tractors have a remarkable effect on the number of TEU movements over 1 year.

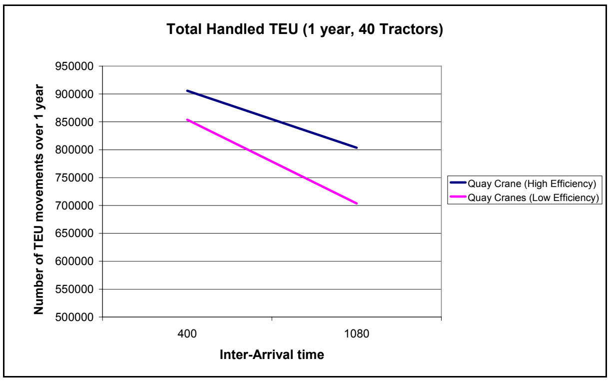

Figure 7: preliminary analysis, TEU movements over 1 year versus inter-arrival times for different level of quay cranes efficiency (45 available tractors)

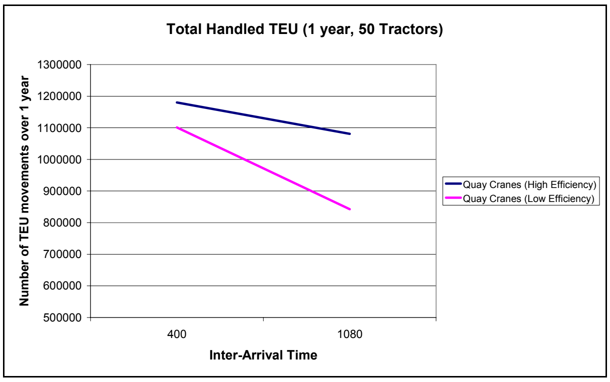

Figure 8: preliminary analysis, TEU movements over 1 year versus inter-arrival times for different level of quay cranes efficiency (50 available tractors)

These preliminary results have been presented and discussed with subject matter experts confirming that the STEP simulation model is able to recreate with satisfactory accuracy the behavior of the real container terminal.

4.2. Berth assignment and number tractors optimization

The optimization of the berth assignment to the incoming ships and number tractors assignment to each quay crane over a time horizon of one month has been performed by using GAs. The fitness function is the average time spent by ships in the port area; the GAs performs a range allocation optimization trying to minimize the average time spent by the ships in the port area.

Table 2: Ships arrival time, number of containers to be unloaded and loaded

Ship ID	Arrival Time	Container To Unload	Container to Load
1	1/5/11 6.00 AM	2441	2035
2	2/5/11 6.00 PM	1446	1890
3	4/5/11 12.00 AM	1608	1780
4	5/5/11 12.00 AM	4406	4236
5	6/5/11 12.00 AM	2371	1963
6	6/5/11 12.00 PM	3710	3697
7	8/5/11 6.00 AM	2729	2200
8	9/5/11 6.00 AM	3250	3359
9	10/5/11 12.00 PM	2921	2891
10	11/5/11 12.00 PM	3516	3500
11	12/5/11 6.00 PM	4385	4250
12	13/5/11 12.00 PM	1681	1790
13	14/5/11 12.00 PM	4177	4088
14	16/5/11 6.00 AM	2340	2169
15	16/5/11 12.00 PM	937	840
16	18/5/11 6.00 AM	4730	4892
17	19/5/11 4.00 PM	2388	2850
18	21/5/11 1.00 AM	2535	2462
19	21/5/11 7.00 PM	3938	3785
20	23/5/11 4.00 AM	4412	4169
21	23/5/11 8.00 PM	1822	1982
22	25/5/11 6.00 AM	4857	4687
23	25/5/11 12.00 PM	2351	2159
24	27/5/11 9.00 AM	3649	3537
25	27/5/11 11.00 PM	2176	2169
26	29/5/11 8.00 AM	1406	1563
27	30/5/11 6.00 AM	3149	3367
28	31/5/11 4.00 PM	1981	1998
29	2/6/11 1.00 AM	2279	2087
30	3/6/11 10.00 AM	3942	3819

It is worth saying that only the total time of those ships that have to unload more than 2300 containers has been considered for the optimization. The main idea is to include in the optimization only bigger ships, which can have an impact on the container terminal business. In addition, the threshold in terms of number of containers (to include or exclude a ship from the optimization process) is one of the parameter of the simulation model; therefore additional scenarios could be investigated considering different threshold values and also eventually including a costs analysis.
The STEP simulation model was used for simulating and evaluating the fitness function for all the solutions proposed by the GAs. In particular, the authors iterated the GAs for 50 generations and the simulation model evaluated the fitness function for each chromosome. Each solution was tested over the pre-defined time horizon (33 days). Table 3 consists of the optimization results in output from the GAs: for each ship, the berth position is reported as well as the number of tractors for each quay crane.

Table 3: GAs optimization results

Ship ID	Berth Position	Tractors for crane 1	Tractors for crane 2
1	2	5	4
2	4	4	5
3	1	4	4
4	5	6	5
5	3	5	4
6	4	4	5
7	2	4	4
8	1	5	6
9	3	5	4
10	5	5	6
11	4	5	6
12	2	4	4
13	1	5	6
14	5	4	5
15	3	4	3
16	2	5	6
17	4	4	4
18	1	5	5
19	5	5	5
20	3	6	5
21	1	4	4
22	4	5	6
23	2	6	5
24	3	5	6
25	5	4	4
26	1	3	4
27	4	5	6
28	2	4	5
29	5	5	4
30	1	6	5

Figure 9 shows the performance graph of the genetic algorithms optimization, in terms of worst, average, and best fitness over 50 generations. Note that based on this optimization procedure it was possible to obtain significant improvements in terms of average time spent by each ship in the port area.

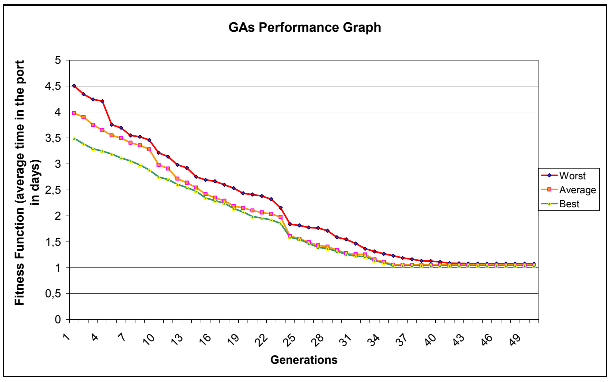

Figure 9: GAs performance graph

The GAs initial population was randomly generated therefore initial solutions provided by GAs are characterized by very high values of the fitness functions. Better initial solutions could be obtained starting from an initial population (berths assignment and tractors assignment) generated according to subject matter experts estimations.

Furthermore, the main aim of the optimization was the correct berth assignment in order to have feedback to improve the allocation of containers in the yard (yard optimization). This in turn leads to a better service level (in terms of reduced times) provided to final customers.

5. CONCLUSIONS

The paper deals with process analysis and optimization in a real container terminal. A simulation model of a container terminal has been developed; the implementation of the simulation model (called STEP) is presented as well as some preliminary analysis devoted to validate the simulation model.

The STEP simulation model has been used jointly with genetic algorithms to carry out a range allocation optimization on berth assignment to each incoming ship and number of tractors to be assigned to each quay crane. The fitness function is the average time spent by ships (only certain ship, those ships that may affect the container terminal business) in the port area; the minimization of this fitness function is pursued as opportunity to provide the final customers with higher service levels.

Further research activities are still on going using the same simulation model to carry out additional optimizations that include also the scheduling of containers unloading/loading operations, number of quay cranes to assign to each incoming ship, allocation of yard cranes and allocation of containers in the yard as well.

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ON THE OPTIMAL SAFETY STOCK LEVELS IN SUPPLY NETWORKS

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ABSTRACT
In this paper, we address the issue of defining the optimal size and distribution of safety stocks in a supply network. The determination of the appropriate safety stock level in complex and stochastic distribution systems is often a complex task, since safety stocks depend upon the production strategy adopted in response to customer demand, and can be located at different points in the supply chain. Moreover, in a multi-echelon, multi-player supply chain (i.e., a supply network), it is likely that safety stocks are interdependent among the players, and they necessitate decision-making with an integrated view of the supply chain. Our analysis is grounded on a discrete-event simulation model, reproducing a fast moving consumer goods (FMCG) supply network, and on real data related to the FMCG context. By exploiting the simulation model, we aim at optimizing the total logistics cost of the supply network as a function of the safety stock coefficient (k), thus identifying the optimal service level the network should deliver to customers.

Keywords: safety stock; supply network design; simulation model; optimization.

1. INTRODUCTION
Supply chain management is the process of integrating suppliers, manufacturers, warehouses, and retailers in the supply chain, so that goods are produced and delivered in the right quantities, and at the right time, while minimizing costs as well as satisfying customer's requirements (Cooper et al., 1997). Managing the entire supply chain is a key success factor for any business, as non-integrated manufacturing processes, non-integrated distribution processes and poor relationships with suppliers and customers inevitably lead to company failure (Chang and Makatsoris, 2001). Efficiently and effectively managing the supply chain involves different interrelated topics, namely (i) defining the supply chain (or supply network) structure, (ii) identifying the supply chain business processes and (iii) identifying the business components (Lambert, 2001). The first topic, in particular, encompasses a set of decisions concerning, among others, number of echelons required and number of facilities per echelon, reorder policy to be adopted by echelons, service level to be delivered to customers, assignment of each market region to one or more locations, and selection of suppliers for sub-assemblies, components and materials (Chopra and Meindl, 2004; Hammami et al., 2008). Moreover, different supply chain configurations react differently to the bullwhip effect, and they result in different levels of safety stocks required.

Determining the appropriate safety stock level in stochastic distribution systems is often a complex task (Inderfurth, 1991). In fact, safety stocks are determined by the production strategy adopted in response to customer demand, and can be located at different points in the supply chain (Randal and Urlich, 2001). Approaches for optimal determination of safety stocks, taking into account cost objectives and service level required to customers, are limited in literature. Moreover, in a complex multi-echelon, multi-player supply chain (i.e., a supply network), it is likely that safety stocks are interdependent among the players, and they necessitate decision-making with an integrated view of the supply chain. In a recent work, Bottani and Montanari (2011) examined the problem of stocks in supply network, as a function of the safety stock coefficient (*k*). They found that high *k* reduces the stock-out at retail stores, thus improving the service level delivered to the customer, but, at the same time, it involves longer time for a product to reach the final customer, involving the risk of product expiry. Since a trade-off exists between the availability of products at retail stores and supply chain lead time, the authors conclude that the optimal value of *k* should be defined based on a careful consideration of all these effects, as well as on the basis of the operating conditions of the network.

In this paper, we focus on this latter issue, i.e. the definition of the optimal size and distribution of safety stocks in a supply network. The study is grounded on a discrete-event simulation model, which was developed in a previous study and reproduces a FMCG supply network, and on real data related to the FMCG context. By exploiting the simulation model, we optimize the total logistics cost of the network as a function of *k*, thus identifying the optimal service level the network should deliver to customers.

The paper is organized as follows. In the next section, we describe the strategy used for simulations; in section 3, we provide the results obtained from the simulation. Section 4 provides managerial implications and conclusions.

2. METHODOLOGY

To set up this study, we start from a previous publication (Bottani and Montanari, 2011), where we developed a simulation model, under MS Excel, to examine four possible configurations of FMCG networks, and we analyzed in details the corresponding performance of such networks. Those network configurations, which are considered also in this study to derive further insights, stem from the combination of different number of echelons and of facilities per echelons, and are defined as follows:

- Configuration 1 - 3 echelons (i.e. manufacturer, first-tier distribution centers and retailer), with 2 players per echelon;
- Configuration 2 - 3 echelons, with 5 players per echelon;
- Configuration 3 - 4 echelons (i.e. manufacturer, first-tier distribution centers, second-tier distribution centers and retailer), with 2 players per echelon;
- Configuration 4 - 4 echelons, with 5 players per echelon.

The number of retail stores is set at 100 in all configurations. The final customer's demand is assumed to be a stochastic variable with normal distribution, without seasonal trends. Moreover, two reorder policies, namely economic order policy (EOQ) and economic order interval (EOI), are simulated for each network configuration. For the sake of clarity, an overview of the input data used to simulate the FMCG network is proposed in Appendix. The reader is referred to Bottani and Montanari (*in press*) for further details related to the simulation model.

By combining the number of network configurations (i.e., 4) with the reorder policies (i.e., 2), we obtain 8 simulated scenarios. Since our analysis is specifically focused on the identification of the optimal safety stock level, we considered two scenarios for the definition of the safety stocks, which correspond to as many supply chain strategies:

- scenario 1 - all supply chain echelon have the same safety stock coefficient. This corresponds to the situation where all players should deliver the same service level to their customers, and can be motivated by the fact the supply chain echelons operate on a coordinated way;
- scenario 2 - manufacturers/distributors have the same safety stock coefficient, while retailers can have a different level of safety stocks. The rationale behind the choice of allowing different values of k is that retailers may have different (higher) exigencies in terms of safety stocks; in fact, as they directly face the final customers' demand, lack of product implies loss of sale, which should be possibly avoided.

For each simulated scenario, 100 replicates were performed, to obtain significant data.

3. RESULTS

As output, we assess the optimal safety stocks coefficient (or, alternatively, the optimal couple of safety stocks coefficients), as a function of the network configuration, the reorder policy applied and the scenario considered. The "optimal" safety stocks coefficient corresponds to the numerical value of k which minimizes the total logistics cost of the network under the scenario considered.

Moreover, we computed the total cost of the network resulting under optimal conditions. For a better understanding of the results, the total cost was shared among the main cost components, i.e.:

- inventory holding cost [€/day]: it is computed starting from the amount of stock available daily at each site and the unitary cost of stocks;
- order and transport cost [€/day]: it is computed starting from the number of orders placed by each player and the unitary cost of order and transport;
- stock-out cost [€/day]: this cost is computed starting from the amount of stock-out and the unitary cost of stock-out.

The total network cost results as the sum of the above cost components.

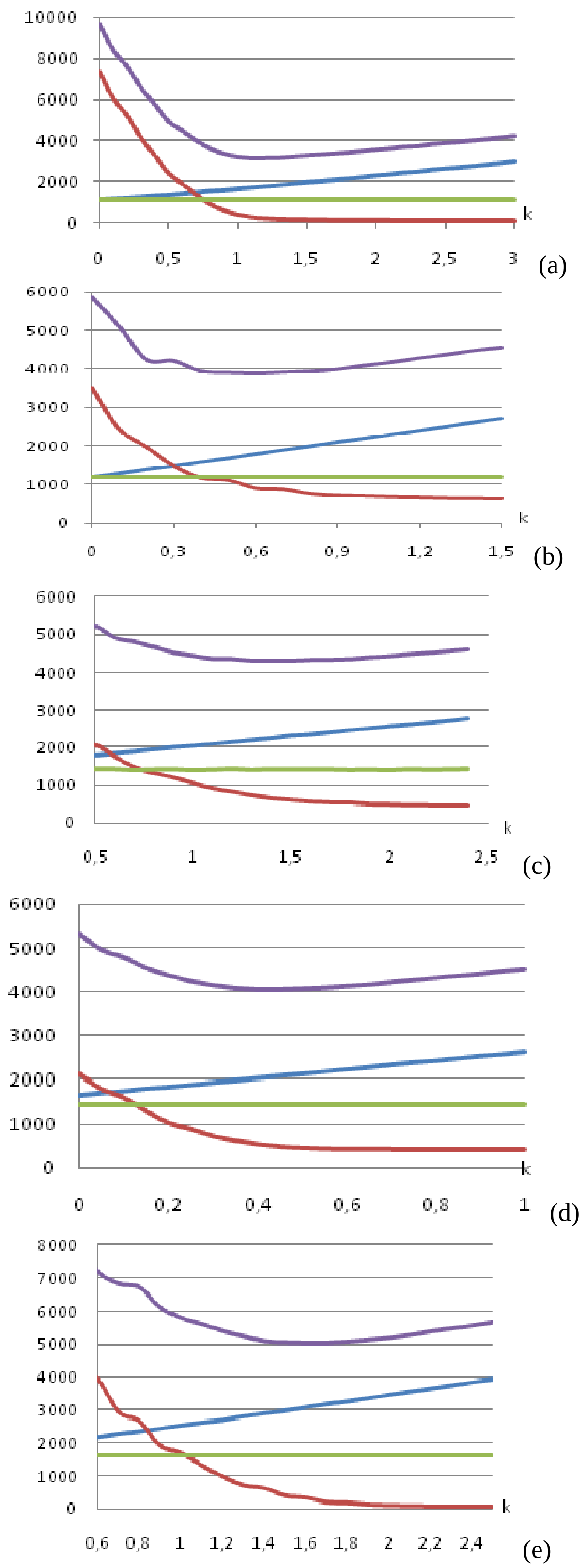
3.1. Results under scenario 1

The first set of simulations was performed by varying *k* within the range [0;3] approximately, and by computing the total network cost under EOQ and EOI policies, for all network configurations considered.

The simulation duration was set at 250 working days, corresponding to approx one year operating period of the network. Results, in terms of the optimal *k* and of the resulting (minimum) total cost, are proposed in Table 1. Detailed outcomes are graphically shown in Figure 1 (a-h).

Table 1: optimum *k* and minimum total cost under scenario 1.

Configuration	EOQ		EOI	
	minimum total cost [€/day]	k	minimum total cost [€/day]	k
1	3130.64	1.1	3853.531	0.6
2	4315.68	1.5	4039.144	0.4
3	5026.72	1.6	6257.308	0.95
4	7578.34	1.5	8337.032	0.65



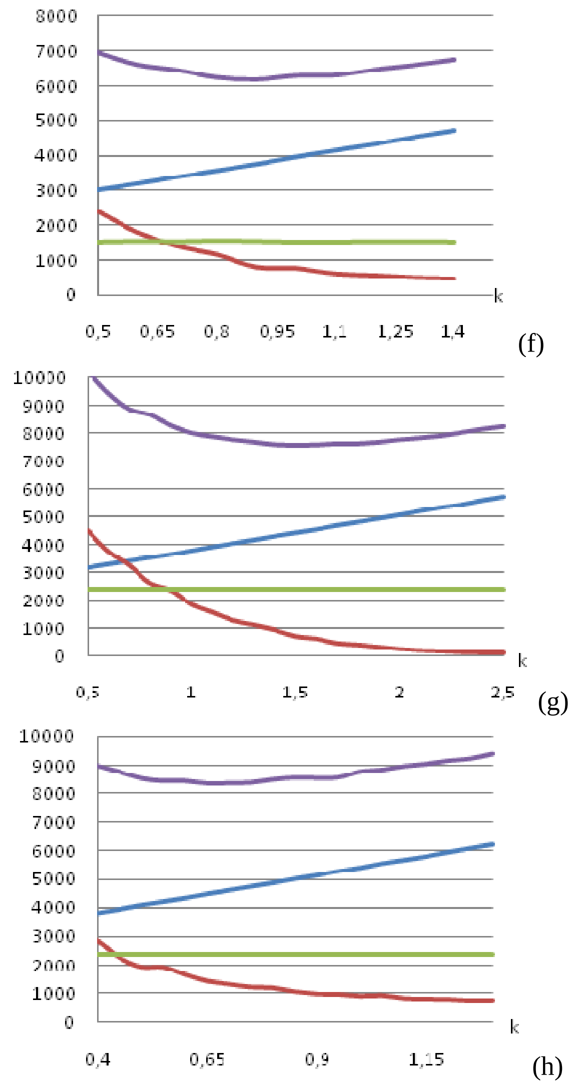


Figure 1: cost components and total cost under scenario 1, for configuration 1 with EOQ vs. EOI policy (a-b); configuration 2 with EOQ vs. EOI policy (c-d); configuration 3 with EOQ vs. EOI policy (e-f); configuration 4 with EOQ vs. EOI policy (g-h).

From Table 1 it is immediate to observe that the highest total cost is obtained under configuration 4, since both an additional echelons and additional players per echelon introduce cost in the network.

From Figure 1 it can also be appreciated that the service level *k* significantly affects the total cost of the network, and specifically:

- it increases the cost of stocks, since highest *k* means highest average stock in the network;
- it decreases the cost of stock-out, because of the greater amount of stocks available;
- it has a limited impact on the order cost.

Moreover, EOI policy often involves higher inventory cost that EOQ policy; a possible reason is that EOI policy generates a higher inventory level in the supply chain, due to the lower number of orders, with wider quantities. Consequently, the optimal *k* under EOI policy is lower than under EOQ policy.

3.2. Results under scenario 2

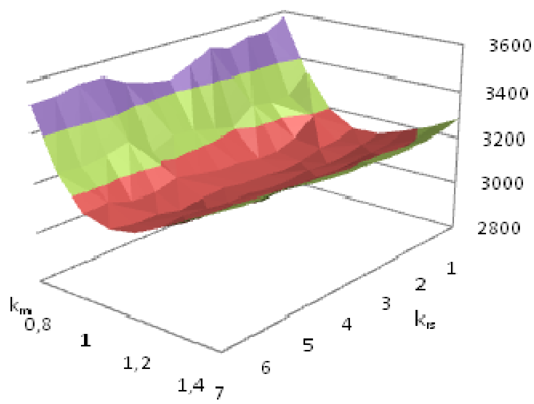
The second set of simulations was performed by allowing different values of *k* for manufacturer or distribution centers and retail stores. They are indicated as k_m for manufacturer or distribution center, and k_{rs} for retail stores.

As per the previous case, we computed the resulting total cost for different couples of k_m/k_{rs}, to identify the combination of such parameters which minimizes the total network cost. Approximately, we varied k_m within the range [0;3] and k_{rs} within the range [0;15].

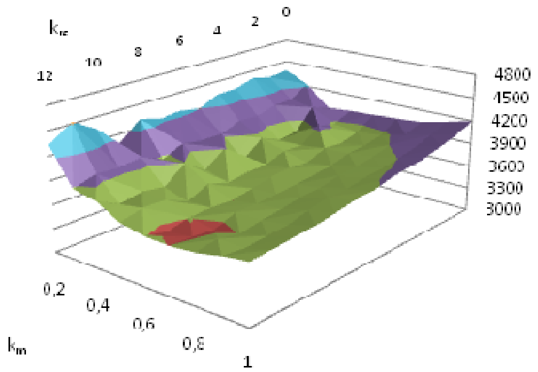
Results, in terms of the minimum total cost and of the optimal combination of k_m/k_{rs}, are proposed in Table 2, as a function of the network configuration and of the reorder policy adopted. The trend of the total cost as a function of k_m and k_{rs} is provided in Figure 2 (a-h) for all configurations examined.

Table 2: optimum *k* and minimum total cost under scenario 2.

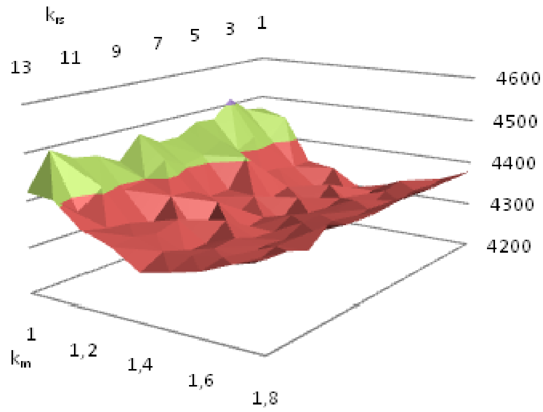
	EOQ			EOI		
Configuration	minimum total cost [€/day]	k_m	k_{rs}	minimum total cost [€/day]	k_m	k_{rs}
1	3069.932	1.1	3	3535.83	0.7	10
2	4280.909	1.3	2	4027.744	0.4	5
3	5009.137	1.5	2	5691.922	0.8	12
4	7577.682	1.4	2	7974.717	0.8	12



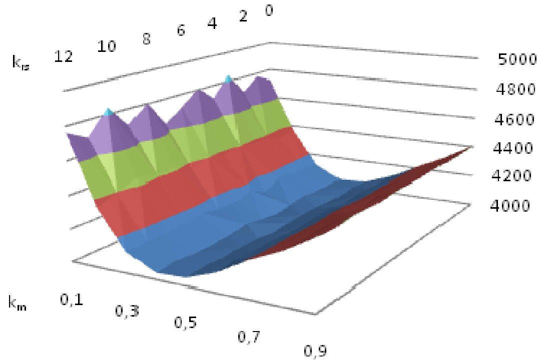
(a)



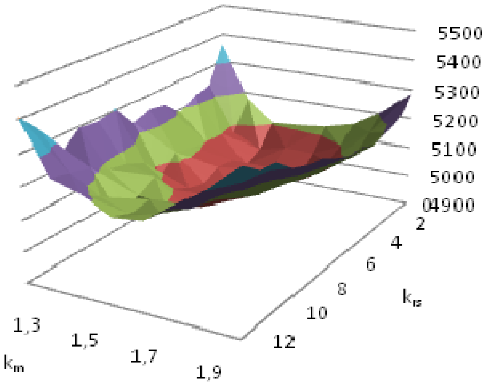
(b)



(c)



(d)



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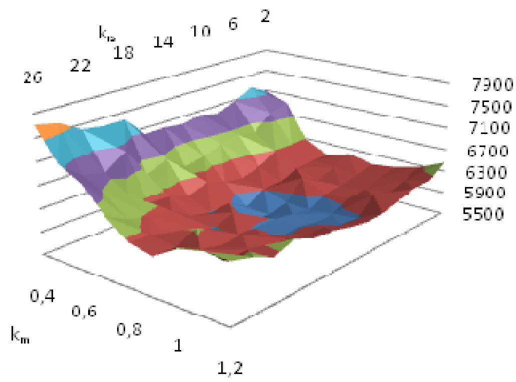
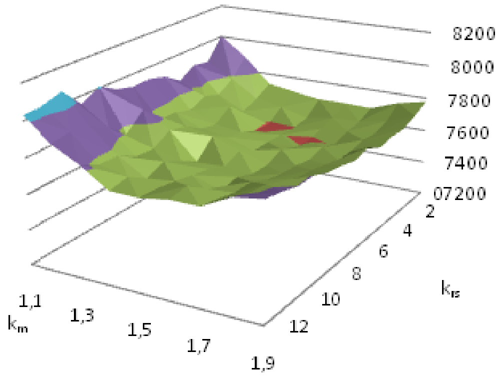
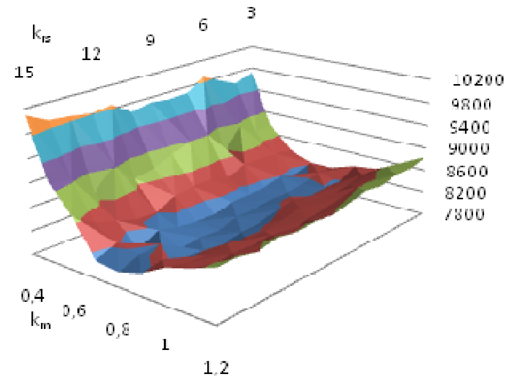


(f)



(g)



(h)

Figure 2: total cost under scenario 2, for configuration 1 with EOQ vs. EOI policy (a-b); configuration 2 with EOQ vs. EOI policy (c-d); configuration 3 with EOQ vs. EOI policy (e-f); configuration 4 with EOQ vs. EOI policy (g-h).

A first outcome from Table 2 and Figure 2 is that, *ceteris paribus*, the service level k_{rs} set for retail stores affects the resulting total cost to a very limited extent. Conversely, the effect of the service level k_m of manufacturer or distribution center on the total cost of the network is significantly higher, and we can argue that the minimum total cost of the network chiefly depends on k_m. For instance, the optimal couple of k_{rs}/k_m obtained under scenario 2 for configuration 1 and EOQ policy are k_m=1.1/k_{rs}=3. Under scenario 1, for the same configuration and operating condition of the network, we found k=1.1 (cf. Table 1), which is very close to the optimal value of k_m. Similar considerations hold for the remaining network configurations, thus confirming that the total network cost is mainly determined by k_m, while the relevance of k_{rs} is lower.

A further consideration is that, no matter the network configuration, under scenario 2 the minimum total cost is achieved by setting quite high k for the retail store. This is especially true when the network operates under an EOI policy; under that reorder policy, k_{rs} varies from 5 to 12. We acknowledge that such values do not appear to be applicable in practical cases; at the same time, however, such results highlight the retail stores require very high stock levels, which, in turn, could be motivated by the need for avoiding out-of-stock situations. Hence, we deduce that retail stores are particularly sensitive to out-of-stock situations under EOI policy. From a practical perspective, this result could also suggest that retail stores should preferably operate under an EOQ policy, where the incidence of out-of-stock is lower (Bottani and Montanari, 2011).

4. ADDITIONAL SCENARIOS AND FUTURE DEVELOPMENTS

In addition to the above described scenarios, it is interesting to consider further experimental developments related to the investigation of more complex demand models. In particular, the authors are investigating the modeling and the experimentation issues related to the impact of complex demand evolution, with non homogeneous distribution in time and quantities, over the final nodes of the supply chain. In fact, when the demand includes seasonal components and periodic elements, in real cases there are complex behaviors emerging such as temporal waves and quantitative shifts that spreads over the final nodes of the supply chain in relation to geographic and commercial features.

Several seasonal behaviors are related to fixed or variable elements due to their nature; for instance, toys demand is strongly related to holiday periods such as Christmas (Wong et al. 2006). Therefore, even in this case the demand related to Christmas could start into arising early or late due to the financial situation of the consumer in a specific geographic area or within a commercial channel.

Methodologies are available and under test to investigate the possibility to mitigate the impact of this variability on the supply chain efficiency, therefore this is pretty challenging (Bruzzone & Mosca 1999; Wang et al. 2006; Longo and Mirabelli 2008, Rahman et al. 2011); in addition to market demand evolution this phenomena are often introduced and amplified by critical events in term of good contamination that spreads over the different areas within a time frame (Bruzzone & Tremori, 2008).

This fact is usually generated by variables affecting the seasonal behaviors that introduce shifts in term of anticipation/delay of the season and/or increase/decrease of the quantities; as anticipated the forecasting phenomena could generate problems in case of multi channels of vendors and/or final consumers and/or within wide geographic areas (Agrawal et al. 2002). The authors was directly involved in several researches related to retail in term to assess demand within regional networks where there is not an homogeneous impact of seasonal components (i.e. Icecreams, fresh food or fashion) (cf. Bruzzone et. al.2005; Bruzzone & Bocca 2006; De Sensi et al. 2008, Bruzzone et al. 2010). In the current case, the authors are interested in introducing such kind of impact:

$$D_m(x,c,t) = i_m(x,c,t_m) D_r(x,c,t_m) \quad (1)$$

$$i_m(x,c,t) = F_d(\min|x - x_i|_2) \cdot F_c(\min|c - c_i|) \cdot F_t(\min|t - t_i|) \quad (2)$$

$$t_m(x,c,t) = t + AD_d(\min|x - x_i|_2) \cdot AD_c(\min|c - c_i|) \cdot AD_t(\min|t - t_i|) \quad (3)$$

Where:

- *x*, Final Point of Sales Geographic Location;
- x_i, i-th element of the Set of Critical Locations affecting the Points of Sales;
- *c*, Commercial channel of the current Point of Sales. Channels have to be indexed in progressive way respecting their ranking in term of average demand per point of sales;
- c_i, i-th element of the Set of Commercial Channels to address final consumers;
- *t*, current time;
- t_i, i-th element of the Set of Critical Events related to the Final Consumer Demand;
- D_m, Modified Demand for a Point of Sales related to the geographic position, commercial channel & time;
- D_r, Reference Demand for a Point of Sales related to the geographic position, commercial channel and time without considering critical phenomena spreading over time, commercial channels and space (i.e. season anticipation);
- i_m, Overall Impact of the critical components on the reference demand for a specific point of sale;
- t_m, Overall Time shift on the reference demand due to the critical components for a specific point of sale;
- F_d, F_c, F_t, Function regulating the increase/decrease of the reference demand related respectively to location, commercial channels and critical events;
- AD_d, AD_c, AD_t, Function regulating the time shift (anticipation delay) of the reference demand related respectively to location, commercial channels and critical events.

For simplicity, it is proposed to compute the distance from point of sales based on geographic Euclidean distance, therefore sometime this distance could require more sophisticated models considering media and social network affecting the diffusion of the phenomena. The functions F and AD could be modeled in different way, therefore for critical event it is recommend to use functions based on the following Y(y) structure:

$$Y(y) = lv + (hv - lv) \cdot e^{-av \cdot (|y|)} \quad (4)$$

- *lv*, minimum value
- *hv*, highest value
- *av*, quickness factor.

The use of supply chain simulator allows to measure how quick and how destructive these phenomena; obviously the experimentation on the simulator of use different supply chain management policies allows to measure the capability to anticipate and/or mitigate these issues as well as the logistics networks robustness and resilience (Longo and Oren, 2008).

5. DISCUSSION AND CONCLUSIONS

In this paper, we have explored, through a simulation model, the issue of defining the optimal size and distribution of safety stocks in a supply network. On the basis of previous studies, we examined 4 network configurations, all referring to the context of FMCG, operating under EOQ or EOI policies. We also considered two possible scenarios, referring to the situation where all network players set the same safety stock coefficient *k* (scenario 1) and where retail stores are allowed to set a different *k*, referred to as k_{rs} (scenario 2). We exploited the simulation model to compute the total cost resulting under each configuration and scenario, with the purpose of identifying the value of *k* which allows obtaining the minimum total cost of the network.

Results obtained highlight the following key points:

- under scenario 1, we found that *k* has a significant impact on the cost of holding stocks and of stock-out, with different effects, while the impact on the order and transport cost is negligible. Moreover, the network is affected by higher total cost when operating under EOI policy,
- under scenario 2, we found that, both under EOQ and EOI policies, the minimum total cost is achieved when retail stores set a very high *k*, meaning that to minimize the total network cost, it is paramount to increase the service level provided by the retail stores;
- moreover, under scenario 2, the total cost of the network chiefly depends on k_m, while the incidence of k_{rs} on the total logistics cost is limited;
- a further result of scenario 2 is that, under EOQ policy, there is not a relevant difference between the optimal *k* value of manufacturers/distributors and retail stores, while k_{rs} is significantly higher than k_m under EOI policy;
- by comparing the results obtained under scenarios 1 and 2, it can also be observed that setting different service level for manufacturer/distribution center and retail store allows obtaining lower total cost of the network compared to the situation where the service level is the same for all echelons. This result suggests that setting specific *k* as a function of the supply chain echelon is a viable strategy to optimize the total cost of the network.

The above outcomes provide interesting guidelines for the optimal design of supply networks. At the same time, some limitations of this study should be mentioned. The main one is that we refer to a specific context, and thus, although the input data used well represent the FMCG industry, our results cannot be generalized to other contexts. Moreover, we assumed the network configurations on the basis of our previous study, to derive further insights about those configurations. Nonetheless, it would be appropriate to also investigate different network configurations, to provide further useful guidelines.

APPENDIX: INPUT DATA USED TO SIMULATE THE FMCG SUPPLY NETWORKS

The input data used to simulate the FMCG supply networks were adapted from previous studies of the authors in the field of FMCG (Bottani and Rizzi, 2008). The main parameters and numerical values are listed below:

- number of RS = 100
- mean of the final customer's = 150 pallets/day;
- standard deviation of the final customer's demand = 25 pallets/day;
- moving average interval = 5 days for retail stores and first-tier distribution centers; 60 days for second-tier distribution centers and manufacturer;
- unitary order and transport cost = 13.3 €/order for retail stores, 2750 €/order for first- and second-tier distribution centers, 5000 €/order for manufacturer;
- unitary cost of holding stocks: 0.572 €/pallet/day for manufacturer and second-tier distribution centers; 0.544 €/pallet/day for first-tier distribution centers; 0.32 €/pallet/day for retail stores;
- unitary stock-out cost: 50 €/pallet
- procurement lead time: 3 days.

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Authors' Index