THE 13TH INTERNATIONAL CONFERENCE ON HARBOR MARITIME MULTIMODAL LOGISTICS MODELING & SIMULATION

OCTOBER 13-15 2010
FES, MOROCCO

HMS
2010

EDITED BY

AGOSTINO BRUZZONE
GERSON CUNHA
CLAUDIA FRYDMAN
NORBERT GIAMBIASI
KHALID MEKOUAR
YURI MERKURIEV
MIQUEL ANGEL PIERA

PRINTED IN FES, OCTOBER 2010

ISBN 2-9524747-4-5
EAN 9782952474740

The 13th International Conference on Harbor Maritime Multimodal Logistics Modeling & Simulation

October 13-15 2010

Fes, Morocco

Organized by

DIPTEM – University of Genoa

Liophant Simulation

Ecole Superieure d'Ingenierie en Sciences Appliquees

University of Aix-Marseille - Lsis Marseille

Mechanical Department, University of Calabria

MSC-LES, Modeling & Simulation Center, Laboratory of Enterprise Solutions

MSLS – Autonomous University of Barcelona

Sponsored by

Academic, Institutes, Industry and Societies Sponsors

Simulation Team

MISS – McLeod Institute of Simulation Science

M&SNet – Modeling & Simulation Network

IMCS – International Mediterranean & Latin American Council of Simulation

University of La Laguna

Miss Latvian Center – Riga Technical University

Miss Spanish Center - UAB

University of Perugia

MAST – Management and Advanced Solutions and Technologies

LAMCE, UFRJ

CIFASIS: CONICET - UNR - UPCAM

EDITORS

AGOSTINO BRUZZONE
MISS-DIPTEM, UNIVERSITY OF GENOA
VIA OPERA PIA 15
16145 GENOVA, ITALY
agostino@itim.unige.it
http://st.itim.unige.it

GERSON CUNHA
MISS-LAMCE, UFRJ
LABORATORY OF COMPUTATIONAL METHODS IN ENGINEERING
FEDERAL UNIVERSITY OF RIO DE JANEIRO - COPPE
P.O.BOX 68552 - ZIP 21949-900
RIO DE JANEIRO, RJ, BRASIL
gersoncunha@yahoo.com.br
http://www.lamce.ufrj.br/InteR/index/index1.htm

CLAUDIA FRYDMAN
LSIS - LABORATOIRE DES SCIENCES DE L'INFORMATION ET DES SYSTEMES
UNIVERSITE AIX-MARSEILLE (U3)
DOMAINE UNIVERSITAIRE DE SAINT-JEROME, AVENUE ESCADRILLE NORMANDIE-NIEMEN, 13397 MARSEILLE CEDEX 20
claudia.frydman@lsis.org
www.lsis.org

NORBERT GIAMBIASI
LSIS - LABORATOIRE DES SCIENCES DE L'INFORMATION ET DES SYSTEMES
UNIVERSITE AIX-MARSEILLE (U3)
DOMAINE UNIVERSITAIRE DE SAINT-JEROME, AVENUE ESCADRILLE NORMANDIE-NIEMEN, 13397 MARSEILLE CEDEX 20
norbert.giambiasi@lsis.org
www.lsis.org

KHALID MEKOUAR
ECOLE SUPERIEURE D'INGENIERIE EN SCIENCES APPLIQUEES
29 BIS AV IBN KHATIB ROUTE D'IMMOUZZER
FES, MOROCCO
k.mekouar@esisa.ma
http://esisa.ac.ma/

YURI MERKURIEV
DEPARTMENT OF MODELING & SIMULATION
RIGA TECHNICAL UNIVERSITY
1, KALKU STREET, LV-1658 RIGA, LATVIA
merkur@itl.rtu.lv
www.itl.rtu.lv/mik/?id=34

MIQUEL ANGEL PIERA
MSLS, DEPARTMENT OF SYSTEM ENGINEERING
UNIVERSITY AUTONOMOUS OF BARCELONA
08193- BELLATERRA- SPAIN
MiquelAngel.Piera@uab.es
www.uab.es

THE INTERNATIONAL MEDITERRANEAN AND LATIN AMERICAN MODELING MULTICONFERENCE, I3M 2010

GENERAL CO-CHAIRS

AGOSTINO BRUZZONE, *MISS DIPTEM, UNIVERSITY OF GENOA, ITALY*
CLAUDIA FRYDMAN, *LSIS, UNIVERSITY OF AIX-MARSEILLE, FRANCE*

PROGRAM CHAIR

KHALID MEKOUAR, *ESISA, MOROCCO*
MIQUEL ANGEL PIERA, *AUTONOMOUS UNIVERSITY OF BARCELONA, SPAIN*

THE 13TH INTERNATIONAL CONFERENCE ON HARBOR MARITIME MULTIMODAL LOGISTICS MODELING & SIMULATION, HMS 2010

GENERAL CO-CHAIRS

AGOSTINO BRUZZONE, *MISS DIPTEM, UNIVERSITY OF GENOA, ITALY*
YURI MERKURIEV, *DEPARTMENT OF MODELING & SIMULATION, RIGA TECHNICAL UNIVERSITY, LATVIA*

PROGRAM CO-CHAIRS

GERSON CUNHA, *MISS-LAMCE, UFRJ, BRASIL*
NORBERT GIAMBIASI, *LSIS, UNIVERSITY OF AIX-MARSEILLE, FRANCE*

HMS 2010 International Program Committee

Enrico Bocca, *Liophant Simulation, Italy*

Eberhard Bluemel, Fraunhofer Institute for Factory Operation and Automation, Germany

Agostino Bruzzone, *University of Genoa, Italy*

Ivan Castilla, *University of la Laguna*

Antonio Cimino, *MSC-LES*, *University of Calabria, Italy*

Francesco Costantino, *Univ. of Rome,Tor Vergata,Italy*

Gerson Cunha, *MISS-LAMCE, UFRJ, Brasil*

Rafael Diaz, *Old Dominium University, USA*

Giulio Di Gravio, *Univ. of Rome,Tor Vergata, taly*

Claudia Frydman, *LSIS, France*

Norbert Giambiasi, *LSIS, France*

Manfred Gronalt, *Univ. of Natural Resources, Austria*

Francesco Longo, *MSC-LES, University of Calabria, Italy*

Yuri Merkuriev, *Riga Technical University, Latvia*

Giovanni Mirabelli, *University of Calabria, Italy*

Tereesa Murino, University of Naples, Italy

Liberatina Santillo, University of Naples, Italy

Alberto Tremori, *SimulationteamT, Italy*

Massimo Tronci, *Univ. of Rome,Tor Vergata,Italy*

Stefan Voss, *University of Hamburg, Germany*

Tracks and Workshop Chairs

Supply Chains
Chair: Rafael Diaz, *Virginia Modeling Analysis and Simulation Center – VMASC, ODU (USA)*

Maritime Training
Chair: Eberhard Bluemel, *Fraunhofer Institute for Factory Operation and Automation (Germany)*

Intermodal transportation systems and services
Chair: Manfred Gronalt, *University of Natural Resources and Applied Life Sciences (Austria)*

Advanced Models and Applications of Logistics & Manufacturing
Chairs: Teresa Murino*, University of Naples Federico II (Italy);* Liberatina Santillo*, University of Naples Federico II (Italy)*

Modelling & Simulation in Logistics, Traffic and Transportation
Chairs: Massimo Tronci, *University of Rome La Sapienza (Italy)*; Francesco Costantino, *University of Rome La Sapienza (Italy)*; Giulio Di Gravio, *University of Rome La Sapienza (Italy)*

GENERAL CO-CHAIRS' MESSAGE

WELCOME TO HMS 2010

The purpose of HMS 2010 edition is to provide an 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 12th official edition, without considering the two preliminary editions carried out in 1996 and 1998 respectively in Genoa and Riga.

The Conference format is consolidated, but it guarantees 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 activity for promoting new R&D projects and Proposals.

The success of HMS 2010 and the high quality of published proceedings is based on the strong efforts of the International Organizing Committee and of 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 Morocco a Country representing a big challenge as well a major player in Logistics and Maritime initiative.

We are confident that this and many other issues will be hotly debated in and out of the Conference Sessions, making HMS 2010 a stimulating and memorable event in the wonderful framework of Fes.

AGOSTINO G. BRUZZONE, MISS-DIPTEM, UNIVERSITY OF GENOA

YURI MERKURIEV, RIGA TECHNICAL UNIVERSITY

ACKNOWLEDGEMENTS

The HMS 2010 International Program Committee selected the papers for the Conference among many submissions and we expected a very successful event based on their efforts; so we would like to thank all the authors as well as the IPCs and reviewers for their review process.
A special thank to the organizations, institutions and societies that are supporting and technically sponsoring the event: University of Genoa, Liophant Simulation, Ecole Supérieure d'Ingénierie en Sciences Appliquées, University of Aix-Marseille, Autonomous University of Barcelona, University of Calabria, Modeling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES), McLeod Institute of Simulation Science (MISS), Modeling & Simulation Network (M&SNet), International Mediterranean & Latin American Council of Simulation (IMCS), Management and Advanced Solutions and Technologies (MAST). Finally, we would like to thank all the Conference Organization Supporters.

Table of Contents

M&S Logistics Traffic and Transportation

Advanced Models and Applications of Logistics & Manufacturing

Supply Chains

STATISTICAL MODELLING OF FINANCIAL STABILITY OF LOGISTICS SYSTEM

Vladimirs Jansons[(a)], Vitalijs Jurenoks[(b)], Konstantins Didenko[(c)]

[(a)]Riga Technical University, Latvia
[(b)]Riga Technical University, Latvia
[(c)]Riga Technical University, Latvia

[(a)]vladjans@latnet.lv, [(b)]vitalijs.jurenoks@rtu.lv, [(c)]konstantins.didenko@rtu.lv

ABSTRACT

Keywords: transport logistics system (TLS), identifying of weak spots, benchmarking, financial stability, statistical modelling, systems optimization

In this article the authors proceed with the research of the stability of transport logistics system (TLS) as a set of separate units providing the whole cycle of logistics operations when delivering cargoes from the consignor to the consignee. In the previous papers (see references) the authors presented the research of financial stability of logistics systems under conditions of uncertainty applying different methods of modelling, namely, statistical modelling – Monte Carlo method, dynamic programming, benchmarking as well as nonparametric methods of modelling. In this article the analysis of financial stability of the logistics system being investigated is made. And most attention is paid to modelling and analysis of the state of the required financial reserve of the logistics firm providing the financial stability of the whole logistics system on the example of delivering cargoes from the consignor to the consignee by a Latvian logistics firm (LF).

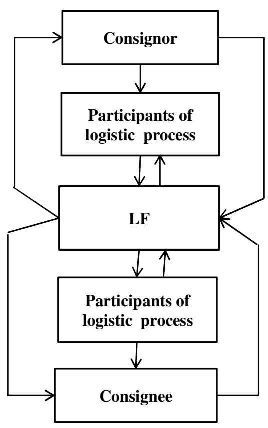


Figure 1: Structure of Transport Logistics System (TLS)

Technological and financial flows among the participants of logistics process as well as the impact of the factors of external and internal environment on the financial stability of TLS are analysed in this article.
By financial stability we understand the ability of all TLS participants to fulfil all the financial obligations undertaken with the view of ensuring complete continuous technological process in the terms agreed.
Applying the basic statements of the theory of constraints the authors analyse the impact of the factors of external and internal environment on the financial stability of the logistics chain and the process of weak points arising in the logistics chain of the financial system.

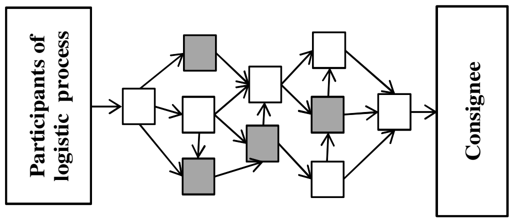


Figure 2: Illustration of Weak Points (Grey Squares) in the Transportation Logistics System (TLS)

1. GENERAL APPROACH AND THEORETICAL BASIS OF SOLUTION OF THE PROBLEM

The logistics process presents coherence and consistency of transport, technological and financial operations to be completed in the period of time when delivering the cargo from the consignor to the consignee. An important part of this process is finding the so called weak points of the logistics system, where deviations from the terms of contract occur due to certain reasons in the real time process. The deviations may comprise:
- deviations (changes) in certain transport and technological operations of TLS and, consequently, additional (not planned before) payments for completing these operations arise;
- deviations (changes) in the terms of making payments for the work completed by TLS participants;
- changes in the payment sums for the TLS transport and technological operations to be made due to fluctuations of the currency exchange rates during the

period of time when the financial operations were made among the TLS participants in different currencies;
- additional technological operations in the logistics process due to external and internal factors of TLS, namely:
- cargo control till the moment of moving the cargo away from the port;
- checking of cargo size in the port;
- customs control of cargo when crossing the national borders and completing other additional technological operations.

Taking as an example a Latvian logistics firm, we will analyze its financial flows with other TLS participants (Figure 3), where $\mathbf{S_{1,i}}$, $\mathbf{S_{2,i}}$ - the planned and actual amounts of receipts on the account of logistics firm (LF) from the **i-**th consignor of cargo, in USD, EUR, LVL, RUR and KZT;

$\mathbf{S_{3,j}}$, $\mathbf{S_{4,j}}$ - the planned and actual amounts of payment to be transferred from the account of LF to the **j-**th participant of TLS (modeled in accordance with contract terms), in USD, EUR, LVL, RUR and KZT;

$\mathbf{T_{1,i}}$, $\mathbf{T_{2,i}}$ - the planned and actual terms of receipt of payment from the **i-**th consignor of cargo on the account of logistics firm (LF);

$\mathbf{T_{3,j}}$,$\mathbf{T_{4,j}}$ - the planned and actual terms of payment of the account by LF to the **j-**th participant of TLS (modeled in accordance with contract terms).

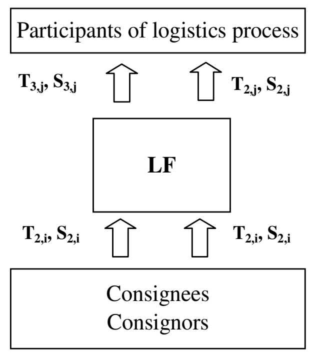


Figure 3: Financial Flows of TLS Participants

Let us also consider in a more detailed way the model of technological and financial operations of the logistics process provided by the Latvian logistics firm (Table 1, Figures 4, 5).

Table 1**:** Main Technological and Financial Operations of the Logistics Process

Logistics operation stage		Type of operation	Execution time of operation				Δ_t	Distribution of value Δt	S	Currency	Distribution of value S	Δ_S	Changes in currency exchange rates	Losses (-) and gains (+) due to currency exchange rates
Payments into LF account	Money transfers from LF account		t1	t2	t3	t4								
A		Contract execution start time						normal		USD	normal			
	B	Sea transportations						even		EUR/USD	even			
B*														
	C	Port operations						even		LVL	even			
	D	Insurance						normal		USD	even			
	E	Customs operations						even		EUR, RUR,KZT	even			
E*														
	F	Rail or road transportations						even		LVL	normal			
F*														
	G	Other operations								EUR, USD, RUR,KZT				
H		Final calculations												

The model of technological and financial operations of the logistics process (Table1) 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 4, are divided into the 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 $\mathbf{S_{1,i}}$;
- t_3 – the moment of time of advance payment transferred from the consignor (consignee) to the account of the logistics firm in the amount $\mathbf{S_{1,i}}$ ($t_1 = t_2$);
- t_4 – the moment of time of receipt of advance payment on the account of the Latvian logistics firm in the amount $\mathbf{S_{2,i}}$;
For the incoming financial flows (B^*, E^*, F^*, H), increasing the current account of LF the moments of time are the following:
- 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 $\mathbf{S_{1,i}}$ paid in advance by the Latvian logistics firm;
- t_2 – the moment of time of receipt by the consignor consignee) of the cargo the 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 $\mathbf{S_{1,i}}$;
- 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 $\mathbf{S_{1,i}}$;
- 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 $\mathbf{S_{2,i}}$.
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 $\mathbf{S_{1,i}}$;
- 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 $\mathbf{S_{1,i}}$;
- 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 $\mathbf{S_{1,i}}$;
- t_4 – the moment of time of receipt of financial resources (balance) on the account of the Latvian logistics firm in the amount $\mathbf{S_{2,i}}$.

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 $\mathbf{S_{3,j}}$;
- 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 $\mathbf{S_{3,j}}$;
- 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 $\mathbf{S_{3,j}}$;
- 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 $\mathbf{S_{4,j}}$.

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 (Figures 4, 5 fluctuations of the currency exchange rates using the method B).

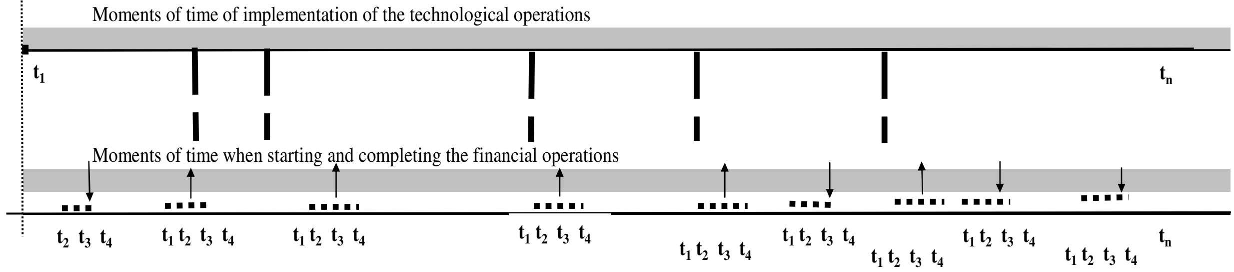


Figure 4: Model of Technological and Financial Operations of a Logistics Process to be Completed

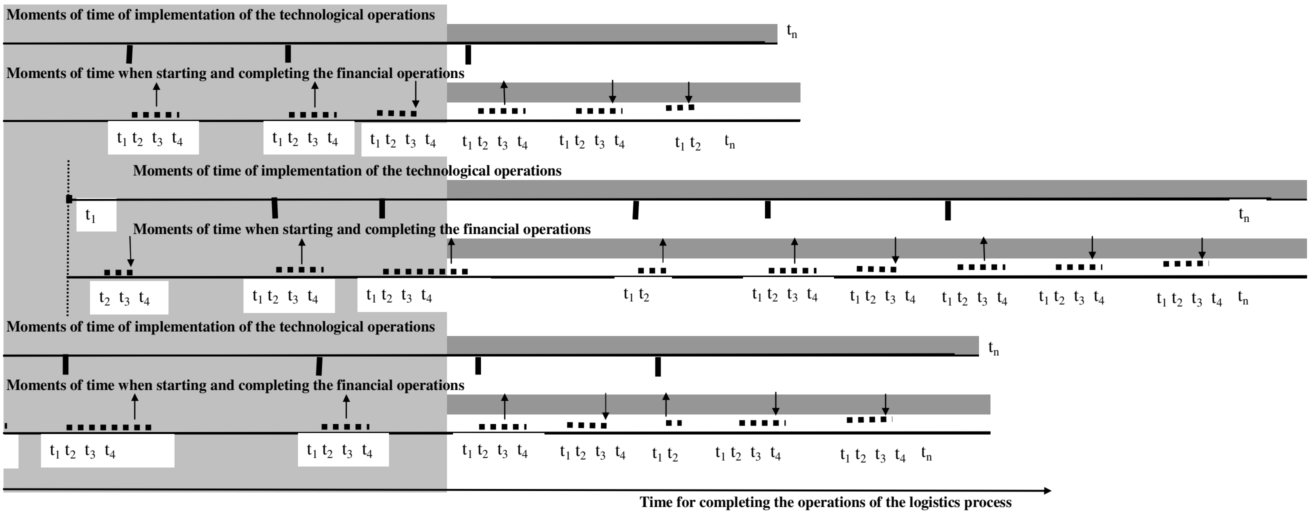


Figure 5: Model of Technological and Financial Operations of Several Logistics Processes to be Completed Simultaneously

Two methods for modelling the fluctuations of the currency exchange rates are considered in this article:
A method, using the empirical information about the fluctuations of the currency exchange rates;
B method, using the stochastic differential equation describing the fluctuations of the currency exchange rates.
The method A is described in a great detail in the research works of many authors (see references). Therefore, this research mainly concentrates on the process of modelling the fluctuations of the currency exchange rates by applying the method B.
B method presents the analysis of the impact of fluctuations in the currency exchange rates on the financial stability of the logistics firm. Therefore, the time delays between the planned and real terms of completing financial operations have also been modeled.
Let us consider the changes of the actual amount of the financial payment S_{t2} when compared to the planned amount of the financial payment S_{t1} when transferring from time t_1 and t_2 ($t_1 < t_2$).

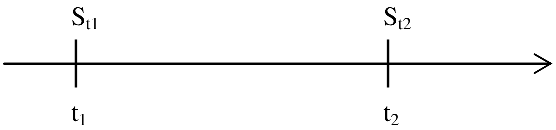


Figure 6: Changes in the Amount of the Financial Payment in the Period of Time t_1 to t_2

Modelling of the actual amount of the financial payment S_{t2} in the moment of time $t_1 < t_2$ is done by applying the correction coefficient K_{t1}:

$$K_{t_1} = \frac{S_{t_1}^{USD}}{S_{t_1}^{EUR}}, \qquad (1)$$

where $S_{t_1}^{USD}$ - the amount of financial payment S_{t1} in the moment of time t_1 in US dollars;
$S_{t_1}^{EUR}$ - the amount of financial payment S_{t1} in the moment of time t_1 in euro.
The financial payments among the TLS participants are made in different currencies depending on the terms of contract and requirements of national legislations. For example, moving the cargo from the USA to Kazakhstan across the territory of Latvia and Russia, the financial payments are made using the following currencies: USD, EUR, LVL, RUR, and KZT. When transporting cargoes to other directions, transactions are also made using the national currencies of the states through the territories of which transportation of goods takes place.
The actual amount of the financial payment S_{t2} may be greater or smaller than the planned financial payment S_{t1}. The deviation (difference) ΔS between $S_{t_1}^{USD}$ and $S_{t_1}^{EUR}$ may be calculated using the formula:

$$\Delta S_{t_1,t_2,USD,EUR} = \frac{S_{t_2}^{EUR}}{K_{t_2}} - S_{t_1}^{USD}. \qquad (2)$$

In the case of making the financial payments in different currencies at the moments of time t_1 and t_2 ($t_1<t_2$), the formula (2) is expressed in the following way:

$$\Delta S_{t_1,t_2,V_1,V_2} = S_{t_1}^{V_1}\left(\frac{1}{K_{t_1,V_1,V_2}} - \frac{1}{K_{t_2,V_1,V_2}}\right). \qquad (3)$$

When $\Delta S_{t_1,t_2,V_1,V_2} > 0$, 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 $\Delta S_{t_1,t_2,V_1,V_2}$ < 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.

In the same way the changes of the currency exchange rates leave an impact on the payments made from the account of the logistics firm to the other TLS participants. In this case, if $\Delta S_{t_1,t_2,V_1,V_2}$ > 0, the amount of the actual financial payment made from the account of the logistics firm and transferred to another participant of the logistics process would be greater than the financial payment planned and it will lead to additional expenses of the logistics firm and decrease its financial stability. On the contrary, if $\Delta S_{t_1,t_2,V_1,V_2}$ < 0, the actual amount of the financial payment made from 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 lead to gaining additional profit for the logistics firm and will increase its financial stability.

Changes of the value of $\Delta S_{t_1,t_2,V_1,V_2}$, leaving an impact on the financial stability of LF depend on the changes of the correlation of currency exchange rates V_1, V_2,..., V_n, 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.

2. MODELLING OF THE FLUCTUATIONS OF CURRENCY EXCHANGE RATES APPLYING STOCHASTIC DIFFERENTIAL EQUATION

The most suitable method for modelling the fluctuations of the currency exchange rates is the application of diffusion equation which is presented in the following way:

$$\frac{dS}{S} = \mu dt + \sigma dB, \qquad (4)$$

where μ - the parameter describing the constant deviations of the currency exchange rates;

σ - the parameter describing dispersion of the fluctuations of the currency exchange rates;

dB=Zdt – random value describing Viner process (white noise); value Z has normal distribution N(0;1).

From the equation (4) we may derive the equation (5).

$$S_{t+\Delta t} = S_t \cdot \exp(\mu\Delta t + \sigma \cdot Z \cdot \sqrt{\Delta t}), \qquad (5)$$

where S_t is the currency exchange rate at the moment of time t.

The results of modelling of the fluctuations of the currency exchange rates, (the initial value of the currency exchange rate on the axis Oy equals 1) applying the equation (5), are presented in Figure 7 (the unit of the change of time on the axis Ox is the value dt = 1/365).

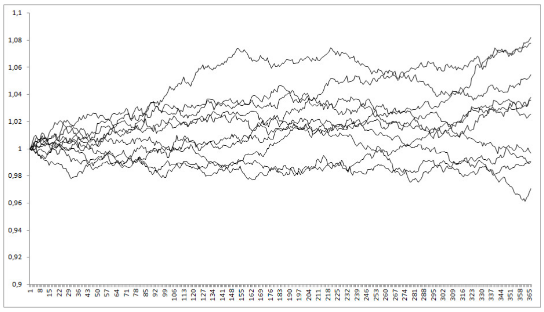


Figure 7: Results of tenfold modelling of fluctuations of currency exchange rates

In this case the fluctuations (changes) of the currency exchange rate may be well described with the help of lognormal distribution (see Figure 8).

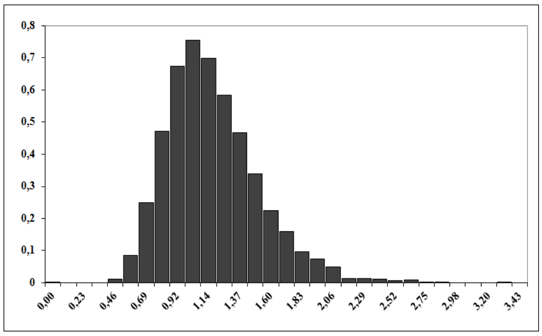


Figure 8: Histogram of Modelled Lognormal Distribution

For determining the parameters μ and σ the following equations were used:

$$\mu = \frac{Average\left[\ln\left(\frac{S_{t+\Delta t}}{S_t}\right)\right]}{\Delta t}, \qquad (6)$$

$$\sigma^2 = \frac{D\_emp\left[\ln\left(\frac{S_{t+\Delta t}}{S_t}\right)\right]}{\Delta t}, \qquad (7)$$

The authors in some other of their research papers (see references) have substantiated the necessity of building and utilizing the financial reserve of the logistics firm for ensuring (providing) the financial stability of the whole logistics system as such (see Figure 9).

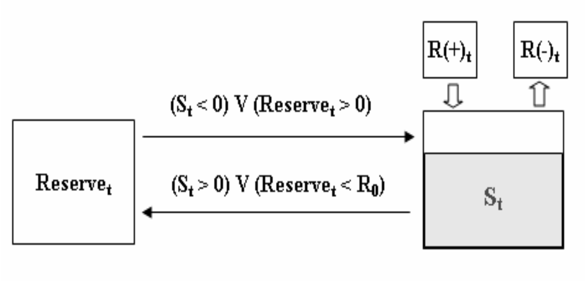


Figure 9: Use of Financial Reserves of Logistics Firm

where $\mathbf{S_t}$ – balance of LF with TLS participants at the moment of time **t**, in euro;
R (+)$_t$ – receipts to the account of LF from the consignor's (consignee's) account at the moment of time **t,** in euro;
R(-)$_t$ – actual amount of payment to be transferred from the account of LF to the other TLS participants at the moment of time **t**, in euro;
Reserve$_t$ – current state (modelled) of financial reserves of LF at the moment of time **t**, in euro;
$\mathbf{R_0}$ – initial amount of financial reserves of LF, in euro.

CONCLUSION

The modelling process of economic system stability is implemented using a set of alternative strategies of realization of logistic processes. By using B method of modelling (described in the paper) becomes possible effectively to define weak points in the financial system of TLS, realise more effectively management of transport logistic process and enlarge the zone of stability of TLS by using the same volume of financial reserve of LF. The important research finding is the stochastic distribution of the financial reserve of LF by modelling and recommending efficient use of the financial reserves of LF with the aim to provide the financial stability of the transport logistics system (TLS) and evaluating the risk of exceeding the financial reserve of LF during the time of cargo transportation.
The theoretical and practical results obtained as a result of this research can be applied in practical activities of logistic companies.

REFERENCES

Jurenoks,V., Jansons, V., Didenko, K., 2007. Modelling of financial stability in logistics in conditions of uncertainty. *21-st European Conference on Modelling and Simulation*, pp. 30-36. June 4–6, Prague, Czech Republic.

Jurenoks,V., Jansons, V., Didenko, K., 2008. Modelling of Stability of Economic Systems Using Benchmarking and Dynamic Programming. *X International Conference on Computer Modelling and Simulation EUROSIM/UKSim,* pp. 295-300. 1-3 April, Cambridge, United Kingdom.

Jurenoks,V., Jansons,V., Didenko,K., 2008. Application of Benchmarking and Index Method in Research of Economic Systems. *X International Scientific Conference "Management and Sustainable Development*", pp. 4-10. March 21-23, Yundola, Bulgaria.

Jurenoks,V., Jansons,V.,Didenko,K.,2009. Investigation of Economic Systems using Modelling Methods with Copula. *XI International Conference on Computer Modelling and Simulation UKSim 2009,* pp. 311- 316. March 25-27, Cambridge, United Kingdom.

Cameron, Colin. A. and Trivedi, Pravin. K., 2006. Micro econometrics: methods and applications. Cambridge University press, 1034 p.

Fitzgerald, John and Gorm, Peter Larsen. 1998. Modelling Systems: Practical Tools and Techniques for Software Development. Cambridge University Press, 288 p.

Dettmer, William H. Goldratt's. 1997: Theory of Constraints: A Systems Approach to Continuous Improvement, Printed in USA, 378 p.

AUTHORS BIOGRAPHIES

VLADIMIRS JANSONS was born in Daugavpils, Latvia and is a graduate of the University of Latvia, where he studied mathematical science and obtained his degree in 1970. For eight years he has worked in the Computing Centre of the University of Latvia. Since 1978 he has been lecturing at Riga Technical University, where in 1983 he was awarded the doctoral degree in the mathematical science. The main field of research pursued is simulation and optimization of economic systems.
E-mail: vladjans@latnet.lv.

VITALIJS JURENOKS was born in Riga, Latvia. In 1976 he graduated from the Faculty of Engineering Economics of Riga Technical University, and for ten years, has worked in an industrial enterprise in Riga. Since 1986, he has been lecturing at Riga Technical University, and in 1987 was awarded the doctoral degree in the science of economics (Dr.oec.). The main field of research pursued is planning, simulation and optimization of economic processes and systems.
E-mail: vitalijs.jurenoks@rtu.lv.

KONSTANTINS DIDENKO was born in Jelgava, Latvia. In 1969 he graduated from the Faculty of Engineering Economics of Riga Technical University. Since 1969 he has been lecturing at Riga Technical University where in 1985 he obtained the doctoral degree in the science of economics. In 2006 he was elected a corresponding member of the Latvian Academy of Sciences. The main field of research pursued is planning and optimization of economic processes and systems.
E-mail: konstantins.didenko@rtu.lv.

Security & Safety Training and Assessment in Ports based on Interoperable Simulation

Agostino G. Bruzzone
MISS DIPTEM University of Genoa, Italy
agostino@itim.unige.it
URL www.itim.unige.it

Alberto Tremori
Simulation Team – DIPTEM
University of Genoa, Italy
alberto.tremori@simulationteam.com
URL www.simulationteam.com

Enrico Bocca
MAST
Savona, Italy
enrico.bocca@mastsrl.eu
URL www.mastsrl.eu

ABSTRACT

The present research proposes a Virtual Port Simulator based on an HLA technology, devoted to cooperative training in Harbor Security Procedures to support Maritime Security Transportation Act and International Ship and Port Facility Security Code (SOLAS). Within these frameworks a clear requirement for port security assessment & training is addressed, therefore the complexity of Harbors as well as the wide type of possible crisis create complex conditions to properly face this challenges. This paper presents a Virtual Port solution developed by the authors in term of architecture, model description, and configuration for training and security assessment. In fact, the creation of a common Virtual Port as synthetic environment with stochastic constructive and virtual simulation, where each federate represents an actor interoperating with other ones. By this approach the simulation supports both training and security assessment in term of procedures and considering the necessity to coordinate the different actors and to consider all the different issues. The final result is the definition of a new approach to face security by a joint simulation that involves concurrently all active actors for port protection.

INTRODUCTION

The paper proposes a Virtual Port Simulator based on an HLA federation devoted to cooperative training and assessment in Harbor Security Procedures.

Port security requirements evolved after September 11 due to the 2002 Maritime Security Transportation Act (MSTA) in the USA. This act spurred a set of actions taken by the international community to mimic the US training regulations, such as International Ship and Port Facility Security (ISPS) Code under Safety of Life at Sea (SOLAS) Convention by International Maritime Organization (IMO). Within this framework a clear requirement for port security training is addressed, therefore the complexity of Harbors as well as the possible crisis creates hard limitations to develop realistic training sessions.

Ports are characterized by co-location and strong interactions among a large and diverse set of active actors. It is important to underline that the most of these actors are civilian. Organizations that work within port operations include Coast–Guard, other Navy agencies, as well as Port Authority, Terminal Operators, Shipping Companies, and Custom and Border Protection Agencies.

All these entities are active with different roles and Responsibilities. In addition to what we call "internal" active actors, Ports have significant interactions with external authorities. Ports, in fact, are part of complex logistic networks in crowded industrialized areas near large metropolitan areas (i.e. in case of a crisis heavy haul traffic to and from the port could strongly affect traffic patterns in the bordering town and requires effective coordination with transportation authorities, local police and the town administration). In port security interaction, coordination and communication among these entities are one of the critical aspects to be investigated during training exercises.

Current security port training is based on simple, pre-defined live exercises. This training has significant limitations in capability and provides insignificant value for facing real threats. Usually, intensive operations are carried out in Ports, due to this fact, live training sessions, regardless of scale, are quite expensive. These factors provide the evidence that the development of training solutions based on simulation represents a highly reliable approach to replicate complex scenarios for the different actors without blocking port activities.
Furthermore, simulation approach is very useful in supporting strategic and operative assessments.
In order to support learning and assessment in decision making for critical security situations in ports, the authors developed a Federation where each active actor operates the respective resources and cooperates with others. For instance, it is possible to set up scenarios involving Coast Guard, Port Authority, Custom and Border Protections as well as Private Security agencies cooperating against different threats (i.e. smuggling, infiltration through ships, port attacks from ground, air or water).
By this approach the simulation supports the definition of security and Standard Operating Procedures (SOP) during the pre alert conditions; it supports distributed simulation to a relevant number of entities and low-cost training sessions in a cooperative manner.
Virtual Port was originally designed to support training of terminal operators (i.e. cranes and truck drivers); it evolved to an interoperable federation for extending the training from single vehicle/device to procedure and policies by supporting cooperative sessions. The paper proposes some aspects related to benefits and problems in developing simulators for security purposes from this legacy federation. It highlights the importance of proper design in interoperable models.

STATE OF ART IN PORT SECURITY TRAINING

Even nowadays Training and Exercise on Security Procedures in Harbors are typically managed in traditional ways, mainly live events. The entire harbor operations are informed that on a certain date a training session for a particular kind of threat will be performed. For instance, the Genoa Harbor (the most important Italian Harbor and a primary Mediterranean port) identified 27 different kinds of incidents (related to both security and safety) and every year organized one or two training events focused on a specific accident. These events vary from simple safety procedure violations (i.e. accidents occurred to harbor operators, complex scenarios such as a ship approaching with alleged hazardous materials, dirty bomb threats). Simulation based training is diffuse but often with attention into a single actor (police, coast guard) and some specific kind of threats. Many efforts are done to carry out innovative researches to face traditional, symmetric attacks, i.e. glider, underwater unmanned vehicles, etc, but sometimes these do not represent the real danger. It is much more easy to prepare an home-made bomb with ammonium nitrate and bring it by car inside a ferry terminal rather than use a submarine; such events are hard to prevent as well train people to do that. Furthermore, prevention of “asymmetric” threats and, in general, after-disaster or after-attack operations requires strong co-operation among all the actors; training for this kind of distributed co-operative task is possible only by simulation.

WHY USING SIMULATION

The use of M&S to evaluate the impact of security matters on logistics/industrial facilities is justified by the need to analyze complex interactions among numerous factors. Simulation techniques are fundamental to test operators and agencies and evaluate impacts of security requirements on people and cargo flows. Security equipment and procedures for logistics facilities can usually be grouped into two major classes:

- Internal: Security control of logistics flow
- External: Security control of external component

The first class refers to all the additional operations that must be carried out to ensure that goods are not dangerous (i.e. container scanning, gate controls, custom checks, etc.). The second class refers to the fact that external entities (i.e. terrorists) might be introduced in some points of the facility’s logistics flow (i.e. contamination of food along the supply chain) or may affect the efficiency of the entire infrastructure (i.e. attacks on a port/airport). One interesting aspect is that intensive logistic flows of entities (i.e. people, materials, etc.) have a mutual influence on one another and can be a potential threat. In fact, with regard to the security activity, intrusion models must be used to control potential interference between Cargo and people in various areas of ports. In this field of application, M&S is often used to study processes, performance levels and costs with regard to regular operating conditions. These simulation models can be used to support an assessment of impact that safety and security procedures may have on logistics throughput as well an evaluation of the role that human resources play in ensuring reliable surveillance and control during continuous and discrete monitoring (i.e. monitoring and inspections for facility border surveillance).

Such models enable managers and decision-makers to evaluate quantitatively the effectiveness of man/machine interactions during standard operations and emergencies (i.e. high and very high intrusion alert). Using these models for risk analysis purposes helps to identify the best practices for emergencies related to relevant targets. These simulators can be used to perform tests related to the effectiveness of different organizational models within critical structures, providing experimental results about the impact of the consequences with regard to interfacing with public institutions. In operative terms, the general experience obtained from simulation models helps to improve integration of automated control systems through ad hoc architecture design which combines the information coming from different sources and evaluating the impact resulting from the use of all possible alternative systems. Simulation tools can be used to carry out a comprehensive assessment of the system's security weakness by modeling its constitutive parts and providing the means for verifying the performance level for the system as a whole, during the simulation run.

VIRTUAL PORT FEDERATION CHARACHTERISTICS

Virtual Port is a distributed interoperable stochastic simulator which includes different players representing port security active actors. The threats are playable characters, therefore the authors are evaluating the adoption of their Intelligent Agents to drive CGF for representing both the menacing behavior as well as other elements (i.e. passengers behavior, other ships, terminals, etc). Stochastic components are affecting internal and external flows of the port, in addition they affect detection, tracking or engagement. This federation includes a federate devoted to Control & Debriefing that supports After Action Review (AAR), as well as online review during the exercise. It generates a local parallel virtual port based on recorded actions until the present moment and moves in space and time to investigate while the simulation is still running on the federation, then eventually closes it and join back to the evolving scenario. The instructor controls environmental conditions (i.e. daytime, fog, rain, sea, wind) as well as scenario and situations, (i.e. number and type of ships involved). This federation automatically controls all the trucks and carriers not directly used by operators. Currently the following objects are part of virtual Port (Fig.1):

- Vessels (i.e. cargo ships, boats, coast guard)
- Cranes (i.e. mobile cranes, reach stackers, gantry cranes, etc.)
- Vehicles (i.e. internal and external trucks, as well as police and custom cars, security, ambulances)
- Aircraft (i.e. helicopter and planes)
- UAV (air, water and underwater)
- Cameras and Sensors (i.e. terminal camera, radar, sonar).
- Gates (i.e. port access gate and terminal gates).
- People (i.e. passengers, workers, threats).

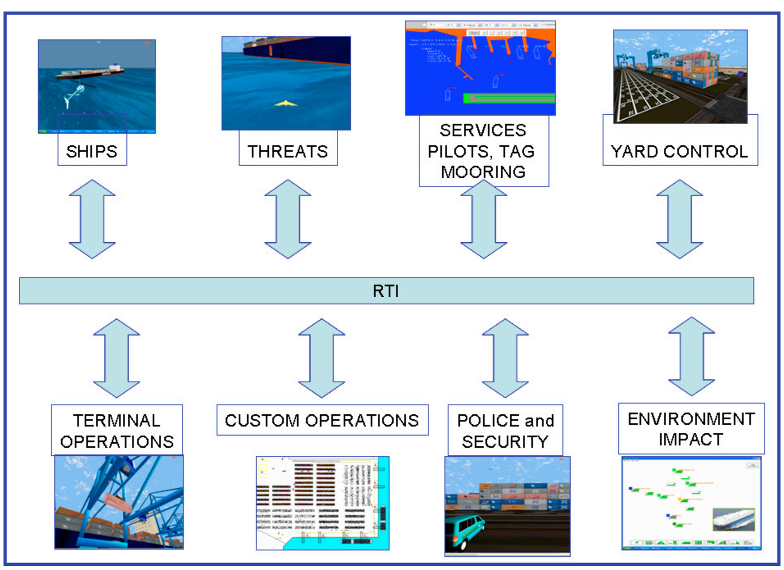


Figure 1. Sample of Virtual Port Federates

Being originated by training solution for port operators this environment is a virtual simulator supporting immersive solutions (i.e. scalable cave from 270° to 360°) and it is integrated with motion platforms (6 degree of freedom), therefore due the modeling approach it is scalable on laptop and operator can navigate the virtual world with mouse and/or joysticks.
The federation allows relocating control of the objects among the different federates by a quick configuration system and scalable solutions for different training sessions.
Virtual Port includes the integration with biomedical devices measuring stress levels. These systems were originally integrated in order to support research for crane operator performances; being compact they support training and investigation even in port security.
Virtual Port includes a High Performance Computer (HPC) federate developed to support the integration with complex computational models running on an computer grid that eventually can take care of simulating complex phenomena (i.e. fallout).
Currently the Virtual Port operates on workstations and laptop. The authors developed a mobile solution for training in ports based on a shelter obtained from a 40' high cube container; this solution is very easy to move and include cave, instructor workstation, multiple training stations, equipped area for connecting laptops, as well as debriefing area with interactive board for AAR and exercise overview.
The use of Virtual Port as a synthetic environment for training in Security and Safety procedures is in an early phase. Authors are developing research activities based on a scenario definition devoted to support Training procedures and configuration of the whole architecture for safety and security assessment in Ports using the federates and models proposed in figures 2-9.
In this initial phase, authors focus on the use of the Federate SEAPORTS (fig. 9) in order to calculate the throughput of containers according to different security procedures.
The example proposed in the following paragraph Virtual Port Test MOP and MOE Experimental Analysis regards the study of the port behavior and relative resources under the effect of different security levels. The performance indexes taken into consideration are defined as *moved TEUs per structural unit*. These indexes measure the total efficiency of the terminal container in terms of available resources utilization.

The most important resources (structural units) are: berth length, dimensions of the yard area, number of portainers. The equations (1), (2), (3) define the performance indexes from a mathematical point of view.

$$Index1 = \frac{TEUs}{BerthLenght} \quad (1)$$

$$Index2 = \frac{TEUs}{YardArea} \quad (2)$$

$$Index3 = \frac{TEUs}{PortainerNumber} \quad (3)$$

Figure 2. Virtual Port HLA Simulation of Custom Operations

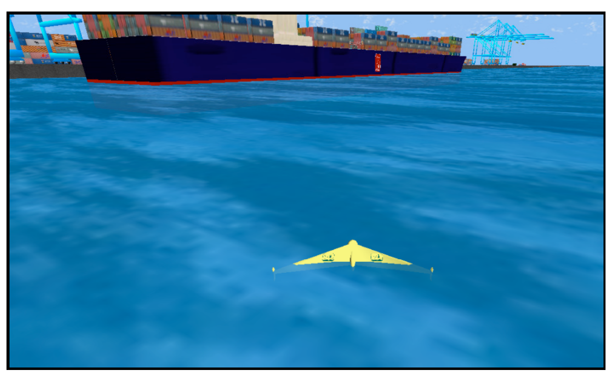


Figure 3. AUV (Autonomous Underwater Vehicle) Federated in the Virtual Port

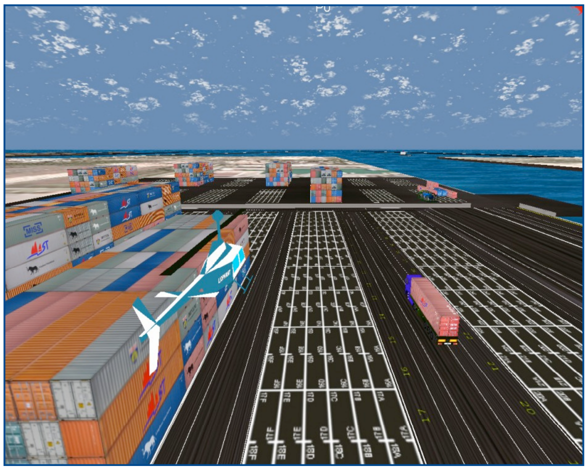


Figure 5. Helicopter Checking Terminal and Port Situation

Figure 6. New Generation UAV (Unmanned Aerial Vehicle) Federated in the Virtual Port

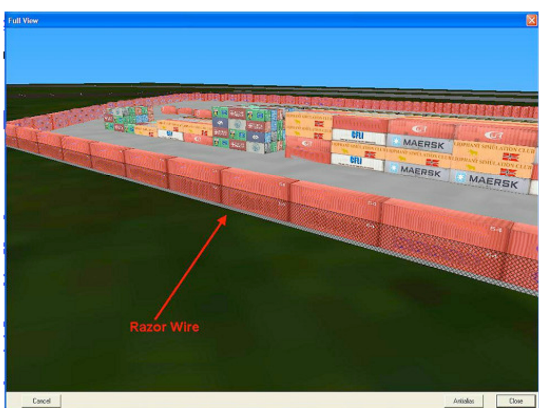


Figure 7. Virtual Model of Terminal Fences and Cameras

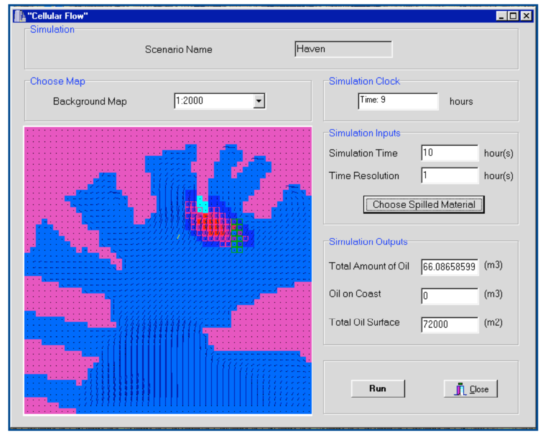


Figure 8. Oil Spills Simulation

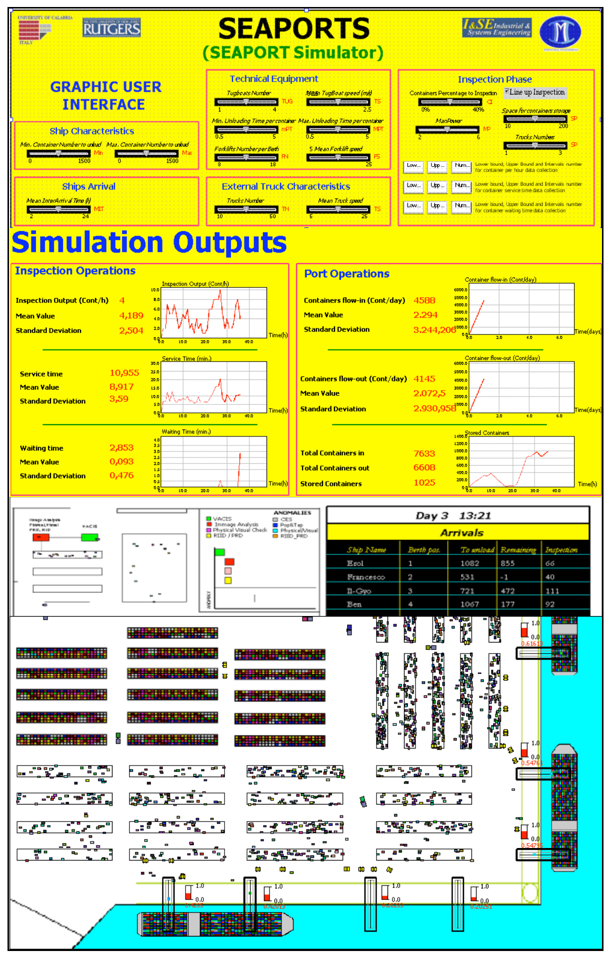


Figure 9. Terminal Operation and Inspection Procedures Simulation (i.e. Gamma Rays and Manual Inspections) for Container Terminals

VIRTUAL PORT TEST MOP AND MOE EXPERIMENTAL ANALYSIS

Definition of Measure of Performance (MOP) and Measure of Effectiveness (MOE) play a fundamental role, especially when high level of complexity arises from the necessity to train several organizations different by nature to cooperate together on new complex scenarios. The authors propose some preliminary metrics for supporting these aspects and guaranteeing the capability of measuring individual progress and combined capabilities along the training process as well as the effectiveness of the procedures for facing specific threats.
Some preliminary analysis have been made in order to validate the simulation model. The results show that in this configuration of Virtual Port are processed 100.000 TEUs/month. Such values are very similar to the statistics recorded in several terminal containers with comparable berth, yard area and movement equipment.
The objective of the application example is the evaluation of the impact on the system of different security levels. Increasing the security level, the percentage of inspected containers increase as well.
Considering the stochastic aspects implemented in the model SEAPORT part of the Federation (movement equipment productivity, time between arrivals of ships, and so on) many simulation runs are needed to obtain significant results.
The mean values of the performance indexes, output from the simulation model, versus the different security levels (from 0% to 32 %) are summarized in table1.

Security Level	Index 1	Index 2	Index 3
[%]	*[TEUs/month]*	*[TEUs/heactares]*	*[TEUs/Portainer]*
0.00%	1,459	15,424	166,582
1.00%	1,447	15,307	165,321
2.00%	1,436	15,189	164,040
4.00%	1,413	14,946	161,422
8.00%	1,366	14,442	155,981
16.00%	1,264	13,370	144,403
32.00%	1,047	11,067	119,525

Table 1 – Results of simulation runs

The decrease of performance indexes in correspondence of higher security level highlights the system propensity to reach the block of all the main activities. The values taken by index 3 (that expresses the portainers efficiency) change from 155901 TEUs/n°portainers (security level 5%) to 88969 TEUs/n°portainers (security level 50%), with an efficiency reduction of 43%. The decreasing trend is also shown on the graph in figure 10.

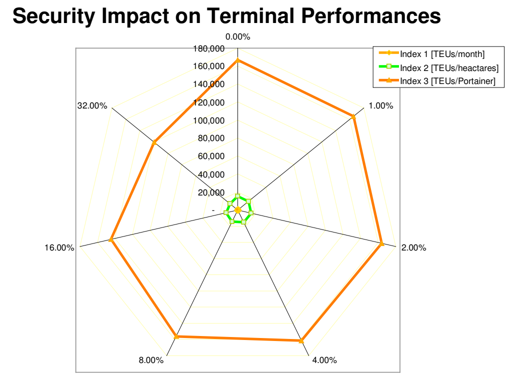


Fig. 10 – Performance Indexes vs Security Alerts

Starting from the analysis of the performance indexes it's possible to make some economic considerations to define the right tools to achieve the goal in term of security, (i.e. more technology advances or better reorganization of internal logistics).
The results show that several parameters influence a target function of a port, underlining again the importance of considering all the agents operating in a harbor to reproduce realism of such a system.

CONCLUSIONS

In Port Protection, and in Homeland Security, it is important to analyze and be trained to *asymmetric threats*. Technology advances allow to identify any kind of weapons or technological threat. It is a big issue to detect one glider but it is of course much more difficult to detect one in a thousand trucks with a bomb made up by simple commercial bag of 50 lb ammonium nitrate entering into port area. It is clear that the security procedures are fundamental for all the actors operating in a port, for this reason a new concept of simulation based training has to be developed and diffuse to support this co-operative approach. At the same time we have also to consider that the port cannot be closed or its operations reduced without big impacts on the whole logistic network. Decision makers have to take into consideration even this aspect, both in training and analysis,
The goal of Virtual Port Federation is to provide a high level of complexity and "asymmetry" of threats but a simple way to develop exercises in order to provide numerous and realistic Training Events involving a huge number of people or actors, in order to represent the real entropy of a port.

REFERENCES

- Amico Vince, Guha R., Bruzzone A.G. (2000) "Critical Issues in Simulation", Proc.of SCSC, Vancouver, July
- Bocca E., Bruzzone A.G., R.A. (2006) "Algorithms devoted to Reproduce Human Modifiers in Polyfunctional Agents", Proc.of SCSC, Calgary, Aug
- Bruzzone A.G., Reverberi A., Cianci R., Bocca E., Fumagalli M.S, Ambra R. (2009) "Modeling Human Modifier Diffusion in Social Networks", Proceedings of I/ITSEC2009, Orlando, November 30-December 4
- Bruzzone A.G., Giribone P. (1998) "Decision-Support Systems and Simulation for Logistics: Moving Forward for a Distributed, Real-Time, Interactive Simulation Environment", Proceedings of the Annual Simulation Symposium IEEE, Boston, 4-9 April
- Bruzzone A.G., Cantice G. (2008) “Software Agents Italian Army Developments and Researches”, Technical Report GESI User Group, Wien, October
- Bruzzone A.G., Mosca R., Massei M., Bocca E. (2008) “Critical Issues in HLA Integration: PIOVRA CGF vs. Wargaming System”, Proceedings of Summer Computer Simulation Conference, Edinburgh, June
- Bruzzone A.G., Massei M., B.M. (2007) “Demonstration for HBM within Civil Disorder Scenarios”, Proc.of SCSC, San Diego CA, July
- Bruzzone A.G., Williams E.(2005) "Summer Computer Simulation Conference", SCS Int., San Diego
- Bruzzone A.G., Page E., Uhrmacher A. (1999) "Web-based Modelling & Simulation", SCS International, San Francisco, ISBN 1-56555-156-7
- Chait R., Sciarretta A., Shorts D.(2006) "Army science & Technology analysis for Stabilization and Reconstruction operations",Tech.Report Center for Technology and National Security Policy. October
- Fishwick, P. (1995) "Simulation Model Design and Execution", Prentice Hall, New Jersey
- Hamilton John A. Jr., Nash David A., Pooch Udo W. (1996) "Distributed Simulation", CRC Press
- Henscheid Z., Middleton D., Bitinas E. (2007), "Pythagoras: An Agent-Based Simulation Environment", Proc.and Bulletin of the International Data Farming Community, Issue 1
- Kuhl F., Weatherly R., Dahmann J., Kuhl F., Jones Anita, (1999) "HLA: Creating Computer Simulation Systems", Prentice Hall; ISBN: 0130225118
- Longo F, Bruzzone A.G., (2005) “Modelling and Simulation applied to security systems”, Proc. of SCSC, Philadelphia, July
- Massei M., B.M., B.C. (2007) "Human Behavior Model for an HLA Federation", Proceedings of EUROSIW2007, Santa Margherita, Italy, June
- Marburger J.H., Ozolek D., Cooperstein T., Reichle S., Miller R.T., Anderson W.A., Dobrianski P. (2008) "Research & development challenges for regional Stability and Capacity Building - Executive Office of the President of the United States", Report of the NSTC on Homeland and National Security, Feb.
- Mosca R., P.Giribone & A.G.Bruzzone (1994) "Simulation & Automatic Parking in a Training System for Terminal Container Yard Management", Proceedings of ITEC94, The Hague, April 26-28
- Raybourn E.M., Roberts B., Diller D., Dubow L. (2008) "Honing intercultural engagement skills for stability operations DARWARS Ambush! NK Game Base Training", Proc. of ASC2008, Orlando
- Rizzoli A.E., Gambardella L.M., Bontempi G. (1997) "Simulation of an Intermodal Container Terminal to assist Management in the Decision-Making Process", Proc. of MODSIM9, International Congress on Modeling and Simulation, Hobart, Tasmania
- Ross-Witkowski C. (2005) "Agent-Based Models and Other Analytic Tools in Support of Stability Operations SAIC" Proc. of MORS, McLean, VA,
- Surdu J.R. Parsons D., Tran O.(2005) "The Three Block War in OneSAF," Proc. of I/ITSEC, Orlando, FL, Dec
- Viazzo S., M.B. (2004) "Simulation to Support Design and Training of Operative Procedures in Intermodal Terminals", Proceedings of HMS2004, Rio de Janeiro, Brazil, 25-30
- Zeigler B.P., Ball G., Cho H.J., Lee J.S. (1999) "Implementation of the DEVS Formalism over the HLA/RTI: Problems and Solutions", Proc. of Spring SIW, Orlando, June

Modeling the Empty Container Flow: An Application of System Dynamics

[(a)]Mandar Tulpule, [(b)]Rafael Diaz, [(c)]Francesco Longo, [(d)]Antonio Cimino

[(a)(b)] VMASC, Virginia Modeling, Analysis, & Simulation Center, Old Dominium University, VA, USA
[(c)(d)] MSC-LES, Mechanical Department, University of Calabria, Italy

[(a)]MTulpule@odu.edu, [(b)]RDiaz@odu.edu, [(c)]f.longo@unical.it, [(d)]acimino@unical.it

ABSTRACT
The volume of container traffic has increased many folds during the last two decades owing to increased globalization of trade. The imbalance of trade has also increased along with the increase in global trade. Presently, trade imbalance exists along all the major trading routes in the world. The increased trade imbalance has resulted in significant cost to the marine industry for handling and repositioning of empty containers. Although trade imbalance is the major cause, many other factors like tariffs, cost of repositioning, cost of new containers and dynamics in leasing industry also impact the flow of empty containers. Detailed analysis of the factors and the dynamics affecting this flow has been made in the relevant literature. However, no attempt has been made so far to model and simulate this system. The purpose of the present study is to model the dynamics of empty container flow using system dynamics. System dynamics gives the user an ability to model relationship among multiple interacting factors, and study the resultant behavior of the system, which precisely, is the purpose of this study. As such the use of system dynamics as the modeling tools seems justified. A simple two port container port system is developed. The model is validated through comparison of actual and simulated container flow for the Port of Los Angeles for a specified time span. Such a model would provide a tool to the decision makers to evaluate various what-if scenarios, which would give them better visibility of the system and assist them in taking the appropriate decisions, from policy point of view.

Keywords: empty container flow, system dynamics

1. INTRODUCTION
With rapid globalization container volumes in global trade have increased many folds in the last couple of decades. The Asian countries particularly China and Korea have evolved into major manufacturing centers for consumer goods sold in the United States. At the same time, export of US goods to the Asian countries has not increased at the same rate in volume and value. The resulting trade imbalances have been a major reason for the rapid increase in the number of empty containers in various ports around the world. Boile (2006) has identified the following as the root causes for empty container accumulation 1.Trade imbalance, 2.Rate imbalance, 3.New container prices vs. cost of inspecting and moving empties, 4.Un-timely shipment and delivery of containers, 5.High storage fee in areas of high demand. The accumulated empty containers can either be repositioned at an interregional level or a global level for reuse, or they may be scraped or sold in a secondary market depending on their residual life. Since the imbalance of trade is not regional but global, the problem of empty container reuse cannot be sufficiently addressed without considering global repositioning. This paper would address issues particularly related to global repositioning and the term 'repositioning' would invariably be used in context of global repositioning.

The causes for empty container repositioning enumerated above are not only responsible for accumulation of empty containers in a particular geographical area but also for the changing location and magnitude of this issue depending on the interplay between these factors. For example, the acute problem of empty container accumulation in the US ports was partially resolved due to the steep increase in the cost of new container boxes in 2003-04 which made the option of repositioning the empty containers to Asia economically feasible (Boile, 2006). Today a large portion of the outbound containers from the United States is composed of empty containers e.g. 45% in 2010 from the Port of Los Angeles (Port of Los Angeles, 2010). On similar lines the ports in Asia were clogged with empty containers in 2009 due to the slump in demand for goods in the United States as the economic recession spread (Bloomberg, 2009). On the other hand some ports might offer reduced rates and incentives for storage of empty containers for attracting business during economic slowdown or as leverage against competing ports in the region prompting an accumulation of empties in that area (Tirschwell, 2009).

The point to be made in the arguments above is that, empty container dynamics are highly subjective to the interactions between large numbers of factors. The complexity of the container industry in general with a multitude of players from the ocean liners to the container leasing agencies and intermodal transporters as well as different options for possession of containers, such as, multiple leasing arrangements, buying new, repositioning, and actual ownership add further dimensions and complexity to the problem of managing empty containers. To avoid the costly repositioning activity a shipping company had the option of leasing containers in a high demand area and off-leasing them in the low demand area. With the purpose of obtaining a greater integration and visibility in the system and a better management of equipment inventory the shipping companies have increasingly moved to direct ownership of containers in recent years, with about 59% of the container being owned by the shipping companies in 2007 (Theofanis & Boile, 2009). Thus the option of off-leasing is significantly diminished. The option of buying new containers in the demand areas and disposing them in surplus areas is also not feasible owing to the high cost of manufacturing new containers, for the past several years. The cost of new containers is currently at a record high (Barnard, 2010). Under this scenario repositioning of empty containers is the only economically feasible option. The advantage associated with this scheme is the reduction in the accumulation of empty container and high utilization of the containers, which is evident from the fact that in 2009, about 95.6 % of the leased containers were on active operating leases (Theofanis & Boile, 2009).

Although reasons for the accumulation of the empty containers may vary, there is little doubt that an excessive accumulation of empty containers and the resulting cost of repositioning empty containers is a major concern. Empty container accumulation is a source of critical social, traffic, environmental and aesthetic problems (Boile, 2006). Also according to Boile (2006), excluding the cost of storage and repositioning over land, the estimated total cost of empty movements in 2003 was 11 billion dollars with an estimated cost of about thousand dollars per container.

The purpose of this paper is to utilize system dynamics to model the complexities associated with the movement of containers between the economic geographies. For the sake of demonstration the author has attempted to model the flow of containers between the Asian region and the United States. The particular advantage of using system dynamics lies in its capability to model multiple interacting factors that affect the system. This allows the user to observe the combined effect of these factors under various scenarios. This model should provide a useful insight in container flow and accumulation to shipping companies and policy makers. The model would prove to be useful in efficient planning and allocation of resources. In the next section the literature relevant to this topic would be reviewed. This would be followed by the model description and demonstration. The paper would conclude by providing a discussion of the results and future work.

2. LITERATURE REVIEW

This section would discuss some of the relevant literature in this field of study. The discussion would be limited to papers addressing issues related to global repositioning of empty containers.

The problem of empty containers repositioning has generally been addressed as an inventory problem, with the objective of determining the optimum quantity of containers to be stored at a port while minimizing the total cost involved (Cimino, Diaz, Longo, & Mirabelli, 2010). These problems have been characterized as dynamic allocation problems by Dejax and Crainic, (1987). Lam et al. (2007) have classified the literature dedicated to empty flows in terms of their application area as operational, tactical and strategic. While the operational models deal with day to day decision making process, the strategic models address long term planning issues like depot location, sizing and so on. Their survey shows that a major section of papers have been dedicated to the operational aspects of this problem.

Li et al. (2004) have proposed a ‘two-point-critical’ policy for minimizing the transport and leasing costs associated with empty containers for a single port. The policy consists of a lower and an upper bound on inventory levels. The port would export empty containers if the inventory rises above the upper bound while it imports containers if the level falls below the lower bound and incur an export or import cost per container respectively. Any shortage of containers is met through leasing the required number of containers in that period which would incur a leasing cost. The results have been extended to a multi port case in Li et al. (2007). However, both these studies have assumed deterministic costs in their analysis. However, costs do change and the preferences of the shipping companies also change with the changing costs. It is also not clear how the policy would function if all the ports exceed their upper limits. This scenario is possible if there is a significant drop in demand as has been observed during the recent recession years. This would lead to a net excess of containers in the global system and an accumulation should be observed somewhere in the system.

Di Francesco et al. (2009) address the repositioning problem under a scenario in which some of the ports in the network do not allow long term storage of empty container and no reliable historical or current information is available to formulate the policy for the next period. They provide a multiple scenario modeling approach where multiple scenarios are generated according to the guesstimated values of the uncertain parameters. The mathematical model is solved by incorporating the generated multiple scenarios to get the optimum number of empty containers to be stored at the given port in the particular time period. Song and Carter (2009) analyze the empty container repositioning problem at a macro level and evaluate four strategies based on coordination of route-sharing and container-sharing on major ocean routes. They report that significant savings can be achieved by combining route-sharing and container-sharing strategies. Dong and Song (2009) use a simulation based optimization approach utilizing genetic algorithm and evolutionary strategies to solve the combined problem of container fleet sizing and empty container repositioning. Their objective is to minimize the total cost associated with this operation under a multi-port, multi-vessel and multi-voyage scenario. This study considers a much more generalized shipping system than considered by previous studies done on similar lines. Lam et al. (2007) have proposed a dynamic programming approach for addressing the issue of empty container relocation. They have used a simulation based approach called temporal difference (TD) learning to derive effective operational strategies that would minimize the average cost associated with empty container relocation. All the above studies have been dedicated to the operational aspects of empty container management. The purpose of the present study is to develop a tool to analyze long term trends in container movement, container fleet size and container accumulation. As such the present study may be classified as addressing the 'strategic' aspects as per the criterion by Lam et al. (2007). The survey by Lam et al. (2007) shows that relatively few papers have addressed the strategic aspects of empty container management. Gendron and Crainic (1995) and Bourbeau and Crainic (2000) use branch and bound techniques to solve the depot location allocation problem for marine container management. The problem addressed in general is to locate depots to receive and store empty containers such that the total cost associated with the movement of container between customers and depots and between depots is minimized. Two recent studies can be found using system dynamics for analysis of marine systems. Amongst them Choi et al. (2007) have used system dynamic to analyze the long term effect of introduction of new technology and equipment on the efficiency of a container terminal. Ho et al. (2008) address the impact of infrastructure investment on port throughput and capacity. Although neither of these studies is related to empty container management, they are relevant to the present study since they are amongst the few, using system dynamics for marine logistics application and are dedicated to the strategic aspects. The discussion above indicates that most of the research on empty container repositioning has been centered on the operational aspects. A few studies dedicated to the strategic aspects have addressed issues such as depot location-allocation and investment impact on port efficiency, throughput and capacity. An excellent analysis of various factors impacting the flow of empty containers and their accumulation has been provided by Boile (2006) and Theofanis and Boile (2009). However, to the author's knowledge no attempt has been made so far to model and simulate a container flow system that incorporates these factors. The authors believe that such an approach would be beneficial to analyze various what-if scenarios and provide useful inputs to decision makers on issues like capacity and tariff structure. It would also assist the shipping companies to comprehend the global container flow trends at a macro level, under various conditions, which can help them manage their operations more efficiently. In the next section the authors would introduce and discuss the salient aspects of the proposed model.

3. MODEL DESCRIPTION

The authors propose to build a simple two port system with a trade imbalance such that one of the ports has an excess of empty containers. Naturally, the port with a positive trade imbalance would have the option of either importing containers from the other port or purchasing new containers. However the preference for this decision would depend on the relative cost of repositioning vs. the cost of purchasing new containers. If the repositioning cost is high, the corresponding cost of leasing new containers would also be high, as the leasing agency would attempt to pass on the high cost of repositioning to the shipping company so as to remain profitable. As such, we assume that leasing of containers and repositioning are equivalent options and hence assume that no leasing option is separately available. Thus the only options available are repositioning or purchasing new. On the other hand the port with a negative trade imbalance would have excess of empty containers and would prefer to export them to the port with high demand. Again, this would be subject to the relative cost of repositioning to the cost of purchasing new containers. If the cost of repositioning is less that the cost of buying new containers, the port with an excess of empty containers would export those to the deficit port. Thus the total shipment from any port would be the loaded export containers plus the empty containers that the port may choose to reposition depending on the cumulative effect of the factors affecting the economic feasibility of the operation. The shipment of loaded containers (prospective) would be contingent upon the availability of empty containers. If the storage tariff at a particular port is low, it would become the preferred location for the storage of excess empty containers and an accumulation of containers could possibly be observed at that port depending on the trends in the volume of the trade. It would be more likely to observe an accumulation if the volume of global trade drops. Figure 1 below displays the system dynamics representation of the discussion above. It can be observed in the figure that the term 'Total inflow USA' is equivalent to the total number of empty containers available. Depending on the number of empty containers available the 'Containers ready for shipping' can be made ready for shipment. The 'Load empty containers' rate disposes off the quantity of empty containers equivalent to the 'Outbound containers/empty container availability' rate, so that the outbound containers are not double counted. The 'Total inflow USA' rate and the 'Containers loaded on ship' rate are limited by the available throughput of the port. Finally the 'repositioning' adds outbound empty containers to the total shipment. The same logic is followed for the second port. This flow model is tied to a simple capacity model for each port, which would decide the possible throughput of containers through that port. The capacity model consists of a stock of available capacity which would decide the throughput of the port. The difference between the available and desired capacity would drive investment in additional capacity and maintenance, while the deterioration of resources over time would reduce the available capacity of the port. Thus if no investment in additional capacity are made the available capacity would deteriorate over time. The capacity model is displayed in Figure 2. A twenty day transit time is assumed for the flow of container to reach from one port to another. Looking at the macro-scope of this study factors such as ship capacity and ship schedules have been ignored. The effect of these factors is assumed to be accommodated in the twenty day transit time.

The integration of the models described above would result in a two port container flow system as displayed in Figure 3 below. Another aspect added to the holistic model is that of 'information delay'. If the trade imbalance between the ports starts to change over time, an attempt would be made to adjust the repositioning policy so that excessive accumulation would not occur in any of the ports. However, trade imbalance is a stochastic parameter and would always change over time. As a result any significant shift in the trend of the trade imbalance can only be appreciated with a certain lag of time. The concept of 'information delay' has been incorporated to take this phenomenon into account. This parameter is the authors attempt to take into account the lack of accurate information and inability to accurately forecast trends, which is experienced in any decision making process in general. A delay of sixty days is thus introduced, before the decision makers can appreciate a significant change in trend of trade imbalance and make corrective actions to their policy.

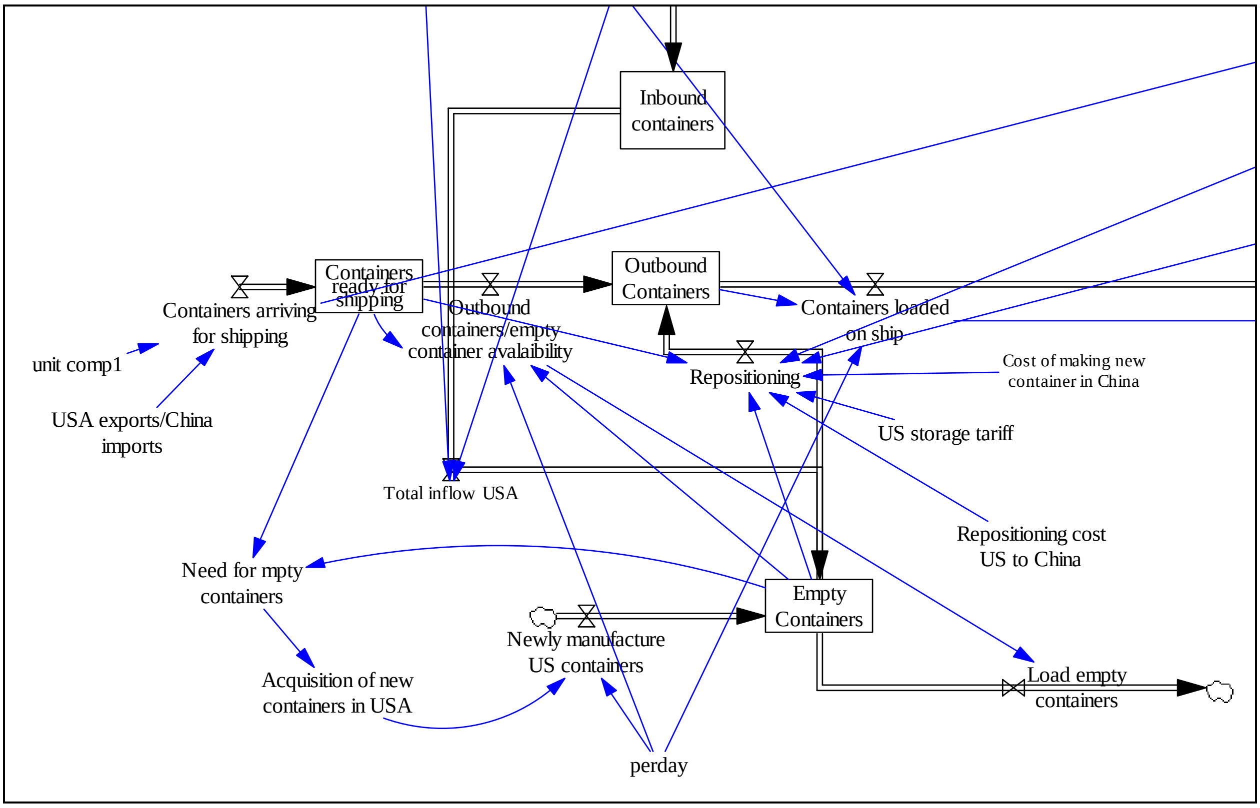


Figure 1: System dynamics representation of container flow for a single port

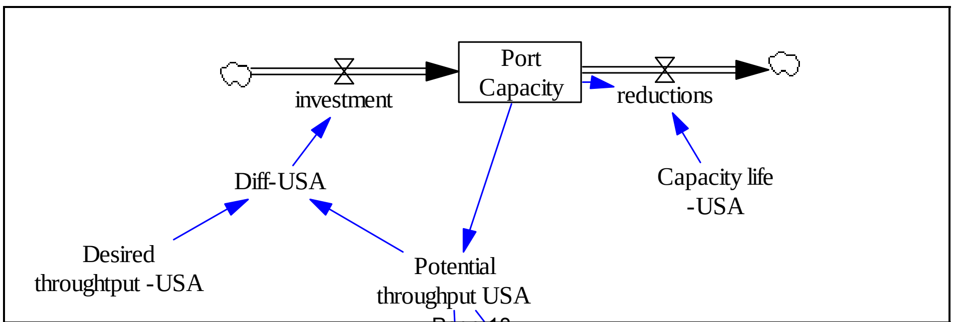


Figure 2: Simplified system dynamics model for port capacity

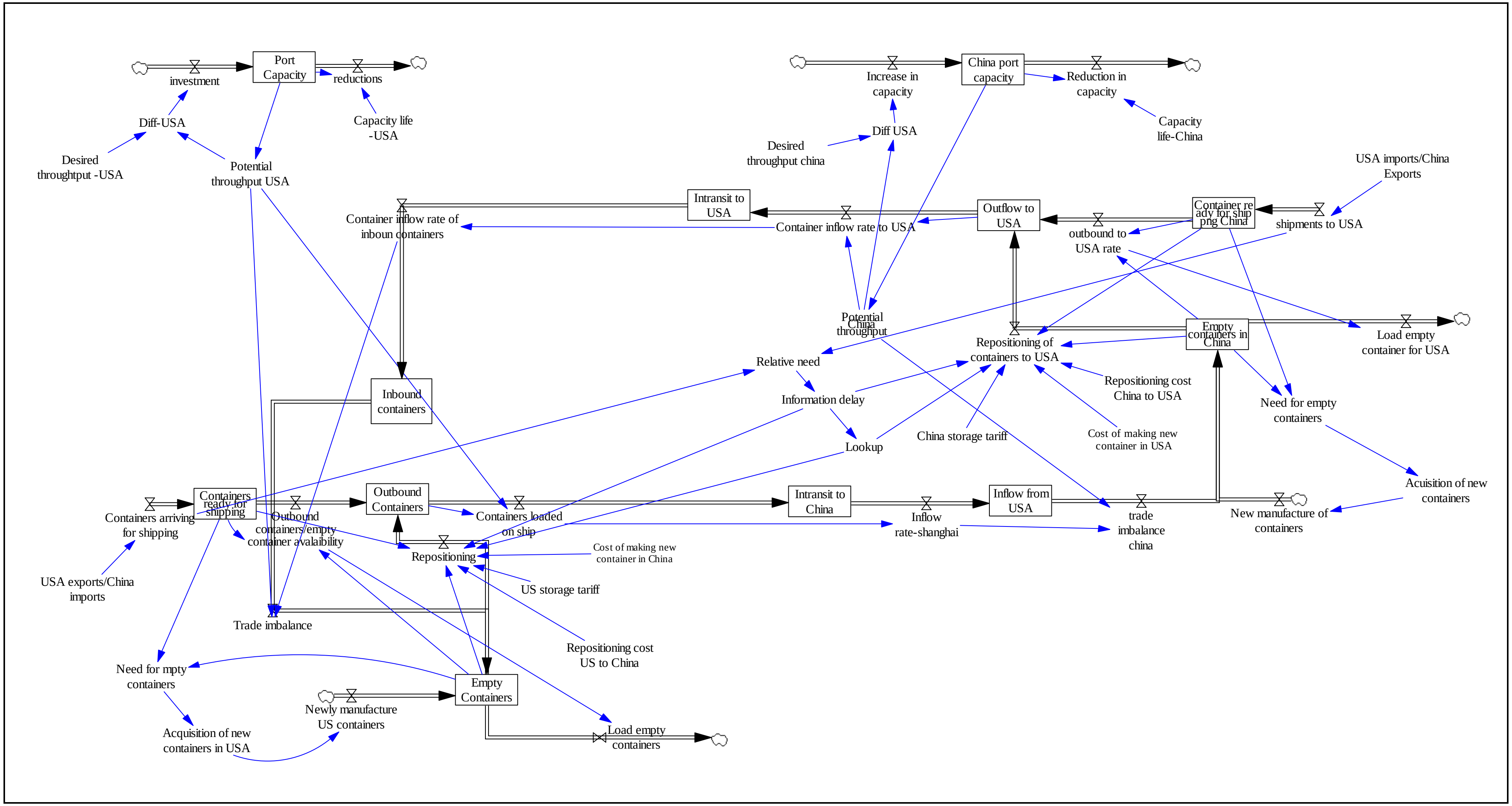


Figure 3: Proposed two port container flow system

4. DEMONSTRATION EXAMPLE AND RESULTS

The model is demonstrated using the Port of Los Angeles as an example. The Port of Los Angeles is a major port on the US west coast and has its major trading partners in Asia. For the sake of this example we assume that the Port of Los Angeles has a single trading partner in China. The TEU statistics for the port of Los Angesles have been obtained from (Port of Los Angeles, 2010). 'Inloaded' TEU are assumed to be the equivalent the import volume which corresponds to the export volume of the Chinese partner port. On similar lines the 'Outloaded' TEU are considered as export from Los Angeles and are assumed equivalent to the imports by the Chinese partner port. Both import and export volume in TEU are modeled as linear functions with the slope of the function equal to the difference between TEU volumes from 2000 to 2006 divided by the time span (2555 days). The numeration is displayed in Table 1. The second section of the piecewise linear function is calculated for the same parameter from 2006 to 2009 in the same manner as described above, and is shown in Table 2.

Table 1: Export/Import input for the model from 2000-2006

	In loaded-Import (TEU)	Out Loaded – Export (TEU)	Out Empty (TEU)
Jan-00	185913.65	73881.05	90174.35
Dec-06	359066.60	129467.75	217201.50
slope	67.77	21.76	49.72

Table 2: Export/Import input for the model from 2006-2009

	In loaded-Import (TEU)	Out Loaded-Export (TEU)	Out Empty (TEU)
Dec-06	359066.60	129467.75	217201.50
Dec-09	283364.40	153836.50	120142.40
slope	-69.13	22.25	-88.64

The resultant import and export input trends for the ten year period can be seen in Figures 4-5 below. The Y-axis represents volume in TEU/Year.

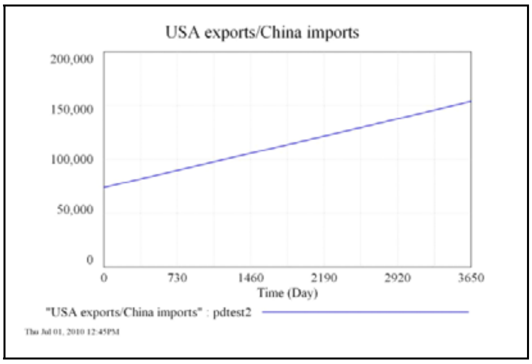


Figure 4: Export trend for port of Los Angeles (2000-2009)

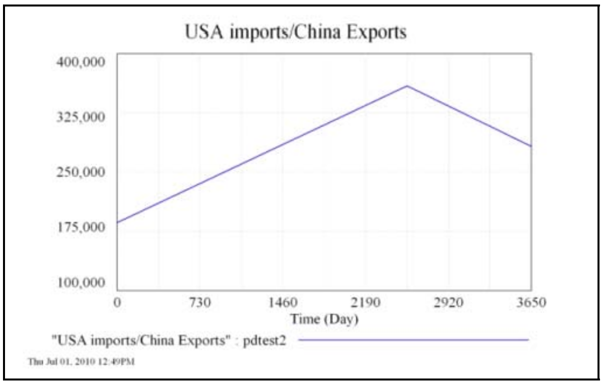


Figure 5: Import trend for port of Los Angeles (2000-2009)

The model as shown in Figure 3 is simulated for a period of ten years or 3650 days and the results are analyzed. For the sake of simplicity it is assumed that the repositioning cost is always less than the cost of making new containers. If no empty containers are available for shipment, they are bought new. Secondly the storage tariff is assumed equal at both the port locations. Also, it is assumed that sufficiently large capacity is available at both the port so that no active capacity constraints are imposed. The major points of interest here are the trends followed by the volume of repositioned containers from the US and the volumes of empty containers in the hypothetical Chinese port.
Figure 6-7 display the simulated and the average actual TEU of container repositioned (out empty) from the Port of Los Angeles from 2000 to 2009 per day. As can be observed the simulated and the actual figure follow similar trend and take comparable values, which provides validation for the proposed model. The second point of validation can be obtained by observing the increased accumulation of empty container on the Chinese (Asian region) port during the later part of the simulation, as displayed in Figure 8. This agrees with the observations of Bloomberg (2009) as far as the trend is concerned and can also be considered as a validation for the proposed model.
Although a more extensive experimentation and validation would be desirable, the validation provided above may be considered sufficient to establish the basic tenets of the proposed model and demonstrate the utility and usefulness of the undertaken exercise.

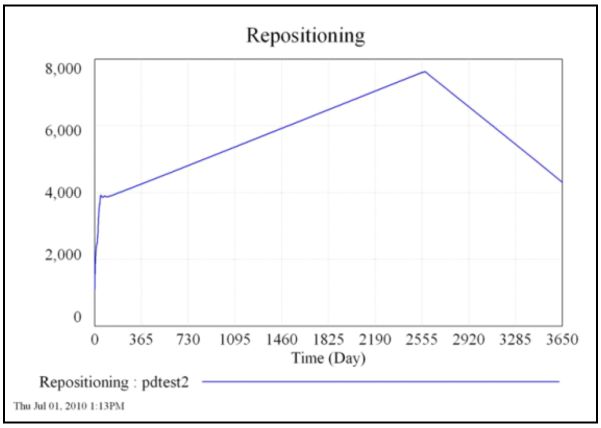


Figure 6: Volume of repositioned TEU for port of Los Angeles (Simulated)

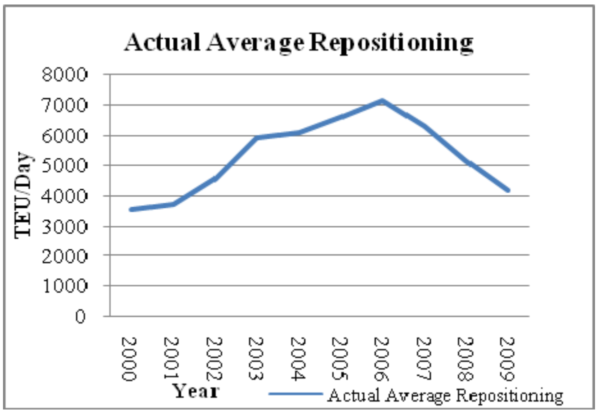


Figure 7: Average volume of repositioned TEU for port of Los (Actual)

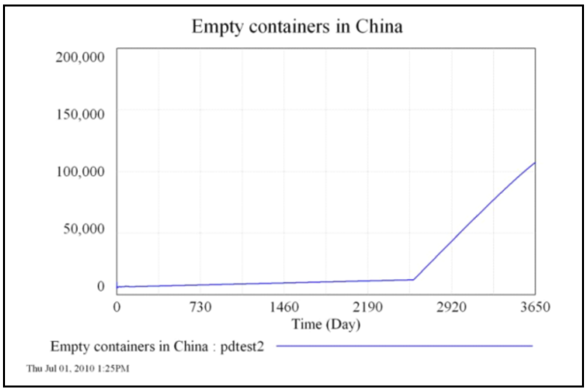


Figure 8: Simulated trend for empty container accumulation in the Chinese port (Y-axis- TEU)

CONCLUSIONS

The volume of containers in the logistics system is decided by the volume of the global trade. With the rapid increase in global trade with the advent of globalization the population of the container around the world has exploded. New containers are manufactured every year to meet the increasing demand for empty containers due to overall increase in volume. Also, due to a large geographical distance between exporting Asian countries and the importing Western countries there is a huge in-transit inventory of containers at various stages from ports and ships to intermodal transport and warehouses.

A slowdown in the global trade as has been observed during the recent recession years, demands a reduction in the inventory of the containers due to reduction in demand. However, unlike the goods they carry the containers are neither easily consumable in secondary markets nor economically disposable. Valuable resources need to be spent on the storage, handling, repositioning and maintenance of these containers. Such cost directly affects the profitability of the highly competitive shipping industry. Secondly, port authorities around the world need to make adequate space arrangements for storage of empty containers, so that the exporter's demand for the empty containers can be met. This is particularly challenging in view of rapid metropolitan development in the vicinity of major ports around the world, and the resulting shortage and high cost of space in the port vicinity. Under this scenario, studies aimed at gaining a better understanding of the dynamics behind container movements are warranted.

The analysis presented above can be termed as an attempt in such a direction. The authors have attempted to model and simulate the container flow for a two port system, by including the major factors that affect the container flow dynamics. The multiple interacting factors like tariffs, cost of manufacturing new container and cost of repositioning affect this system. System dynamics is a tool that provides the ability to model complex relationships and study the resultant system behavior. This capability makes system dynamics as an idea tool for modeling the container flow system.

A demonstration and validation of the model has been provided using the Port of Los Angeles as an example. This model can assist both the shipping companies and the port authorities in a more efficient decision making as far as the facility size, expansion planning, tariff structures and inventory management of containers is concerned. This would also help researchers to develop new approaches to handle this problem in a better and cost effective manner.

The present study can be significantly expanded to consider multi-port systems. In the present study we have assumed a fixed relationship between the cost of repositioning and the cost of manufacturing new container. However, this relationship changes depending on major drivers for these factors namely the cost of oil and the cost of steel respectively. It would be interesting to include such primary drivers in the analysis so as to make the model more generalized. Also the effect of different storage tariff structures on the accumulation of container may also be accessed. Lastly, the experimentation and validation provided in the present study can be fitting for demonstration purposes only, which is the intended purpose of this study. However, a more rigorous experimentation and validation of the expanded model would be desirable.

Lastly, the authors would like to acknowledge, that certain non scholarly sources of information such as news reports and articles have been referred in the present study as a basis of particular assertions. However, the authors believe that, the credibility of these sources and the expertise of the individuals reporting the facts, particular to this field, sufficiently satisfy the required validity of information as far as this study may require.

REFERENCES

Barnard, B. (2010, Jun 22). New Container Prices Hit 19-Year High. *The Journal of Commerce* .

Bloomberg. (2009, March 2). *Empty Containers Clog South Korea's Busan Port as Trade Slumps*. (K. Park, & S. Cha, Editors) Retrieved June 30, 2010, from http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aurr22fhQ5gs&refer=japan

Boile, M. (2006). *Empty intermodal container management.* Rutgers University, Center for Advanced Infrastructure and Trasportation.

Bourbeau, B., & Crainic, T. G. (2000). Branch-and-bound parallelization strategies applied to a depot location and container fleet management problem. *Parallel Computing , 26*, 27-46.

Choi, H. R., Park, B. J., Yoo, D. H., Kang, M. H., & Yoon, S. J. (2007). A Study on System Dynamics Modeling to Strengthen the Competitiveness of a Container Terminal. *Proceedings of the 2007 WSEAS International Conference on Computer Engineering and Applications.* Gold Coast, Australia.

Cimino, A., Diaz, R., Longo, F., & Mirabelli, G. (2010). EMPTY CONTAINERS REPOSITIONING: A STATE OF THE ART OVERVIEW. *Spring Simulation Conference.* Orlando, Florida.

Dejax, P. J., & Crainic, T. G. (1987). A Review of Empty Flows and Fleet Management Models in Freight Transportation. *Transportation Science , 21* (4), 227-248.

Dong, J.-X., & Song, D.-P. (2009). Container fleet sizing and empty repositioning in liner shipping systems. *Transportation Research Part E , 45*, 860-877.

Di Francesco, M. , Crainic, T. G., & Zuddas, P. (2009). The effect of multi-scenario policies on empty container repositioning. *Transportation Research Part E , 45*, 758-770.

Gendron, B., & Crainic, T. G. (1995). A Branch-And-Bound Algorithm For Depot Location and Container Fleet Management. *Location Science , 3* (1), 39-53.

Ho, K. H., Ho, M. W., & Hui, C. M. (2008). Structural Dynamics in the Policy Planning of Large Infrastructure Investment under the Competitive Environment: Context of Port Throughput and Capacity. *Journal of Urban Planning and Development , 134* (1), 9-20.

Lam, S.-W., Lee, L.-H., & Tang, L.-C. (2007). An approximate dynamic programming approach for the empty container allocation problem. *Transportation Research Part C , 15*, 265-277.

Li, J.-A., Leung, S. C., Wu, Y., & Lie, K. (2007). Allocation of empty containers between multi-ports. *European Journal of Operational Research , 182*, 400-412.

Li, J.-A., Liu, K., Leung, S. C., & Lai, K. K. (2004). Empty Container Management in a Port with Long-Run Average Criterion. *Mathematical and Computer Modelling , 40*, 85-100.

Port of Los Angeles. (2010). Retrieved June 30, 2010, from Port of Los Angeles: http://www.portoflosangeles.org/maritime/stats.asp

Song, D.-P., & Carter, J. (2009). Empty container repositioning in liner shipping. *Maritime Policy & Management , 36* (4), 291-307.

Theofanis, S., & Boile, M. (2009). Empty marine container logistics: facts, issues and management strategies. *GeoJournal , 74* (1), 51-65.

Tirschwell, P. (2009, July 1). *Roundtable:The Journal of Commerce*. Retrieved June 30, 2010, from The Journal of Commerce: http://www.joc.com/maritime/empties-inflating-asian-port-stats

AUTHOR BIOGRAPHIES

Mandar Tulpule is currently pursuing a Ph.D. in Modeling and Simulation at the Old Dominion University's Virginia Modeling, Analysis, and Simulation Center (VMASC). He holds a M.E degree in Industrial and Systems Engineering from the North Carolina State University, Raleigh and a B.E in Mechanical Engineering from Pune University, India. His key research interest includes modeling & simulation, operations management, supply chain and logistics. He has two years experience as a manufacturing and supply chain engineer prior to his academic career.

Rafael Diaz graduated from the Old Dominion University with a Ph.D. in Modeling and Simulation in 2007, and became a Research Assistant Professor of Modeling and Simulation at Old Dominion University's Virginia Modeling, Analysis, and Simulation Center (VMASC). He holds an M.B.A degree in financial analysis and information technology from Old Dominion University and a B.S. in Industrial Engineering from Jose Maria Vargas University, Venezuela. His research interests include operations research, operations management, production and logistic systems, reverse logistics, dependence modeling for stochastic simulation, and simulation-based optimization methods. He worked for six years as a process engineer and management consultant prior to his academic career.

Francesco Longo received his Ph.D. in Mechanical Engineering from University of Calabria in January 2006. He is currently Assistant Professor at the Mechanical Department of University of Calabria and Director of the Modelling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES). He has published more than 80 papers on international journals and conferences. His research interests include Modeling & Simulation tools for training procedures in complex environment, supply chain management and security. He is Associate Editor of the "Simulation: Transaction of the society for Modeling & Simulation International". For the same journal he is Guest Editor of the special issue on Advances of Modeling & Simulation in Supply Chain and Industry. He is Guest Editor of the "International Journal of Simulation and Process Modelling", special issue on Industry and Supply Chain: Technical, Economic and Environmental Sustainability. He is Editor in Chief of the SCS M&S Newsletter and he works as reviewer for different international journals. His e-mail address is: f.longo@unical.it and his Web-page can be found at http://www.ingegneria.unical.it/impiantiindustriali/index_file/Longo.htm

Antonio Cimino took his degree in Management Engineering, summa cum Laude, in September 2007 from the University of Calabria. He is currently PhD student at the Mechanical Department of University of Calabria. He has published more than 20 papers on international journals and conferences. His research activities concern the integration of ergonomic standards, work measurement techniques, artificial intelligence techniques and Modeling & Simulation tools for the effective workplace design. His e-mail address is: acimino@unical.it and his Web-page can be found at http://www.ingegneria.unical.it/impiantiindustriali/index_file/Cimino.htm

TRAINPORTS - TRAINing in marine Port by using Simulation

[(a)]**Agostino Bruzzone**, [(b)]**Antonio Cimino**, [(c)]**Francesco Longo**, [(d)]**Giovanni Mirabelli**

[(a)]DIPTEM, University of Genoa, Italy
[(b)(c)(d)]MSC-LES, University of Calabria, Mechanical Department, Rende (CS), Italy

[(a)] agostino@itim.unige.it, [(b)]acimino@unical.it, [(c)]f.longo@unical.it, [(d)]g.mirabelli@unical.it

ABSTRACT
Modeling & Simulation (M&S) provides nowadays one of the best solutions for personnel and managers training in complex environments. In the paper the authors propose an overview on some advanced simulators, TRAINPORTS, (HLA compliant) that recreate in three-dimensional virtual environments the Gioia Tauro Container Terminal. The simulators include different federates (i.e. Straddle Carriers, Quay Cranes, Reach stackers and Trucks) and can be used to support marine workers training providing the sensation to be in a real container terminal environment. Simulators architecture and Federates/Federation description are provided.

Keywords: Modeling & Simulation, 3D Simulation, containers terminal, virtual environment, HLA

1. INTRODUCTION
In the last decades, Modeling & Simulation (M&S) has become a powerful tool for training purposes. The use of M&S for training occurs when there are situations most expensive or too dangerous to allow trainees to use the real equipment and to do real operations in the real world. The benefits obtained from the use of simulators in training tasks are:

- practicing the theoretical concepts that have been taught and shows the consequences of actions in a very immediate and visual manner;
- providing the instructor with a controlled environment where a large amount of data can be recorded and analyzed to evaluate the trainee's evolution/performances;
- avoiding danger situations that usually occurs when unexperienced users manipulate real machines;
- reducing costs associated to training operations;
- providing trainees with the possibility of working in any desired conditions (i.e. arbitrary weather conditions).

The above listed benefits has motivated an increase of the use of advanced systems based on M&S for operators training in different domains/areas (Wilson et al. 1997). A tremendous amount of researches has been published. Among the existing interactive visual simulators, the flight simulation is the most mature and representative application. Melnyk (1999) built a flight simulator with a complex and effective six Degree-Of-Freedom (DOF) motion system to generate the realistic feeling of takeoff, landing and in-flight turbulence. Menendez and Bernard (2000) used a room of four projected surfaces to create a fix-based airplane and helicopter simulator. Chin-Teng et al. (2001) created a multipurpose virtual-reality-based motion simulator for studying the stability of the 6 DOF Stewart Platform used as a flight simulator. Asiding from the flight simulator, the other well-known application is the driving simulation. Greenberg and Park (1994) developed a driving simulator for the Ford company. Lee et al. (1998) presented a driving simulator based on the use of four PCs only. Freund et al. (2001) proposed a simulator for excavators and construction machines. Park et al. (2001) presented a low-cost driving simulator where four hosts were employed and configured in server/client architecture to construct its computing environment. Other researches studies include various military training programs (Zeltzer et al., 1995) and power-plant operators training (Tam et al., 1998). Zeltzer et al. (1995) designed a simulator to train the officer of the deck on a submarine. Tam et al. (1998) proposed an operator training simulator prototype for power-utility personnel. Moreover, several researchers and scientists used M&S for developing training tools in industrial applications (Jiing-Yih et al. 1997, Cramer et al. 2000, Anon 2000). Other examples of training simulators are reported in Carraro et al. (1998), Ferrazzin et al. (1999) and Kwon et al. (2001). Carraro et al. (1998) developed a bicycle simulator that uses the Virtual Reality Modelling Language browser as its user interface. Ferrazzin et al. (1999) proposed a motorcycle rider simulator being used for testing new prototypes before actually producing them. Kwon et al. (2001) propose an interactive bicycle simulator including a Stewart platform to generate 6 DOF motions, the handle and pedal resistance systems to provide force feedback and the visual simulating system to create the virtual scene. Training in virtual environment has been also successfully used in marine ports and container terminals. Several simulators have been developed for training purposes, specially in activities which involve

high risks and costs, as it is the manipulation of heavy harbor equipment such as different types of cranes, trucks, etc. (Seron et al., 1999; Kim, 2005). Wilson et al. (1998) developed a virtual environment to simulate overhead crane operation by combining 3-D factory drawings with 3-D simulation models of crane and load motion. Huang (2003) presented a method to design an interactive visual simulation on a cluster of desktop computers for the mobile crane training. Daqaq (2003) developed a virtual simulation of ships and ship-mounted cranes to be used as a training platform for ship-mounted crane operators. Rouvinen et al. (2005) developed a gantry crane operator-training simulator to be used for training operators involved for the movement of the containers between the pier and the ships. Furthermore specific research works have been developed also for supporting training of operators for security procedures within terminal containers (Longo et al 2006; Longo, 2010,). Actually the authors have a remarkable experience in developing simulators for operators training in container terminals. For further information refer to Bruzzone et al. (2007), Longo (2007), Bruzzone et al. (2008-a), Bruzzone et al. (2008-b) and Bruzzone et al. (2009), Bruzzone et al. 2010, Cimino et al. (2010).
In the paper the authors propose an overview on the architecture of some advanced simulators (HLA compliant) with specific attention to one of the simulators recently developed: the Gioia Tauro Container Terminal. Simulators developed by authors usually 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. The development of each federate includes three components: the virtual environment, the geometric model and the dynamic process module. The virtual environment is provided by the software tool Vega Prime (by Presagis) and hosts the marine port environment developed by using the 3D real time modeling tool Creator (by Presagis). The marine port environment includes berth and yard, berth cranes, container handling equipment and facilities. The main port operations are implemented within the dynamic process module (the simulation engine and allows all the interactions in the 3D environment). Before getting into details of the paper, in the sequel a brief description of the paper organization is reported. Section 2 presents the Gioia Tauro Container Terminal (technical charateristics and equipments); section 3 presents the typical simulator architecture; section 4 describes the simulator operational models and, finally, the last section summarizes the scientific contribution of the paper and research activities still on going.

2. THE GIOIA TAURO CONTAINER TERMINAL

The container terminal considered in this research project is the Gioia Tauro container terminal, located in South Italy (see figure 1 for Gioia Tauro container terminal localization). Gioia Tauro port is today one of the bigger container terminals in Italy and the biggest transshipment container terminal in the Mediterranean area.

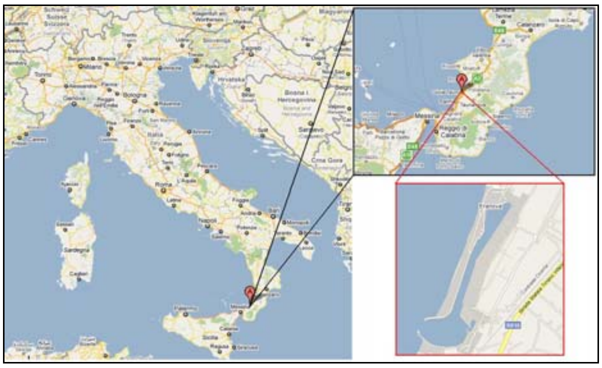


Figure 1: Gioia Tauro Container Terminal localization

It is the seventh biggest container terminal in Europe, handling about 3.7 million TEUs per year (the port handles over one-third of Italy’s national traffic). The structure covers approximately 440 hectares of land area (water excluded) and contains 1.7 milion square meters of stocking yards. The port is connected by road and rail services. The container traffic, which is carried out by the Medcenter Container Terminal SpA, is the main business activity, but the port has also a significant amount of automobile transshipment managed by the BLG Automobile Logistics S.r.l..
The upper part of figure 2 shows a panoramic view of the Gioia Tauro Container Terminal, the lower part depicts the container terminal lay-out.


Figure 2: Panoramic view and lay-out of the Gioia Tauro Container Terminal

The Yard area is characterized by:

- 67,000 yards slots;
- 2350 reefer plugs;
- Handling capacity: 4,200,000 TEU per year;
- Deep water berths: from 12.5 meters up to 18 meters;
- Meters of quays (used by Medcenter Container Terminal SpA): 3,395 meters;
- Meters of wharf (used by Medcenter Container Terminal SpA): 3,395 meters (used by BLG Automobile Logistics Srl): 384 meters;
- Quay Cranes: 22 gauntry cranes, 3 mobile cranes;
- Yard Equipment: 125 Straddle Carriers, 13 Reach Stackers;
- Adjacent rail services;

Figure 3 shows the positive trend of the Gioia Tauro container terminal in terms of number of handled TEU per year starting from 1995.

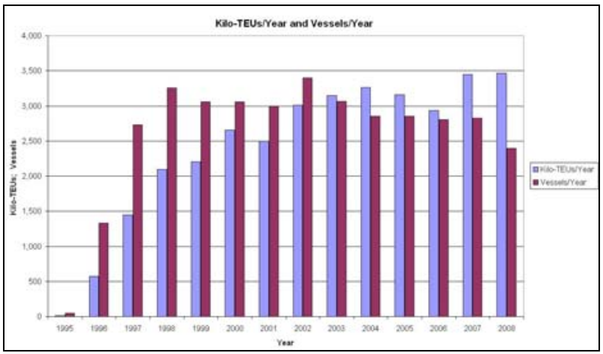


Figure 3: Trends for TEUs/year and Vessels/year

3. SIMULATORS ARCHITECTURE

Usually simulators development for marine operators training takes into account the following aspects:

- provide the user with an advanced simulator to support operators training in container terminals (specifically training of operators involved in containers handling operations);
- provide the user with an enabling technologies for container terminal layout design;
- provide the user with a tool for evaluating operators performances and for investigating interactions between all the actors operating in the yard.

As previously reported, simulators are based on High Level Architecture (standard for interoperable simulation models). The HLA is as integrated approach that has been developed to provide a common architecture for simulation. Before going into the details of simulator architecture let us introduce the following definitions in order to make the reader more familiar with the HLA:

- Federate: an individual HLA-compliant simulator application;
- Federation: a simulation system composed of two or more (often many more) federates that "play" together;
- Run Time Infrastructure (RTI): software that manages the simulation and integrates the simulators;

The HLA architecture is based on a set of rules, defined within the RTI, which govern and define relationships among federation components (federates). The simulator development phase involves the following steps:

1. Federates development: this step focuses on creation of federates to be integrated in the TRAINPORTS federation;
2. Federation development: this step regards the implementation of the federation itself integrating each federate and proceeding in the testing;
3. Federation VV&A: the specific goal is to verificate, validate and accreditate the federation.

As already mentioned the authors developed multiple HLA complaints simulators (see for instance Bruzzone et al. 2010); in this paper the TRAINPORTS simulator consisting of one federation and the following four federates is presented: Straddle Carrier, Quay Crane, Reach Stacker and Truck. Figure 4 shows the TRAINPORTS architecture.

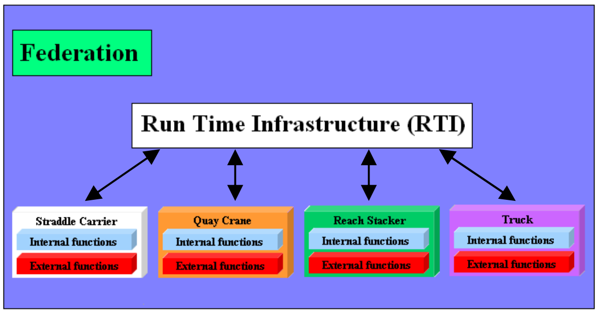


Figure 4: TRAINPORTS architecture

Section 3.1-3.2 goes into the details of the TRAINPORTS development process.

3.1. Federates development

Each federate is characterized by three integrated and cooperating components: a hosting environment (the environment in which the federate is located, the container terminal under consideration), the federate lay-out (federate geometric model), the dynamic interactions that evolve in the hosting environment and modify the federate configuration as time goes by (interactions generated by workers, containers movements, vessels arrival, etc.). Each federate integrates the three above-mentioned components. The translation into computerized models of the three cooperating components is as follows: the hosting environment is a Virtual Environment (VE), the federate layout is a 3D Geometric Model (GM), and the interactions that evolve in the hosting environment and modify the federate configuration are dynamic processes implemented within the Dynamic Processes Module (DPM). Note that the DPM interacts with the GM and, in turn, the GM is contained in the VE. The integration of the DPM, GM, and VE creates the Simulator Architecture as shown in Figure 5.

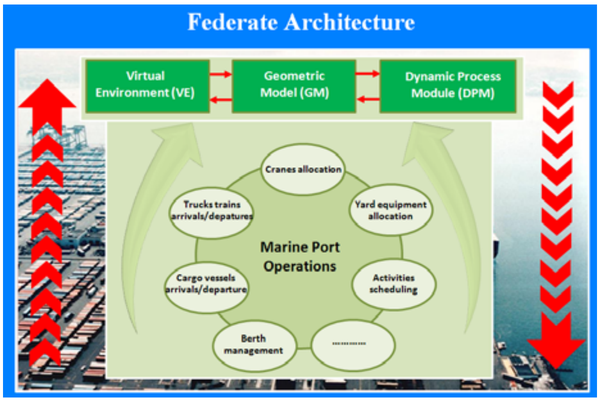


Figure 5: Simulator Architecture

The Federate architecture has been implemented by using different software tools. The VE has to host and interact with port GM. The interactions that take place into the VE recreate the marine port operations; as before mentioned such processes are implemented within the DPM and the DPM can be implemented in the general purpose language C++. As a consequence the VE has to provide an interface with the C++ environment. To this end the Vega Prime platform (developed by Presagis) has been used for implementing the VE. Vega Prime is one of the most widely used tools for the creation of real time 3D application based on visual simulation. The software gives quite good performances on low cost hardware platform and its architecture is completely based on C++. The complete integration of the GM within the VE could be obtained by using the modelling toolset Creator (by Presagis). The Creator allows modelling objects, entities and sites and can be easily interfaced with Vega Prime.

The first step of the federate implementation was the creation of the containers terminal VE by using the software Creator. The geometric models of berths, yard area, cranes, handling equipment, containers have been recreated. After the containers terminal VE implementation, the next step was the development of the federate GM and each of then was then imported into the container terminal virtual environment.

At this stage there are no interactions between the federates GM and the VE. The next step was the implementation of the DPM and its functionalities. The authors implement all the dynamic interactions that evolve in a containers terminal environment into the DPM. The architecture of the DPM has been completely developed using Microsoft Visual C++.

As previously reported TRAINPORTS includes the following four federates:

- *Straddle Carrier Federate (SCF)*: the SCF recreates the operations devoted to move containers in the yard and from/to quay cranes. The SCF will be equipped with a virtual bridge; the virtual bridge will be inserted within the virtual cockpit giving the trainee the possibility to see the container terminal virtual three-dimensional environment. The trainee has the possibility to change different views: from inside the cockpit (to have the sensation to be within the straddle carrier); outside (to see the whole straddle carrier from different points), flight of a bird panoramic (to have a panoramic view of the scene). By using an external steering wheel, pedals and joystick the trainee can move and use the straddle carrier according to inputs he/she provides.
- *Quay Crane Federate (QCF)*: QCF recreates the operation devoted to move the containers from the ships to the berth yard and viceversa. This module is developed to select training candidates, train new operators (to speed more quickly), evaluate and improve operator skills. QCF puts the trainee at the controls of a typical quay crane equipped with telescoping boom and jib, and a variety of loads and hook blocks. Instruments reading is displayed (boom angle, length, height, radius and quadrant) along with a simulated load moment indicator. The driver's interface is accurate in terms of lights, steering, indicators and pedal controls. The simulated vehicles dynamics are based on mathematical models using actual vehicle information to provide accurate behavioral realism. Moreover, as the SCF, the trainee has the possibility to change different views: from inside the cockpit (to have the sensation to be within the quay crane); outside (to see the whole quay crane from different points), flight of a bird panoramic (to have a panoramic view of the scene).
- *Reach Stacker Federate (RSF):* the RSF recreates the operations required for loading the containers from the yard area to the trucks. Such module puts the trainees at the control of typical mobile virtual stacker and allows them to evaluate and improve their skills. The driver's interface is accurate in terms of lights, steering, indicators and pedal controls and the trainee has the possibility to change different views;
- *Truck Federate (TF):* the TF recreates the operations devoted to move the containers from the yard area to their final destination. The simulator is designed to provide an excellent training system for heavy vehicle operators and allows the trainee to experience and get familiar with engine dynamics, transmission dynamics,

brake dynamics and steering dynamics. The driver's interface is accurate in terms of lights, steering, indicators and pedal controls. Finally, the simulator provides training in unpredictable and hazardous situations as well as normal and seasonal weather conditions.

Figure 6 shows the Straddle Carrier while figures 7, 8 and 9 provide the reader with different views of the Gioia Tauro containers terminal VE.

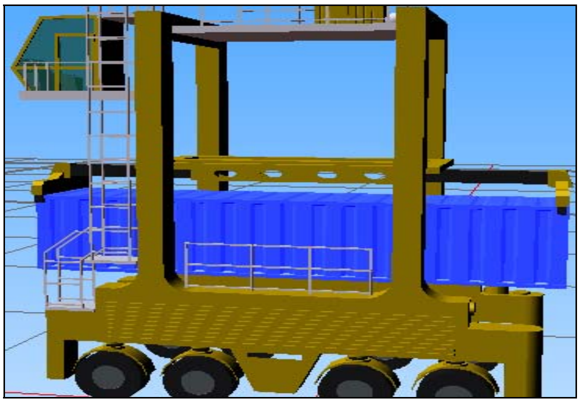


Figure 6: Straddle Carrier GM

Figure 7: Quay Crane GM

Figure 8: Containers terminal VE

Figure 9: Containers terminal VE

3.2. Federation development and validation

Integrating each federate in order to develop the federation and validating the federation in term of proper implementation and correct tuning of the factors and parameters represent another critical step. Considering these aspects the authors proceed in this process by applying standard IEEE 1516.3 High Level Architecture Federation Development and Execution Process as well as fundamentals of 5000.61 directive related to VV&A (Verification, Validation and Accreditation); obviously it will be necessary to tailor properly the VV&A on this specific case; this approach will guarantee to complete effectively the verification and validation of the overall system; the researchers use extensively a network of experts in simulation applied to port logistics in order to guarantee the success of this phase; the availability of real logistics operators will provide full validation of the redesign capabilities of the system in relation to virtual function test of scenarios involving both HIL (Hardware in the Loop, for instance automation systems and sensors on the crane spreader) and MIL (Man in the Loop, for instance policies for exchanging container between different cranes).

4. TRAINPORTS OPERATIONAL MODES

At the beginning of each new training session, TRAINPORTS simulator automatically generates the mission: the user can defines for every single operator which container has to be moved and the new position/destination to be reached.

The mission can be "multiple destinations", in other words the trainee could be asked for moving the container from a yard allocation or a truck trailer and back again. Also, different levels of complexity can be selected, extra-move included, based on the necessities; to this end the simulator provides the user with "interference" in term of means and persons.

By using C++ language intelligent algorithms have been implemented in TRAINPORTS simulator models and devoted to track other federates during communication drawback. Due to this fact dynamics of physics are introduced in each federate model. In fact, containers and trailers properties are shared among different users, on the contrary trucks, cranes and people properties are functions of each platform user.

The high level of complexity of such procedures can be understood if we consider that during the simulation several kind of vehicles are involved; due to this the containers handling must include a continuous reassignment of the different attributes.
The adopted solution for the federation architecture will allow that different vehicles will be able to interact; this approach will support not only training, but also policy definition, procedure design and infrastructure reengineering. These operations are very important in a intermodal systems where the overall efficiency depend upon synergy and harmony among equipment, people and planning. The policy redesign was already experienced by the researchers in port ship handling by using virtual simulation; in logistics intermodal operation it is also possible to get great benefits from this analysis; in effect the proposed synthetic environment allows to proceed in the redesign of the handling devices themselves; for instance it will be possible to change the virtual cockpit of a crane and to identify the benefits in term of overall logistics performances and safety levels through an experimental campaign on the simulators.

CONCLUSIONS

M&S could provide a promising alternative to real world training. A M&S approach for training allows the trainees to evaluate and improve their skills in using working equipment as well as to do an operation in a safe virtual environment. The paper proposes a virtual 3D Simulator for training for marine workers. The Simulator presented recreates the Gioia Tauro container terminal, one of the bigger container terminals in Italy and the biggest transshipment container terminal in the Mediterranean area. The simulator will be based on the High Level Architecture and the development process consists of three steps. The first step focuses on the creation of federates to be integrated in the TRAINPORTS federation: each federate consists of the main components: the VE, the GM and the DPM. The federate implementation starts with the development of the containers terminal VE by creating the geometric models of berths, yard area, cranes, handling equipment, containers. The containers terminal VE implementation is followed by the development of each federate GM and then each of them is imported into the container terminal virtual environment. The implementation of the DPM and its functionalities completes the federates development step.
After the federate development, the authors integrated each federate in order to develop the federation and validated the federation in term of proper implementation and correct tuning of the factors and parameters by applying standard IEEE 1516.3 High Level Architecture Federation Development and Execution Process as well as fundamentals of 5000.61 directive related to VV&A (Verification, Validation and Accreditation).

REFERENCES

Anon, VR in Industrial Training, Virtual Reality, Grindelwald, Vol. 5, No. 4, pp. 31-33.

Bruzzone, A. G., Bocca, E., Longo F., Massei M., 2007. Logistics Node Design and Control over the Whole Life Cycle based on Web Based Simulation. International Journal of Internet Manufacturing and Services, vol. I (I); p. 32-50, ISSN: 1751-6048

Bruzzone A. G., Poggi S. and Bocca E., 2008-a. Framework for interoperabile operations in port facilities. Proceedings of ECMS 2008, June 3rd - 6th, 2008. Nicosia, Cyprus.

Bruzzone A. G., Longo F. 2008-b. VIP - Virtual Interactive Port. In: Proceedings of Summer Computer Simulation Conference. Edinburgh, 16-19 June, SAN DIEGO: SCS, ISBN/ISSN: 1-56555-323-3

Bruzzone A. G., Fadda P., Fancello G., D’Errico G., Bocca E., Massei M., 2009. A Vibration Effect as Fatigue SOURCE in A PORT CRANE Simulator for Training and Research: Spectra Validation Process. Proceedings of the International Workshop on Harbour, Maritime & Multimodal Logistics Modeling & Simulation (HMS09), Tenerife, Spain.

Bruzzone A.G., Fadda P., Fancello G., D'Errico G., Bocca E., Massei M. (2010). Virtual world and biometrics as strongholds for the development of innovative port interoperable simulators for supporting both training and R&D. International Journal of Simulation and Process Modeling, Vol. 6, Issue 1, pp. 89-102.

Carraro, G.U., Cortes, M., Edmark, J.T., Ensor, J.R., 1998. The peloton bicycling simulator. Proceedings of The Third Symposium On Virtual Reality Modeling Language, pp. 63-70.

Chin-Teng, L., I-Fang C., and Jiann-Yaw L., 2001. Multipurpose Virtual-Reality-Based Motion Simulator. Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, Vol. 5, pp. 2846-2851.

Cimino A., Longo F., Mirabelli G. (2010). Operators training in container terminals by using advanced 3d simulation. In: Proceedings of the Summer Computer Simulation Conference. Ottawa, Canada, July 11-15, SAN DIEGO: SCS

Cramer, J., Kearney, J., and Papelis, Y., 2000. Driving Simulation: Challenges for VR Technology. IEEE Computer Graphics and Applications, Vol. 16, No. 12, pp. 1966-1984.

Daqaq Mohammed F., 2003. Virtual Reality Simulation of Ships and Ship-Mounted Cranes. Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University.

Ferrazzin, D., Salsedo, F., Bergamasco, M., 1999. The MORIS simulator. Eighth IEEE International Workshop on Robot and Human Interaction (RO-MAN ‘99), pp. 135–141.

Freund, E., Rossman, J., and Thorsten, H., 2001. Virtual Reality Technologies for the Realistic Simulation of Excavators and Construction Machines: From VR-Training Simulators to Telepresence Systems. Proceedings of SPIE - The International Society for Optical Engineering, pp. 358-367.
Greenberg, J.A., Park, T.J., 1994. Driving Simulation at Ford. Automotive Engineering, pp. 37–40.
Huang, J.-Y., 2003. Modelling and designing a low-cost high-fidelity mobile crane simulator. International Journal of Human-Computer Studies, 58(2):151–176.
Jiing-Yih, L., Ji-Liang, D., Jiun-Ren H., Ming-Chang, J., and Chung-Yun G., 1997. Development of a Virtual Simulation System for Crane-Operating Training. Proceedings of ASME, Paper No. 6p 97-AA-45.
Kim, G., 2005. Designing Virtual Reality Systems: The Structured Approach. Springer.
Kwon, D.S., et al., 2001. KAIST interactive bicycle simulator. IEEE International Conference on Robotics and Automation (ICRA), Vol. 3, pp. 2313-2318.
Lee, W.S., Kim, J.H., Cho, J.H., 1998. A driving simulator as a virtual reality tool. IEEE International Conference on Robotics and Automation 1, 71–76.
Lindheim, R., Swartout, W., 2001. Forging a new simulation technology at the ICT. IEEE Computer 34 (1), 72–79.
Longo, F. 2010. Design And Integration Of The Containers Inspection Activities In The Container Terminal Operations. International Journal of Production Economics, vol. 125(2); p. 272-283.
Longo F. (2007). Students training: integrated models for simulating a container terminal. In: Proceedings of the International Mediterranean Modelling Multiconference (European Modeling & Simulation Symposium). Bergeggi, Italy, Ocotber 4-6, GENOA: vol. I, p. 348-355.
Longo F., Mirabelli G, Bocca E., Briano E., Brandolini M. (2006). Container Terminal Scenarios Analysis And Awareness Trough Modeling & Simulation. In: Proceedomgs of the European Conference on Modeling and Simulation. Bonn, Germany, May 28th – 31st, vol. I, p. 619-624.
Melnyk, R., 1999. Flight simulators: a look at Linux in the Aerospace Training Industry. Linux Journal 64, Article No. 5. Available online at http://www.linuxjournal.com/
Menendez, R.G., Bernard, J.E., 2000. Flight simulation in synthetic environments. IEEE 19th Proceedings of the DigitalAvionics Systems Conferences, Vol. 1, pp. 2A5/1-2A5/6.
Park, M.K., et al., 2001. Development of the PNU vehicle driving simulator and its performance evaluation. IEEE InternationalCo nference on Robotics and Automation (ICRA), Vol. 3, pp. 2325-2330.
Rouvinen, A., 2005. Container gantry crane simulator for operator training. In Publishing, P. E., editor, Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics, volume 219, pages 325–336.
Seròn, F., Lozano, M., Martìnez, R., P´erez, M., Vegara, P., Casillas, J., Martìn, G., Fernàndez, M., Pelechano, J., Brazàlez, A., and Busturia, J., 1999. Simulador de gruas portico portuarias. In Congreso Espanol de Informàtica Gràfica (CEIG'99).
Tam, E.K., et al., 1998. A low-cost PC-oriented virtual environment for operator training. IEEE Transactions on Power Systems 13 (3), 829–835.
Wilson, B., Mourant, R., Li, M., and Xu, W., 1998. A Virtual Environment for Training Overhead Crane Operators: Real-Time Implementation. IIE Transactions, Vol. 30, 1998, pp. 589-595.
Zeltzer, D., Pioch, N.J., Aviles, W.A., 1995. Training the officer of the deck. IEEE Computer Graphics and Applications 15 (6), 6-9.

AUTHOR BIOGRAPHIES

Agostino Bruzzone since 1991, he has taught "Theories and Techniques of Automatic Control" and in 1992 he has become a member of the industrial simulation work group at the ITIM University of Genoa; currently he is Full Professor in DIPTEM. He has utilized extensively simulation techniques in harbour terminals, maritime trading and sailboat racing sectors. He has been actively involved in the scientific community from several years and served as Director of the McLeod Institute of Simulation Science (MISS), Associate Vice-President and Member of the Board of the SCS (Society for Modelling & Simulation international), President of the Liophant Simulation, VicePresident of MIMOS (Movimento Italiano di Simulazione) and Italian Point of Contact for the ISAG (International Simulation Advisory Grouyp) and Sim-Serv. He has written more than 150 scientific papers in addition to technical and professional reports in partnerships with major companies (i.e. IBM, Fiat Group, Contship, Solvay) and agencies (i.e. Italian Navy, NASA, National Center for Simulation, US Army). He teaches "Project Management" and "Industrial Logistics" at the University for students in the Mechanical Engineering (4th year), Management Engineering (4th year) and Logistics & Production Engineering (3rd Year) Degree Courses. His Web-page can be found at http://www.liophant.org/liophant/memb/agostino.html

Antonio Cimino took his degree in Management Engineering, summa cum Laude, in September 2007 from the University of Calabria. He is currently PhD student at the Mechanical Department of University of Calabria. He has published more than 20 papers on international journals and conferences. His research activities concern the integration of ergonomic standards, work measurement techniques, artificial intelligence techniques and Modeling & Simulation tools for the effective workplace design. His e-mail address is: acimino@unical.it and his Web-page can be found at http://www.ingegneria.unical.it/impiantiindustriali/index_file/Cimino.htm

Francesco Longo received his Ph.D. in Mechanical Engineering from University of Calabria in January 2006. He is currently Assistant Professor at the Mechanical Department of University of Calabria and Director of the Modelling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES). He has published more than 80 papers on international journals
and conferences. His research interests include Modeling & Simulation tools for training procedures in complex environment, supply chain management and security. He is Associate Editor of the "Simulation: Transaction of the society for Modeling & Simulation International". For the same journal he is Guest Editor of the special issue on Advances of Modeling & Simulation in Supply Chain and Industry. He is Guest Editor of the "International Journal of Simulation and Process Modelling", special issue on Industry and Supply Chain: Technical, Economic and Environmental Sustainability. He is Editor in Chief of the SCS M&S Newsletter and he works as reviewer for different international journals. His e-mail address is: f.longo@unical.it and his Web-page can be found at http://www.ingegneria.unical.it/impiantiindustriali/index_file/Longo.htm

Giovanni Mirabelli is currently Assistant Professor at the Mechanical Department of University of Calabria. He has published more than 60 papers on international journals and conferences. His research interests include ergonomics, methods and time measurement in manufacturing systems, production systems maintenance and reliability, quality. His e-mail address is: g.mirabelli@unical.it and his Web-page can be found at
http://www.ingegneria.unical.it/impiantiindustriali/index_file/Mirabelli.htm

A 256 VARIABLE NONLINEAR TRANSPORTATION PROBLEM

William Conley

Austin E. Cofrin Business School
University of Wisconsin Green Bay 54301 U.S.A.

conleyw@uwgb.edu

ABSTRACT

The classic mathematical transportation problem which is presented in most operations research or industrial engineering courses involves shipping from a number of warehouses to a number of customers, where the shipping costs are linear. The idea being if it costs one euro dollar to ship one unit, from location A to location B, it will cost 100 euro dollars to ship 100 units from warehouse A to customer B. These linear assumptions (for all the shipping costs) are usually made so that various linear programming techniques (simplex and other linear approaches) can be used to efficiently solve the overall optimization problem. However, in the practical business world of large scale shipping there are usually considerable returns to scale (nonlinear costs) associated with the deliveries to customers. Therefore, an example of this kind is presented here and solved using simulation techniques.

Keywords; nonlinear transportation problem, Monte Carlo

1. INTRODUCTION

Specifically the example presented involves shipping a product from 16 warehouses to 16 preferred customers where each of the 16X16=256 shipping routes has a different nonlinear cost structure, which reduces the unit shipping costs from warehouse I to customer J as the number of units shipped increases.

The example here has between 525,000 and 600,000 units (in various amounts) of the product stored in the 16 locations and the customer demands are for between 525,000 and 600,000 units (in different amounts) at each destination. Also, the total supply equals the total demand in this case (which is usually true in the long run). However, the supply rarely equals short term demand in the real world and the MSMCO simulation approach can be modified to deal with some less than or greater than constraints rather than equations, if supplies and demands are not balanced.

2. THE SAMPLE CASE STUDY

We define 256XIJ variables, where XIJ is the amount of product leaving a warehouse I and heading to customer J. We also have 16 equations for the XIJ values leaving each warehouse, plus 16 equations for the XIJ values arriving at the 16 preferred customers in the correct amounts they ordered. Additionally, we have a nonlinear cost equation. Although it may cost one euro dollar to ship one unit of product, it may cost a lot less than 100 euro dollars to ship 100 units. Therefore, the 256 variable nonlinear transportation problem (with discounts for bulk shipping) is solved with the multi stage Monte Carlo optimization (Conley, 2003) simulation technique. The shipping company's goal is to reduce the overall shipping costs that were running in the 1.5 to 2 million euro dollars range down to about one million euro dollars. Therefore, the right hand side of the cost equation is set at one million euro dollars. The other 32 equations are in units of product shipped. We use multi stage Monte Carlo optimization (MSMCO) to try to minimize the sum of the absolute values of the differences between the left and right hand side of the 33 equations. This will approximately solve the system. The multi stage Monte Carlo system makes repeated solution attempts in an ever moving and decreasing in size feasible solution region following a trail of better and better answers (lower total error) though 257 dimensional spaces. The cost equation is C=ΣΣ7.+.05*(i+j)*(x(i+j))**(.6+.01*(i+j)) = 1000000 where i=1,2, …16 and * is multiply and ** is raise to a power.

Specifically, for our 33 equation 256 variable system (transformed into a 257 dimensional optimization problem) 40,000 random sample answers are looked at in stage one and the best one (stored and printed) had a total error in all 33 equations of 119,996,528. Then stage two looked at another 40,000 sample answers in a reduced region initially centered at the best answer from stage one. This produced a new best answer of 114,673,528. Then stage three similarly does another 40,000 sample solutions reducing the error further.

Even though these initial "discovery" stages have very high total errors, by stage 50 the total error is down to 34. The 256XIJ values produced in stage 50 solved all 32 of the warehouse and customer equations and had a 34 euro dollar error in the cost control equation where the goal was a cost of one million euros.

This simulation took about 3 minutes to run the 50 x 40,000 = 2,000,000 function evaluations on an inexpensive desk top PC. The complete printout of the total errors of the 50 stage MSMCO (multi stage) simulation is in Table 1. Tables 2 and 3 present the other relevant parts of the answer.

3. THE ANSWER PRINTOUTS

Table 1 (as mentioned) presents the 50 stage printout of the total errors. They are very high in the early discovery stages of the MSMCO simulation run. However, once they start to track a good answer the error terms start dropping dramatically to a 33+ Euro dollar cost error and a virtual zero, error (.5 unit total) on all of the 32 leaving and arriving equations. The tables follow here.

Table 1: The Stage Errors

Stage Number	Total Errors
1	119996528.0000
2	114673528.0000
3	101945352.0000
4	93896400.0000
5	84041472.0000
6	67086016.0000
7	51818592.0000
8	30441744.0000
9	18462332.0000
10	10419225.0000
11	4611007.0000
12	1350197.2500
13	829315.1875
14	470044.2813
15	235782.6875
16	158225.0000
17	85789.7500
18	69592.3125
19	44407.7500
20	36262.8125
21	20031.7500
22	14905.0625
23	10706.0625
24	7548.3125
25	4448.8750
26	3890.5625
27	2486.1250
28	1994.3125
29	1264.9375
30	909.5000
31	714.6875
32	516.1250
33	409.8125
34	300.6250
35	229.2500
36	150.5000
37	120.0000
38	99.5000
39	79.3125
40	64.7500
41	58.4375
42	47.9375
43	44.8125
44	40.5000
45	39.1250
46	37.8125
47	36.6250
48	36.2500
49	35.1250
50	33.0625

Table 2 presents the number of units shipped from each warehouse to each customer. The 16 numbers in the 1 grouping represent the unit shipping amounts leaving warehouse 1 and bound for customers 1 through 16 (reading left to right top to bottom in the grouping labeled one). They add up to 600,000 units. The 16 numbers in the 2 groupings represent the unit shipping amounts leaving warehouse 2 and bound for customer 1 through 16 (reading left to right top to bottom in the grouping labeled two). They add up to 595,000 units (and so on for the other 14 warehouses).

Taking the upper left hand entry in each of the 16 groupings and adding them up gives you the 525,000 total units bound for customer 1 that come from warehouses 1 through 16 (and so on).

Table 2: The Shipping Amounts

	Column 1	Column 2	Column 3	Column 4
1	44592.266	28204.779	24779.855	38818.793
1	44660.852	42474.914	36898.750	8789.456
1	24376.973	32607.883	44095.602	35170.844
1	47782.434	107502.773	32258.361	6985.296
2	860.316	4483.140	52095.824	4920.257
2	55721.340	41307.066	19379.221	13734.656
2	15755.903	10778.478	37142.035	84397.047
2	134475.094	33806.871	67846.141	18296.627
3	14016.597	82811.031	33526.914	3709.981
3	2007.490	14209.472	475.354	57077.633
3	60822.930	65550.570	14076.178	48264.734
3	49168.039	10770.127	104711.500	28801.520
4	55947.031	50030.691	134804.719	45923.613
4	12304.259	16243.791	28020.822	2435.157
4	10291.113	78165.891	36343.551	1473.928
4	28673.438	3491.757	38109.355	42740.895
5	2080.985	12592.176	105.309	166457.266
5	17227.412	40241.980	29042.160	14684.987
5	25134.654	10384.798	57884.641	64610.441
5	31199.455	32094.121	23535.330	52724.262
6	1486.628	27140.459	36218.969	15398.490
6	2398.268	38748.012	45646.762	17540.447
6	14546.153	52363.535	38594.148	28070.598
6	3121.571	86585.625	33644.195	133496.156
7	266746.000	17605.098	9369.590	15545.590
7	11775.452	47188.070	30555.365	18927.512
7	8619.394	15634.977	921.640	55111.660
7	888.766	4657.088	61295.070	5158.753
8	16740.145	4613.849	15247.325	986.281
8	30984.273	22648.006	105562.391	5193.723
8	11082.579	112332.195	72157.844	72018.586
8	5704.437	28591.939	30635.119	30501.340
9	23591.436	2920.417	83545.125	23442.521
9	71350.711	7149.650	6071.913	28681.975
9	105054.766	29472.561	1399.122	25688.439
9	98983.820	1544.764	22257.094	28845.840
10	2816.591	9420.608	17896.875	38675.965
10	80396.500	30036.746	88567.492	3042.466
10	31810.510	4844.226	153020.750	13448.157

10	5353.755	70741.266	94.583	4833.566
11	17829.125	81727.445	16869.154	6623.472
11	13223.104	13930.215	13169.904	8801.730
11	117752.563	34185.121	33070.383	12759.497
11	22923.820	58233.043	32604.734	66296.680
12	4566.582	19541.547	2702.872	7670.750
12	39572.512	48614.906	13704.979	162585.531
12	54835.453	4228.451	10454.256	3485.226
12	89607.859	46765.195	14803.914	21860.117
13	7547.889	15834.984	4474.897	14508.642
13	64135.563	151853.094	12974.294	74015.195
13	16960.918	307.568	23610.848	18164.500
13	18629.258	8608.676	45110.926	63262.758
14	10455.435	103111.766	1596.627	113677.133
14	27811.521	6396.921	6037.331	26470.602
14	5542.942	57488.332	30804.586	65985.578
14	1965.880	18959.227	24096.121	34599.902
15	29200.139	57121.152	59628.168	27809.139
15	10280.215	28387.352	96994.922	34976.105
15	47973.891	420.451	12072.192	37972.953
15	11927.979	30296.170	19933.180	25006.080
16	26522.867	12840.830	42137.781	15832.064
16	61150.555	569.841	21898.381	83042.867
16	14439.232	61235.004	9352.340	13377.782
16	34594.410	47351.375	44064.352	36590.328

Table 3 gives the individual equation errors for the 32 leaving and arriving units followed by the cost equation error 33+ Euros in the left column. The right hand column gives the right hand side constants on all 33 equations.

Table 3: Error on Left Constants on Right

Equation Errors	Right Hand Side
0.00000	525000.00000
0.00000	530000.00000
0.00000	535000.00000
0.00000	540000.00000
0.00000	545000.00000
0.00000	550000.00000
0.00000	555000.00000
0.00000	560000.00000
0.00000	565000.00000
0.00000	570000.00000
0.06250	575000.00000
0.00000	580000.00000
0.00000	585000.00000
0.00000	590000.00000
0.00000	595000.00000
0.06250	600000.00000
0.12500	600000.00000
0.00000	595000.00000
0.00000	590000.00000
0.00000	585000.00000
0.00000	580000.00000
0.00000	575000.00000
0.00000	570000.00000
0.00000	650000.00000
0.06250	560000.00000
0.00000	555000.00000
0.00000	550000.00000
0.06250	545000.00000
0.00000	540000.00000
0.06250	535000.00000
0.00000	530000.00000
0.00000	525000.00000
33.06250	1000000.00000

4. LINEAR VERSUS NONLINEAR SHIPPING COSTS

Linear programming was developed in the early to mid 20^{th} century as a result of the well-developed theory of linear algebra for solving systems of equations. It involves solving linear equations and/or inequalities while heading to the goal of optimizing an objective function subject to linear constraints (equations and inequalities). The key result that made this type of multivariate linear optimization possible is the fundamental theorem of linear programming which states that the optimal solution is at a “corner point” in the feasible solution space. This solution technique is great for small or large scale (number of variables) shipping problems that are truly linear in nature or can at least be reasonably approximated with a linear system.

The difficulty of course is that many shipping problems are multivariate and nonlinear with constraints and these are more difficult to solve. A fundamental theorem of nonlinear programming (if it existed) would say that the optimal solution could be anywhere in the feasible solution space (at a corner point or in the interior of the feasible solution spaces).

That is why simulation based multivariate nonlinear optimization techniques such as multi stage Monte Carlo optimization (MSMCO) can be useful when other techniques do not work or are not available.

5. MULTI STAGE MONTE CARLO OPTIMIZATION

The multi stage (MSMCO) simulation technique randomly looks around the entire feasible solution space in stage one and samples several thousand feasible solutions and stores and prints the best answer so far. That is the traditional Monte Carlo (or random) optimization technique. However, with MSMCO that is just stage one. Then centered about this best answer so far, stage two looks at thousands more feasible solutions in a slightly reduced search region and stores and prints its “best answer” so far. Then stage three in a slightly more reduced region centered about the stage two best answers repeats this process. Our particular example here did a 50 stage MSMCO simulation. It started with huge error terms in the early stages. However, by stage 50 it had produced a useful answer to a 33 by 256 nonlinear system.

This type of program can be run quickly on the modern inexpensive desk top computer available in our 21^{st} century. Some additional applications of multi stage Monte Carlo optimization (MSMCO) to various shipping problems are in (Conley 2003). More general applications of the MSMCO technique are in (Wong 1996) and (Conley 2008). It is a fairly versatile approach to general nonlinear optimization problems. The problems are more difficult to solve as the number of variables increases. However, computer speeds help with that difficulty.

REFERENCES

Conley, W. C., 2003. "The TSP Statistics and total quality management and shipping." Proceedings of the International Workshop on Harbour, Maritime, and Multimodel Logistics Modeling and Simulation (Sept, 2003, Riga Latvia) Riga Technical University, 53-57.

Conley, W. C., 2008. "Ecological optimization of pollution control equipment from a planning and simulation perspective." *International Journal of Systems Science*, Vol. 39, No. 1, 1-7.

Wong, J. Y., 1996. "A Note on optimization in integers." *International Journal of Mathematical Education in Science and Technology*, Vol. 27, No. 6, 865-874.

AUTHOR BIOGRAPHY

William Conley received a B.A. in mathematics (with honors) from Albion College in 1970, an M.A. in mathematics from Western Michigan University in 1971, a M.Sc. in statistics in 1973 and a Ph.D. in mathematics-computer statistics from the University of Windsor in 1976. He has taught mathematics, statistics, and computer programming in universities for over 30 years. He is currently a professor emeritus in Business Administration and Statistics at the University of Wisconsin at Green bay. The developer of multi stage Monte Carlo optimization and the CTSP multivariate correlation statistics, he is the author of five books and 203 publications world wide. He is a member of the American Chemical Society, a fellow in the Institution of Electronic and Telecommunication Engineers and a senior member of the Society for Computer Simulation.

DISPATCHING OF MULTIPLE SERVICE VEHICLES IN THE DYNAMIC-DIAL-A-RIDE PROBLEM

Thomas Pickles[a], Barış Balcıoğlu[b], Beno Benhabib[c]

[(a) (b) (c)] University of Toronto
Department of Mechanical & Industrial Engineering
5 King's College Road Toronto ON M5S 3G8 Canada

[(a)] tom.pickles@utoronto.ca, [(b)] baris@mie.utoronto.ca, [(c)] beno@mie.utoronto.ca

ABSTRACT

Dispatching of multiple service vehicles is studied for the Dynamic Dial-A-Ride Problem (Dynamic DARP). In the Dynamic DARP service vehicles transport demands from pick-up to drop-off locations which are both independently and uniformly distributed within a unit square service region. Three policies are compared: First Come First Serve (FCFS), Nearest Neighbour (NN), and Dynamic Nearest Neighbour (DNN). Simulation results show NN outperforms FCFS by margins of up to 40%, and DNN provides further improvements up to 10% over NN. Analytical approximations are then developed for the multiple vehicle FCFS policy and the single vehicle varying velocity NN policy. The service environment is then expanded to more realistic city-like conditions. Simulation results confirm the relative policy performance holds. Finally, anticipatory vehicle routing is applied such that idle service vehicles are proactively routed. Anticipatory routing provides up to an 18% improvement over the reactive policies.

Keywords: Dynamic Vehicle Routing, Policy Comparisons, Approximations, Simulation

1. INTRODUCTION

The Vehicle Routing Problem (VRP) is defined in simple terms as seeking to serve a number of customers with a fleet of vehicles in an effective and efficient manner. Due to its practicality and wide range of applications the VRP has attracted considerable academic attention. Traditionally, studies have focused on static and deterministic versions of the problem using a set of predetermined demand locations (Xu, 1994). However, in reality, demands (customers or objects) often arrive randomly in time and therefore require continuous dispatching processes (Bertsimas and Van Ryzin, 1991). In most routing situations the problem is inherently dynamic and stochastic in nature. Furthermore, the classical objective of VRPs, to minimize travel distance and associated direct travel costs, may not always prove to be the most important factor. In many dynamic situations, such as the ones mentioned above, minimizing the wait for service time is more important than minimizing travel cost.

Bertsimas and Van Ryzin (1991) were the first to study a dynamic and stochastic version of the VRP. The authors introduced the Dynamic Travelling Repairman Problem (DTRP) with the objective of minimizing the wait for service. The DTRP is defined as follows: demands arrive in time according to a Poisson process in a uniformly distributed random location within a Euclidean region. The demands are then serviced at that location for an independent and identically distributed amount of time by a single repair vehicle which travels to the demands with constant unit velocity. The authors analyzed several solution policies: First Come First Serve (FCFS), Partitioning (PART), Travelling Salesman Policy (TSP), Space Filling Curve (SPC), and Nearest Neighbour (NN). Of particular interest for this paper are the FCFS and NN policies. FCFS is the simplest policy where demands are serviced in the order in which they arrive. In the NN policy, the demand closest to the service vehicle is serviced first, independent of the order in which the demand arrived. For the single server DTRP under heavy traffic conditions the NN policy was shown to perform with the lowest average system time. Bertsimas and Van Ryzin (1993) extended the DTRP to the multiple service vehicle case but were primarily concerned with developing analytical system bounds and thus did not conduct further trials of the NN policy. Ozesenli and Demirel (2005) used simulation for the DTRP in a more realistic city-like environment in which the repairman will not have a constant velocity and proposed the Shortest Arrival Time (SAT) policy.

An extension to the DTRP is the Dynamic Pick-up and Delivery Problem (DPDP) where the service vehicle must transport each demand between an origin and a destination. The primary difference between the DPDP and the DTRP is that in the DTRP the vehicle spends time at the location of each demand to serve it and thus does not change location during service, but in the DPDP the vehicle transports the demand and thus does change location during service.

The one-to-one DPDP can be further subdivided into the Dynamic Stacker Crane Problem (Dynamic SCP), Dynamic Vehicle Routing Problem with Pick-up and Deliveries (Dynamic VRPPD), and the Dynamic Dial-A-Ride Problem (Dynamic DARP) (Berbeglia, Cordeau and Laporte, 2010). The Dynamic SCP deals with optimizing a trucking fleet to move full truck loads directly from its pick-up to delivery location. The Dynamic VRPPD applies when vehicles can serve more than one request at the same time and is normally applied to courier services. Of particular interest to this paper is the Dynamic DARP where requests consist of users that need to be transported from a pick-up location to a drop-off location. Typical applications of Dynamic DARP include taxi services in cities (Berbeglia, Cordeau and Laporte, 2010).

The Dynamic DARP was introduced by Swihart and Papastavrou (1999) with the objective to minimize the expected time in the system for demands. The problem definition is analogous to that of Bertsimas and Van Ryzin (1991) with the alteration that each demand must be transported to independent and uniformly distributed delivery locations, which are independent of the pick-up locations. Three policies were compared: Sectoring, Stacker Crane, and Nearest Neighbour (NN). As in the DTRP, the NN policy delivered the lowest system times under heavy traffic conditions for the Dynamic DARP. Xiang, Chu, and Chen (2008) introduced several constraints, such as break down of vehicles, scheduled and dynamic arrivals, maximum work time for each driver, etc., in the DARP problem in which demand and delivery points are the vertices of a network.

This paper explores various policies for the Dynamic DARP with the primary objective being to minimize system time. In particular, various policies are first explored and compared in a simple base case scenario. Next, analytical expressions are derived for certain policies such that full simulations need not be run to obtain ballpark results. The policies are then applied to a more realistic city-like region to test if the relative performance holds under such conditions. Finally, anticipatory behaviour is explored to examine if its use results in improved performance.

2. POLICIES

The three policies studied in this paper are now described in detail.

2.1. First Come First Serve (FCFS)

In FCFS demands are simply served in the order in which they arrive in the system. If multiple vehicles are idle, the demand is serviced by a random vehicle. Idle service vehicles remain in their current location.

2.2. Nearest Neighbour (NN)

In NN the demand closest to the vehicle is serviced first, independent of the arrival order. Specifically, if there is more than one customer waiting a vehicle that drops off a demand will next service the demand with the pick-up location that is the smallest distance from the service vehicle's current location. If a new demand arrives and multiple service vehicles are idle, the demand is serviced by the nearest vehicle. Conversely, if there are no idle vehicles the demand must wait for service until it is the nearest demand to a newly idle vehicle. Once a service vehicle has been assigned to a demand it cannot be rerouted until the demand reaches its drop-off location.

2.3. Dynamic Nearest Neighbour (DNN)

The DNN policy is similar to NN with some minor adjustments. Again, demands are serviced by the nearest vehicle, independent of the arrival order. However, unlike NN, under certain circumstances service vehicles can be rerouted to a new demand without completing service for the existing demand.

Before entering a more detailed explanation, the necessary terminology is introduced. A service vehicle is said to be 'assigned' when it is travelling towards a demand's pick-up location. A vehicle is 'busy' when it has picked up the demand and is travelling between the pick-up and drop-off locations. If a new demand arrives and there are no idle service vehicles, the demand may be serviced by an 'assigned' vehicle if the new demand is closer to the 'assigned' vehicle than the currently assigned demand. If the new demand satisfies this criterion for more than one 'assigned' service vehicle, the new demand is serviced by the vehicle which is nearest to it. The service vehicle is re-assigned from the current demand to the new one, and changes its travelling direction towards the new demand. The dropped demand remains where it is and is now treated as any other waiting demand. This process is referred to as a 'vehicle assignment reroute'. However, if when the new demand arrives there are one or more idle vehicles the new demand is always serviced by the nearest idle vehicle regardless of the location of any 'assigned' vehicles. As in NN, when a service vehicle becomes newly idle it is 'assigned' to the nearest waiting demand. It is important to mention that despite its name the DNN is only a partially dynamic policy

3. COMPARISON OF BASE CASE POLICIES

As a basis for discussion, an understanding of the relative performance of the three policies in the basic environment as defined by Swihart and Papastavrou (Swihart and Papastavrou 1999) is required. This chapter summarizes the performance of the FCFS, NN, and DNN policies, but first begins with a detailed problem definition of the base case.

3.1. Problem Definition

The service vehicles are located in a square region of area A=1. The demands for service arrive randomly in time according to an exponential distribution with arrival rate λ. The expected time between arrivals is defined as $x=1/\lambda$. The demand pick-up locations are independently and uniformly distributed within the square region. The drop-off locations are also independently and uniformly distributed and are independent of the pick-up locations. The distances between locations are defined in the Euclidean plane. In the base case the service vehicles travel with a constant unit velocity and they travel in a straight path between locations (i.e., there are no roads). Under these conditions, distance and time are equivalent. When a service vehicle is idle it remains in its current location. The number of service vehicles is denoted by N, where N=1 for the single vehicle case and N>1 for the multiple vehicle cases.

The service time, s, is defined from when the service vehicle begins travelling to the demand's pick-up location until the demand reaches its drop-off location. The service time consists of two components: s_w, the time the service vehicle spends travelling to the demand's pick-up location, and s_t, the time the service vehicle spends transporting the demand between the pick-up and drop-off location. Thus, $s = s_t + s_w$. The rate of services is defined as $\mu = 1/s$. Wait time, W, is equal to the time from when the demand arrives until the service vehicle begins travelling towards its pick-up location. The actual wait time of the demand until the service vehicle arrives is expressed as $W + s_w$. The total system time, T, is defined from the instant the demand arrives until it reaches its drop-off location. Therefore, $T = s + W$. The overall objective is to minimize the system time, T.

The utilization, ρ, of an individual service vehicle is defined as the proportion of the time the vehicle is servicing a demand relative to the overall time. Utilization under the FCFS policy is related to the arrival and service rates by

$$\rho = \frac{\lambda E[s]}{N} = \frac{\lambda}{\mu N} \tag{1}$$

For the system to remain stable, ρ must remain less than one. The utilization is closely related to the traffic intensity (arrival rate) of the system (Xu, 1994). In general, the greater the traffic intensity the larger the value of ρ.

3.2. Results

The simulation results comparing the system times of the FCFS, NN, and DNN policies for the cases of 1, 10, 20, and 100 service vehicles are considered. Under all four cases the NN and DNN policies significantly outperform the FCFS policy. Furthermore, DNN shows a small improvement over NN. For all three policies the system becomes more efficient as the number of vehicles increases. The relative performance of the policies is examined further, beginning with a comparison between NN and FCFS, followed by DNN and NN.

3.2.1. Comparison of NN to FCFS

The NN policy outperforms the FCFS policy by different magnitudes depending on the arrival rate and the number of service vehicles. The relative performance of the two policies is compared in Figure 1.

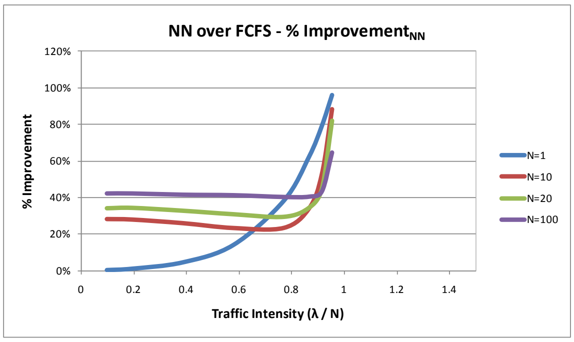


Figure 1: System Time Percent Improvement for NN Over FCFS

The typical improvement of NN over FCFS ranges from around 25% to 40%, but it increases exponentially near the FCFS traffic intensity limit. At lower arrival rates the improvement is greater for a larger number of vehicles. However, in the single vehicle case the improvement of NN over FCFS continually increases as λ increases while in the multiple vehicle cases it is fairly steady until asymptotic behavior. Furthermore, it appears that as N increases the relative performance becomes less affected by the arrival rate.

It is also of interest to examine the variation in the service time, s, for the NN policy as the number of vehicles changes. The results are summarized in Figure 2.

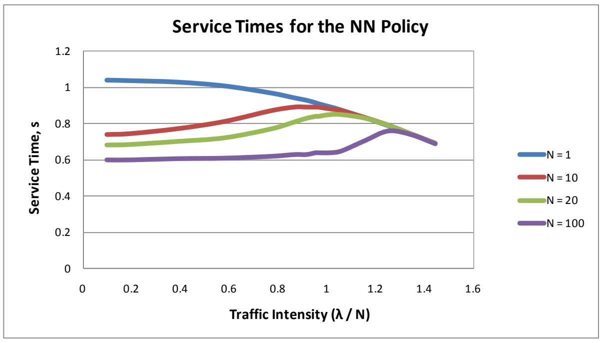


Figure 2: Service Times for NN Policy

The single vehicle case behaves as one would expect. As λ increases the service time decreases. With more customers in the system to choose from, the service vehicle finds demands that are, on average, nearer to the vehicle's current location thus decreasing s_w and therefore s. However, for the multiple vehicle case the results are more interesting. As λ increases, s also increases until some critical point where s then behaves as in the single vehicle case. A potential explanation for this phenomenon is that with low arrival rates there are typically several idle vehicles when each demand arrives. Since the nearest vehicle is selected for service, s_w will be less than 0.52 (mean distance between two points independently generated uniformly distributed points in the unit square). As λ increases there are fewer idle vehicles on average and thus s_w increases. Once λ becomes large enough, the controlling factor shifts from the number of idle vehicles to the number of demands in the system. At this point each newly available vehicle has multiple demands to choose from so s_w once again begins to decrease. It should also be noted that as N increases the critical value of λ also increases.

3.2.2. Comparison of DNN to NN

In order to understand the incremental gains of DNN over NN it is logical to compare DNN directly to NN rather than to FCFS. This comparison is summarized in Figure 3.

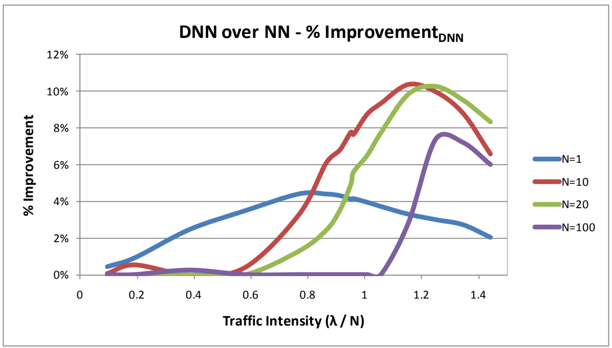


Figure 3: System Time Percent Improvement for DNN Over NN

The maximum improvement of DNN over NN ranges from around 4% to 10% depending on the number of service vehicles. With a single service vehicle the maximum improvement is a modest 4%. With 10 or 20 vehicles the improvement reaches a maximum of just over 10% and in the 100 vehicle case the improvement retreats to just under 8%.

It is also worth explaining the hill shapes of the improvement curves. At low arrival rates the DNN system times converge to those of NN. With large times between arrivals and many idle vehicles there is likely an idle vehicle close to a new customer and it is extremely unlikely for a vehicle assignment reroute to occur. As a result there is practically no difference in the behaviour of the two policies. But as the arrival rate increases the number of vehicle assignment reroutes also increases and at some point a difference between the policies can be seen. It should be noted that the greater the number of service vehicles the higher the critical traffic intensity point where the difference is first noticed. The greater the arrival rate the more assignment reroutes that occur in the DNN policy and the average s_w decreases as vehicles are picking up more newly arriving nearer customers. At some point the improvement reaches a maximum and then begins to decline because of the impact of a second factor. With larger arrival rates there are many customers awaiting service. It is likely that any newly idle cab will be near a currently waiting customer decreasing the chances of a beneficial vehicle assignment reroute. As the traffic intensity continues to increase fewer and fewer reroutes occur and the improvement declines.

4. ANALYTICAL APPROXIMATION OF POLICY PERFORMANCE

In addition to the simulated results, it would be valuable to derive analytically the expected policy performance. This is first done in detail for the FCFS policy followed by approximations of the NN policy.

4.1. Analytical Derivations for FCFS System Time

It is desired to develop analytical expressions to estimate the system times for the FCFS policy. The discussion begins with the single vehicle unit velocity case, followed by a varying velocity service vehicle and finally multiple service vehicles.

4.1.1. FCFS Single Service Vehicle with Unit Velocity

The expected service and system times for the single vehicle FCFS case are derived analytically. The approach is analogous to that used in Bertsimas and Van Ryzin (Bertsimas and Van Ryzin 1991), but modified for the Dynamic DARP case.

Larson and Odoni (1981) define geometric probability as follows: Given two uniformly and independently distributed points Y_1 and Y_2 in a square of area A, then

$$E[Y_1 - Y_2] = c_1\sqrt{A} \quad E[Y_1 - Y_2] = c_1\sqrt{A}$$

$$E[(Y_1 - Y_2)^2] = c_2 A \tag{2}$$

where $c_1 \sim 0.52$ and $c_2 = 1/3$

The expected service time can be written as follows

$$E[s] = E[s_w] + E[s_t] \tag{3}$$

where both $E[s_w]$ and $E[s_t]$ are equal to the expected distance between two uniformly distributed points in a square area and therefore follow Eq. (2) such that

$$E[s_w] = c_1\sqrt{A} = 0.52\sqrt{1} = 0.52$$
$$E[s_t] = c_1\sqrt{A} = 0.52\sqrt{1} = 0.52 \tag{4}$$

Then the expected service time is shown as follows

$$E[s] = c_1\sqrt{A} + c_1\sqrt{A} = 2c_1\sqrt{A} = 2(0.52)\sqrt{1} = 1.04 \tag{5}$$

Further, the analytical expression for the expected system time in the single vehicle FCFS case can be derived. Since

$$E[T] = E[W] + E[s] \tag{6}$$

and $E[s]$ is already known, to determine $E[T]$ the expression for $E[W]$ must be derived.

The single vehicle FCFS can be modeled as an $M/G/1$ queue (Bertsimas and Van Ryzin 1991). As a result, the well-known Pollaczek-Khinchin formula (Kleinrock 1976) can be used

$$W = \frac{\lambda s^2}{2(1-\rho)} \quad (7)$$

where s^2 is the second moment of the service time.

Using Eq. (2) the variance of the service time can be expressed as

$$Var[s] = Var[s_w] + Var[s_t] = 2Var[s_t] = 2(E[s_t^2] - E[s_t]^2) = 2(c_2A - c_1^2A) \quad (8)$$

From Eq.s (5) and (8) the second moment of the service time can be shown as

$$E[s^2] = 2c_2A + 2c_1^2A \quad (9)$$

$$E[s^2] = Var[s] + E[s]^2 = 2(c_2A - c_1^2A) + \left(2c_1\sqrt{A}\right)^2 = 2c_2A + 2c_1^2A$$

By inserting Eq.s (1) and (9) into (7) the expected waiting time is then

$$E[W] = \frac{\lambda(2c_2A + 2c_1^2A)}{2(1 - 2\lambda c_1\sqrt{A})} \quad (10)$$

Therefore, from Eq.s (5), and (10) it follows that the expected system time is

$$E[T] = \frac{\lambda(2c_2A + 2c_1^2A)}{2(1 - 2\lambda c_1\sqrt{A})} + 2c_1\sqrt{A} \quad (11)$$

4.1.2. FCFS Single Service Vehicle with Varying Velocity

The derivation is then extended to the cases where the service vehicle can travel with a constant velocity of magnitude v. The service time for the FCFS policy with a service vehicle travelling at velocity v is expressed as

$$E[s] = \frac{E[s_w] + E[s_t]}{v} \quad (12)$$

Then, from Eq. (4) it is easily shown that

$$E[s] = \frac{2c_1\sqrt{A}}{v} \quad (13)$$

Using an analogous approach as to that of Eq. (9) it is easily shown the second moment of the service time equals

$$E[s^2] = Var[s] + E[s]^2 = \frac{2(c_2A - c_1^2A)}{v^2} + \frac{\left(2c_1\sqrt{A}\right)^2}{v^2} = \frac{2c_2A + 2c_1^2A}{v^2} \quad (14)$$

Again, since FCFS can be modelled with an $M/G/1$ queue the waiting time can be calculated using Eq. (7) and thus the expected system time for the varying velocity FCFS policy can be expressed as follows

$$E[T_{FCFS-VV}] = E[W] + E[s] = \frac{\lambda E[s^2]}{2(1-\rho)} + \frac{2c_1\sqrt{A}}{v} = \frac{\lambda(2c_2A + 2c_1^2A)}{2(1-\rho)v^2} + \frac{2c_1\sqrt{A}}{v} \quad (15)$$

The analytical formula underestimates the simulated results by a small margin. But the relative error is never more than 5% which is close enough to consider the results to be in agreement.

4.1.3. FCFS Multiple Service Vehicles

The varying velocity formula can now be extended to estimate the system times for the multiple vehicle FCFS case. First, it is assumed that the ratio of the expected waiting time to the probability the waiting time is greater than zero for the multiple vehicle case is equal to the equivalent ratio for the varying velocity case. This is expressed as follows

$$\frac{E[W_{FCFS-Multi}]}{P\{W_{FCFS-Multi} > 0\}} \cong \frac{E[W_{FCFS-VV}]}{P\{W_{FCFS-VV} > 0\}} \quad (16)$$

The individual terms of Eq. (16) are each explained, beginning with the probability of the waiting time being greater than zero for the varying velocity case. This term is simply equal to the utilization and is therefore solved as follows

$$P\{W_{FCFS-VV} > 0\} = \rho = \lambda E[s] = \frac{2\lambda c_1\sqrt{A}}{v} \quad (17)$$

Furthermore, the waiting time for the varying velocity case is defined previously within Eq. (11). Lastly, the term representing the probability that the wait time is greater than zero for the multiple vehicle FCFS case is more difficult to solve. An exact solution is not known but it can be represented using $M/M/N$ queue with the same λ and μ. The probability then becomes an Erlang C distribution expressed as

$$P\{W_{FCFS-Multi} > 0\} \cong C(N, \lambda) \quad (18)$$

where N is the number of service vehicles.

The expected waiting time for the multiple vehicle FCFS are then estimated as

$$E[W_{FCFS-Multi}] \cong C(N, \lambda) \times \frac{\frac{\lambda(2c_2A + 2c_1^2A)}{2(1-\rho)v^2}}{\rho} \quad (19)$$

And then the expected system time can be expressed as

$$E[T_{FCFS-Multi}] \cong C(N, \lambda) \times \frac{\frac{\lambda(2c_2A + 2c_1^2A)}{2(1-\rho)v^2}}{\rho} + 1.04 \quad (20)$$

For most cases the error between the simulated and analytical results hovers around 2% and even in the extreme case the maximum error is no more than 6%. This is certainly close enough to consider Eq. (20) to be an accurate analytical approximation of the expected system times for the FCFS policy with multiple service vehicles travelling at a constant unit velocity (see

Jagerman and Melamed, 2003 for the basis of this approximation).

4.2. Analytical Approximations for NN Single Service Vehicle

It would be desirable to also derive analytical expressions for the system times of the NN policy, but due to the unknown service distance this becomes a very difficult exercise. However, it is feasible to develop approximate analytical expressions based on coefficients derived from initial simulation runs. This is first done for the NN single vehicle varying velocity policy. The discussion begins with a derivation based on the unit velocity case and then the results are extended to the situation with a service vehicle travelling at a non-unit velocity.

4.2.1. NN Single Vehicle with Unit Velocity

In their work on the multiple m-vehicle infinite capacity DTRP, Bertsimas and Van Ryzin derive upper bounds for system time performance (Bertsimas and Van Ryzin 1993). Both light traffic and heavy traffic bounds are presented, with the heavy traffic bound being of interest here.

Bertsimas and Van Ryzin define the utilization of the service vehicle differently than in this paper. To avoid confusion the Bertsimas and Van Ryzin utilization is dubbed *r* and is defined as

$$r = \lambda E[s_t] \cong 0.52\lambda \qquad (21)$$

The heavy traffic ($r \rightarrow 1$) lower bound can then be expressed as

$$T^* \geq \gamma^2 \frac{\lambda A}{m^2 v^2 (1-r)^2} - \frac{E[s_t](1-2r)}{2r} \qquad (22)$$

where $\gamma \geq \frac{2}{3\sqrt{2\pi}} \cong 0.266$

While the γ constant derived for the DTRP cannot be applied directly, Eq. (22) can be suited to the Dynamic DARP.

First, for convenience, part of Eq. (22) is defined separately and is termed *K*,

$$K = \frac{\lambda A}{(1-r)^2} \qquad (23)$$

It follows that there is a linear relationship between *K* and the system times for the single vehicle unit velocity NN policy. The R^2 value of 0.9986 validates the linear regression fit is a good one. Given this relationship it stands that with the correct coefficients for slope, *a*, and *y*-intercept, *b*, the system time can be accurately approximated for any λ using a linear equation. Motivated by Eq. (22), the *y*-intercept is fixed as the service time and the slope is determined from simulation results such that

$$E[T] = 0.515087K + 1.04 \qquad (24)$$

The equation is verified against the simulation results. A maximum error of only 4% indicates the analytical approximation is valid.

4.2.2. NN Single Vehicle with Varying Velocity

The formula obtained from the unit velocity case can now be extended to the situation in which the service vehicle travels with a constant velocity of magnitude *v*. Simulated results could again be used to obtain the coefficients *a* and *b* for each individual velocity. However, the exercise becomes more useful if the same coefficient values apply independent of the velocity such that

$$E[T] = 0.515087\frac{K}{v^2} + \frac{1.04}{v} \qquad (25)$$

This hypothesis is tested against the simulation results for the NN single vehicle policy with velocity increases of 10 and 20 times the unit velocity. Throughout all arrival rates the error stays less than 5% indicating that the analytical approximation provides an accurate estimate of the system time. Therefore, the hypothesis is indeed correct and the coefficients obtained from the unit velocity case can be used to calculate the expected system time for the NN policy with a single service vehicle travelling at a constant velocity of magnitude *v*.

4.3. Analytical Approximations for NN Multiple Service Vehicles

It is also desired to find analytical approximations for the NN policy with multiple service vehicles travelling at a constant unit velocity. An analogous approach to the varying velocity case is used.

Ideally, as in varying velocity, it would be best if the same coefficients could be derived from the single vehicle case and applied to all other vehicle cases. Unfortunately, from experimentation it is known that this does not hold true.

Although each number of vehicles requires its own set of coefficients, it can still be shown that analytical approximations can be derived for the NN multiple vehicle policy. As an example, the case of 10 service vehicles is presented. First, it is important to understand that the relationship between *K* and the system time is no longer linear. Therefore, a quadratic polynomial must be used for the regression fit. An R^2 value of 0.9916 indicates that the second order polynomial is indeed a good fit. Therefore, the equation used for the analytical multiple vehicle system time approximation is

$$E[T] = c\frac{K^2}{N^3} + d\frac{K}{N^2} + \frac{e}{N} \qquad (26)$$

From simulation the coefficient values can be determined. For the *N=10* case the values are:

$$c = -0.000752, d = 0.67723, e = 7.3$$

Using the same method the coefficient values for other N cases can also be obtained. Here, the cases of $N=10$ and $N=20$ are examined. Again, the maximum relative error is less than 5%, further proving the regression fit is strong.

5. APPLICATION OF POLICIES IN CITY-LIKE ENVIRONMENT

The relative performance of the policies is studied under somewhat more realistic conditions, which is dubbed the "City" environment. Although this "City" model is a large simplification of an actual city, it is still believed some insight can be gained into how the policies may perform in the real world.

5.1. Description of "City" Environment

The unit square service region is divided into two halves along the vertical midpoint line. The left half is termed the *city* and the right half the *suburbs*. Both the *city* and *suburb* sections have areas of $A_c=A_s=0.5$. The total area of the region is still $A=1$.

The simulation time is divided into repeating 24 hour time chunks representing a fictitious *day*. The first 12 hours of the *day* are termed the *morning* and the second 12 hours the *evening*.

The "City" environment is constructed to emulate a simplified form of a typical city's traffic patterns. During the *morning* 50% of the demands have a pick-up location in the *suburbs* and a drop-off location in the *city*. The pick-up locations are uniformly distributed within the *suburbs* and the drop-off locations are independent of the pick-up locations and uniformly distributed within the *city* area. The other 50% of demands have pick-up and drop-off locations independent of the *city/suburb* divide as in the base case. Furthermore, there is an emulated *rush hour* period between hours 7 and 10 where the arrival rate of demands is doubled. In the *evening* the pattern is reversed such that 50% of the demands have pick-up locations in the *city* and drop-off locations in the *suburbs* and the other 50% remain independent of the *city/suburb* boundaries. The *evening rush hour* with the doubled traffic rate occurs between hours 16 and 19.

5.2. Comparison between "City" Policies

The results are compared between the policies under the "City" conditions.

5.2.1. Comparison of NN "City" to FCFS "City"

The relative performance of the NN and FCFS policies in the city-like conditions is summarized in Figure 4.

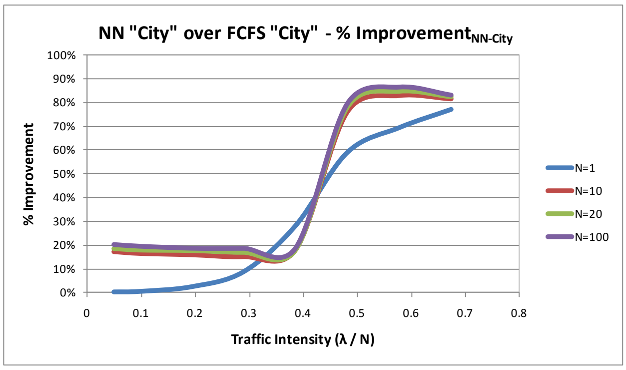


Figure 4: System Time Percent Improvement for NN "City" Over FCFS "City"

As in the base case the NN policy outperforms FCFS in the "City" environment. The improvement follows a similar shape but the differences between the number of vehicles is less pronounced. In fact, there is virtually no difference between any of the multiple vehicle cases. Furthermore, the magnitude of the improvement is slightly less under the "City" conditions. At low arrival rates the improvement hovers around 20% compared to values of 25-40% for the base case and the asymptotic behaviour is less severe in the "City" environment.

5.2.2. Comparison of DNN "City" to NN "City"

Similarly, the relative performance of the DNN and NN "City" policies is shown in Figure 5.

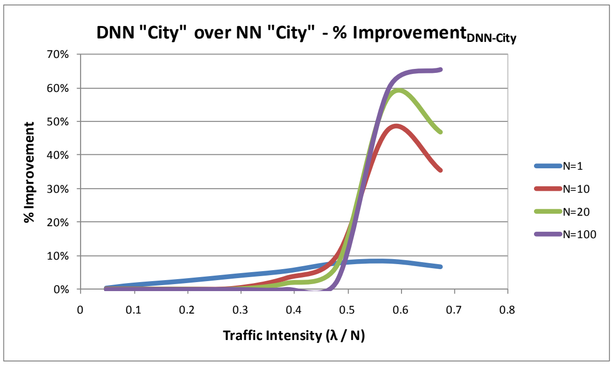


Figure 5: System Time Percent Improvement for DNN "City" Over NN "City"

The DNN "City" policy outperforms NN "City". However, here the pattern is quite a bit different from the base case. For lower traffic intensities the improvement is non-existent to very small, but at higher arrival rates the improvement spikes to 40-60% dwarfing the maximum improvement of only 10% in the base case.

The primary conclusion from the analysis is that the relative order of the policies remains unchanged in the city-like environment.

6. ANTICIPATORY BEHVAVIOUR IN CITY-LIKE ENVIRONMENT

The dynamic routing policies studied thus far show dependable performance improvements, even in the city-like conditions. However, these policies are all reactive in nature in that routing decisions are not made until a new customer arrives. What if, instead of idle taxis remaining in their current location waiting for the next call, idle taxis are routed to locations that are most likely to see new customers? Would this result in further performance improvements? Such a policy is what is referred to as anticipatory vehicle routing or, more generally, anticipatory behaviour. In essence, the goal of anticipatory behaviour is to predict, with some uncertainty, how to best distribute the vehicles throughout the service area to most efficiently serve the upcoming demands.

6.1. Description of Anticipatory Behaviour Model

The details of the anticipatory model studied are now described. The algorithm is designed in an attempt to optimize the number of service vehicles present in each sector to best meet the upcoming demand profile. For example, in the *morning* the flow of demands is from the *suburbs* to the *city*. This leaves an excess of vehicles in the *city*. Therefore, on completed service, a portion of the service vehicles are directly rerouted to the *suburbs.* In order to optimize the anticipatory routing, it is crucial that the correct proportion of vehicles be rerouted. Such a derivation of this proportion is now presented.

Consider the *morning* commute. Recall that 50% of the demands have pick-up locations in the *suburbs* and drop-off locations in the *city*, and the other 50% have random pick-up and drop-off locations. Since half of the random drop-off locations will be in the *city*, overall 75% of the vehicles will end in the *city* and only 25% in the *suburbs*. Conversely, 75% of the demands will have pick-up locations in the *suburbs* and only 25% in the *city*. With no anticipatory routing the mismatching of service vehicle locations to the demand profile is apparent.

To properly match the demand profile 75% of the total number of vehicles should be present in the *suburbs*. With 25% of the taxis already ending in the *suburbs*, 50% of the total number of service vehicles should be routed from the *city* to the *suburbs*. Therefore, in the *morning*, of the service vehicles with a drop-off location in the *city* 66.67% are rerouted back to the *suburbs* even if no specific demand is waiting. It is randomly determined which of the vehicles are rerouted. In the *evening* the logic remains the same but the pattern is reversed.

It is important to note that the preceding rules only apply when there are no customers waiting. If a service vehicle becomes newly idle and there are one or more waiting demands the vehicle is immediately sent to service a waiting demand, and therefore the anticipatory routing no longer applies. Furthermore, idle service vehicles which are travelling towards a new anticipatory location are still eligible to be assigned to incoming demands. The intermediate position of a travelling idle vehicle is dynamically updated and compared to the location of the incoming demand as would be done if the service vehicle were not moving.

An additional point centers around the policies studied with anticipatory vehicle routing. It does not seem logical to apply FCFS with anticipatory behaviour because the service order is based on arrival time rather than relative location. As a result the policy is not studied here. The NN and DNN policies are considered. Both policies behave exactly as before except for the fact that service vehicles are anticipatorily routed to better meet the upcoming demand patterns.

To route the idle vehicles an additional feature is added to the “City” conditions. Cab-stops are introduced such that when a service vehicle becomes idle it does not remain at its current position but travels to a cab-stop. The cab-stops emulate one additional real-life feature in that idle vehicles do not normally wait where their last drop-off was but instead at designated taxi waiting areas. In the model there are a total of eight cab-stops – four in the *city* and four in the *suburbs* – aligned vertically through the center of each sector. The cab-stop locations are chosen such that a uniformly distributed newly idle service vehicle has an equal probability of being nearest each of the eight stops. Each cab-stop encompasses a nearest vehicle area with a width of 0.5 and a height of 0.25.

Given the overall profile of anticipatory vehicle routing, the problem then becomes to which particular cab-stop to send each service vehicle. If a vehicle is not being rerouted to the opposite sector, it will simply travel to the nearest cab-stop. If the vehicle is being anticipatorily routed it will travel to the nearest cab-stop in the opposite sector. For example, in the *evening*, a vehicle located in the *suburbs* at (0.82, 0.46) would be sent to the nearest *city* cab-stop at (0.25, 0.375).

6.2. Comparison of Anticipatory Policies to “City” Policies

The primary goal of studying anticipatory routing is to understand the improvement, if any, it generates over the reactive “City” policies. This comparison is shown for the NN and DNN policies in Figures 6 and 7, respectively.

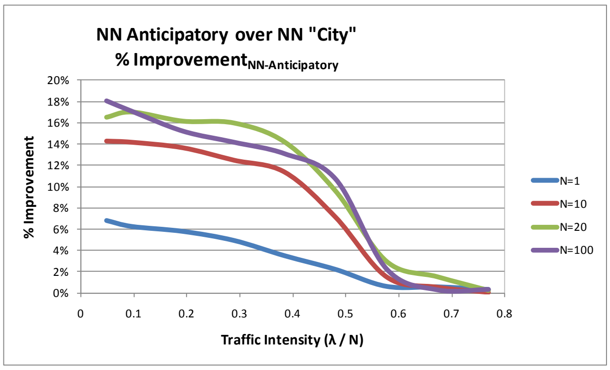


Figure 6: System Time Percent Improvement for NN Anticipatory Over NN “City”

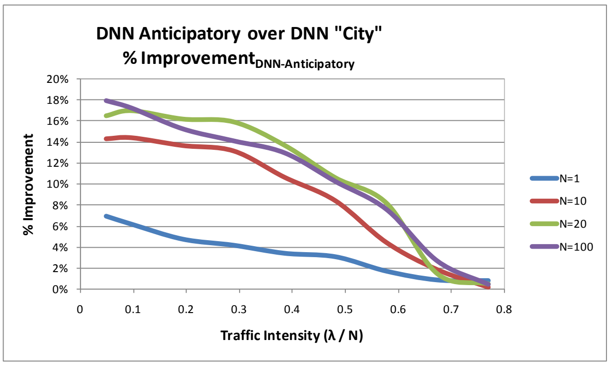


Figure 7: System Time Percent Improvement for DNN Anticipatory Over DNN "City"

The first note is that the improvement for the NN and DNN policies is very similar. This provides evidence that the effect of adding anticipatory behaviour does not significantly depend on to which of the two policies it is applied. Therefore, the performance of anticipatory behaviour is discussed in general terms.

Anticipatory vehicle routing does outperform the reactive "City" policies. While the magnitude of the improvement does not depend on the policy, it is affected by the traffic intensity and the number of service vehicles. The maximum improvement of around 18% occurs at the lowest traffic intensities. The magnitude of the improvement remains relatively constant up to medium traffic before it begins to decline more quickly. In heavy traffic the system times are statistically equal to those of the "City" policies. Furthermore, the improvement is greater for the multiple vehicle cases than the single vehicle case. The maximum improvement for $N=1$ is only around 7%. The 20 and 100 vehicles cases outperform the 10 vehicle case but the improvements for $N=20$ and $N=100$ are quite close. This suggests the magnitude of the improvement increases with number of service vehicles up to a point where it then begins to level off.

These results are not entirely surprising. It seems logical the improvement would decrease as the arrival rate increases. At low traffic intensities rerouted idle service vehicles have sufficient time to reach or make significant progress towards the opposite sector before they are assigned to an incoming demand. As the arrival rate increases idle taxis are assigned to new demands more quickly and on average have less travelling time towards the other sector, thus lowering the benefit. At high traffic intensities there is almost always a waiting demand and thus the anticipatory policy collapses to the reactive "City" policy and no improvement is seen.

7. CONCLUSION

This paper makes several contributions to the understanding of service vehicle routing in the Dynamic DARP. First, the well understood NN policy was extended and modestly improved to incorporate partially dynamic behaviour. It was shown that this DNN policy outperformed NN by up to 10% under the base conditions. Secondly, the analytical understanding of the policies was furthered. Analytical formulas for the multiple vehicle FCFS policy were derived. Furthermore, accurate approximations for the single vehicle varying velocity NN policy were presented using only a single set of simulation runs. While not yet completed, this potentially paves the way for similar expressions for multiple vehicle policies. Thirdly, it was demonstrated that the relative performance of the FCFS, NN, and DNN policies holds true under somewhat more realistic city-like conditions. Lastly, the understanding of anticipatory behaviour for service vehicle dispatching was furthered. It was shown that anticipatory vehicle routing for the more complex NN and DNN policies outperforms the reactive policies by up to 18%.

8. FUTURE WORK

The major areas of potential future work are discussed next.

8.1. Future Work for Comparison of Base Case Policies

The DNN policy is not a fully dynamic solution. Two of the major shortcomings include: (i) if a new demand arrives and there is one or more idle vehicles, the demand is always serviced by an idle vehicle even if an assigned vehicle is nearer, and (ii) no dynamic reassignments occur when a service vehicle becomes newly idle after reaching a drop-off location. There is a significant opportunity to develop and test a fully dynamic nearest neighbour policy. It is hoped that such a policy could produce much greater improvements than the current magnitudes of no more than 10%.

While there are many potential solutions to the implementation of a fully dynamic policy, one possibility is discussed here. The policy is concisely summarized as: When a service vehicle (demand) becomes idle (arrives) it is assigned to its nearest demand (service vehicle), and dropped service vehicles (demands) are considered as becoming idle (arriving). Whenever a service vehicle becomes idle or a new service vehicle arrives, the service vehicle-demand pairs are dynamically reassigned. This is done in such a way that once a vehicle and demand have been paired they are removed from future comparisons for that trigger such that algorithm is guaranteed to quickly converge to a solution

8.2. Future Work for Analytical Approximations of Policy Performance

As the policies become more dynamic and the service environments more complex, producing analytical expressions for system time performance becomes increasingly more difficult. With that being said, it is still believed there is an opportunity to develop an analytical approximation for the multiple vehicle NN policy that requires only one set of initial simulation runs. It is unclear exactly how this is to be accomplished but the single vehicle varying velocity NN model could be used as a starting point.

8.3. Future Work for Objective 4: Application of Policies in "City" Environment

The "City" environment studied was a very simple approximation of the real-world. The conditions could be expanded to better simulate real life conditions. Potential improvements could include: the addition of roads to constrain taxi movement, an increased number of neighbourhoods, a larger number of service vehicles, more complex traffic patterns and rush hour modelling, or traffic disturbances such as stoplights. Although many improvements can be made it seems unlikely that any model could accurately simulate the complexity of a real city so the models should still only be used to assess relative, not absolute, performance. That being said, there is still value in understanding the effects that different real-life phenomenon could have on policy performance.

8.4. Future Work for Anticipatory Behaviour in "City" Environment

Anticipatory vehicle routing represents a significant opportunity for future work. There are many possible directions to take in future research, so the ones presented here are merely suggestions. The effect of the vehicle anticipation routing method could be further studied. For example, instead of travelling to a particular location, taxis could be sent to patrol throughout the specified sector. Furthermore, anticipatory behaviour could be applied to the previous future work suggestions. It would be interesting to understand how the performance of anticipatory routing would change under more realistic "City" conditions. Furthermore, anticipatory behaviour could be applied to a fully dynamic policy. If possible, it would be of interest to understand how close such a policy would come to the optimal system performance.

REFERENCES

Berbeglia, G., Cordeau, J.F. and Laporte, G., 2010. Dynamic pick-up and delivery problems. *European Journal of Operations Research*, 202 (1) 8-15.

Bertsimas, D.J. and Van Ryzin, G., 1991. A stochastic and dynamic vehicle routing problem in the Euclidean plane. *Operations Research*, 39 (4), 601-615.

Bertsimas, D.J. and Van Ryzin, G., 1993. Stochastic and dynamic vehicle routing in the Euclidian plane with multiple capacitated vehicles. *Operations Research*, 41 (1), 60-76.

Jagerman, D.L. and Melamed, B. 2003. Models and Approximations for Call Center Design. *Methodology and Computing in Applied Probability*, 5, 159-181.

Kleinrock, L., 1976. *Queuing Systems, Vol. 1: Theory*. New York: Wiley.

Larson, R. and Odoni, A., 1981. *Urban Operations Research*. New Jersey: Prentice Hall.

Ozesenli, O.N., and T. Demirel. 2005. A dynamic approach (SAT) to vehicle allocation problem with uncertain demands for service sector. *35th International Conference on Computers and Industrial Engineering. Istanbul, Turkey.*

Swihart, M.R. and Papastavrou, J.D. 1999. A stochastic and dynamic model for the single vehicle pick-up and delivery problem. *European Journal of Operations Research*, 114 (3) 447-464.

Xiang, C., C. Chu, and H. Chen. 2008. The study of a dynamic dial-a-ride problem under time-dependent and stochastic environments. *European Journal of Operations Research*, 185 (2) 534-551.

Xu, H., 1994. *Optimal policies for dynamic and stochastic vehicle routing problems*. Thesis (PhD). Massachusetts Institute of Technology.

AUTHORS BIOGRAPHY

Thomas Pickles is a 4th year mechanical engineering undergraduate student in the Department of Mechanical and Industrial Engineering at the University of Toronto. His research interests are in the areas of discrete event simulation and maintenance optimization. He has won several scholarships for academic excellence including University of Toronto Scholar, Professional Engineers of Ontario Scholar, and Natural Sciences and Engineering Research Council of Canada scholarship.

Barış Balcıoğlu is an Associate Professor in the Department of Mechanical and Industrial Engineering at the University of Toronto. He received his Ph.D. in Industrial and Systems Engineering from Rutgers University in 2003. His research and teaching activities are in the areas of queueing theory, discrete-event simulation, performance analysis of call centers and production/inventory systems, and reliability and maintenance engineering. His research has been supported by the Natural Sciences and Engineering Research Council of Canada.

Beno Benhabib received his Ph.D. degree in mechanical engineering from the University of Toronto, Canada, in 1985. Since 1986, he has been a Professor of mechanical and industrial engineering at the University of Toronto, with cross appointments to the Department of Electrical and Computer Engineering as well as to the Institute of Biomaterials and Biomedical Engineering. His current research interests include development of autonomous robotic systems for manufacturing, biomedical, and service industries.

DATA ANALYSIS AND PROCESSING TOOL FOR AUTOMATIC IDENTIFICATION SYSTEM (AIS) VESSEL DATA TO SUPPORT SIMULATION MODELING

Cory M. Rogers[a], Keith D. Hofseth[b], Richard M. Males[c]

[a]CDM, Carbondale, IL, USA
[b]U.S. Army Corps of Engineers, Institute for Water Resources, Alexandria, VA, USA
[c]RMM Technical Services, Inc.

[a]rogerscm@cdm.com, [b] keith.d.hofseth@usace.army.mil, [c]males@iac.net

ABSRACT

Automated Identification System (AIS) data provides ship tracking information for cargo vessels in coastal waters. Information includes vessel position, speed, draught, dimensions, and destination port. This information is updated on an hourly basis. The analysis of AIS data for individual vessels and for a given port provides a large amount of useful information on vessel routes and loading that can be used in conjunction with port simulation models. The Institute for Water Resources of the US Army Corps of Engineers is developing the Automatic Identification System - Data Analysis and Pre-Processor (AIS-DAPP) tool for visualization and analysis that can be used to support simulation modeling and planning activities. The AIS-DAPP applies genome sequencing practices to identify services from the data. It also works seamlessly with Google Earth™ for spatial visualization and incorporates analytical routines to determine common routes, speed within channels, and draught entering and leaving a port, all needed for simulation modeling.

Keywords: port simulation, automated identification system

1. INTRODUCTION

The U.S. Army Corps of Engineers is responsible for maintaining the navigable waterways of the United States, including ports and harbors. Improvements to the ports that are under the jurisdiction of the Corps must be economically justified based on analysis of the relative benefits to navigation (reduced transportation cost) and the cost of the improvements (P&G 1983).

The analysis of economic justification is done using a "without project" condition, i.e., the future configuration of the harbor if no improvement project is carried out, as compared to a "with project" condition, in which vessel traffic is projected based on the assumption of the new improvements being in place. Benefits resulting from such improvements are often dependent upon their effect on reducing transportation cost, for example deepening a channel allows deeper drafting vessels to service the port.

2. PROBLEM SETTING

Container vessels are not characterized by "there and back again" routes typical of bulk cargo vessels. Container vessels are deployed on liner service routes which typically have 5-15 ports. The sailing draft, and thus channel depth utilization, at each port can vary widely. This presents a difficult analysis for Corps' planners who are asked "what will be the economic impact of deepening the channel at port x"? As port X is only one of several ports on the service route the answer is highly dependent on the characteristics of the other ports on the service and the nature of the trade on that service. Figure 1 shows the Maersk Columbus Loop Service.

Figure 1: Maersk Columbus Loop Service

The Corps is currently evaluating the effects of deepening the channel at Savannah harbor. The analyst is asked to estimate incremental changes from deepening depths ranging from 2 to 6 feet. This requires the analyst to predict fleet deployment changes and changes in at the port vessel drafts for each increment of depth.

To aid the Corps analyst the IWR has developed an evolving set of statistical, forecasting and simulation tools for analysis of vessel movement in harbors. The AIS-DAPP provides the capability to visualize, analyze and synthesize historical AIS data for use in container port channel improvement studies and associated simulation modeling. Specifically, the AIS-DAPP was developed to aid the evaluation of channel improvements at U.S. container ports and to help populate IWR's HarborSym simulation model (Hofseth, Heisey, Males and Rogers, 2006).

3. LITERATURE REVIEW

The availability of AIS data is a major breakthrough for maritime transportation simulation systems. Shipping companies tend not to share information with the potential of rendering business practices that may give an edge to a competitor or expose what they may consider a trade secret (Greaves and Figliozzi, 2008). Previous work has been executed on land based vehicle position streams similar to the AIS data. Many of these studies have a component similar to an element of the author's current research efforts – Breaking the positional stream into movement segments bounded by stopping points. Stopping point identification from GPS streams is currently founded on a criteria expression parameterized on dwell time. Other criteria in the flagging expression using GPS data include heading changes and zero velocity (Mathew and Reddy, 2008). It should be made clear that these research papers involved GPS data streams of land based motor vehicles and that the trips and movement segments are much smaller than that of ocean going vessels. Identification of actual shipping routes, route usage rates, and vessel characteristics is very important to planners charged with optimizing maritime ports of call. The elements to be optimized can change based on stakeholder involvement and current constituent concerns. In a recent work, the European Space Agency released maps of actual shipping routes obtained through near real time ship identification by an orbital radar system overlaid with SO2 and NO2 maps (ESA, 2009). The vessel route information that was previously unavailable can show causality in environmental issues as well as provide for many other potential optimization targets. With respect to quality of human entered data in the AIS data stream, Bailey, et al. show a non-trivial error rate attributed to several factors including improper or lack of training (Bailey et al, 2008). This finding lead to the implementation of computed trip segmentation in the analytic tool.

4. CHARACTER OF AIS DATA

The IWR has acquired AIS data on worldwide container ship movements for some 3000 vessels during the period 2007-2008 from a commercial provider. This information is based on coastal stations, thus at sea movements out of range of land-based stations are not currently available, although at sea data is anticipated to be available for AIS data in the near future. The primary data consists of "ping" records (8.5 million in total) giving information on:

- Unique Vessel Identifier
- Movement Date and Time
- Latitude and Longitude
- Destination Port
- Ship Name
- Vessel Characteristics (Type, Length, Beam)
- Draught
- Speed

Sample data extracted from the large data set for a single vessel is shown in Table 1.

Table 1: Sample AIS Data (Single Vessel)

Sample AIS "Ping" Data (selected)					
Longitude	Latitude	Move Date	Destination	Draught	Speed
139.677515	35.4005667	1/5/07 3:55	Yokohama	12	0.1
139.677551	35.4005450	1/5/07 4:53	Yokohama	12	0.1
139.677528	35.4005700	1/5/075:55	Yokohama	12	0.1
139.677563	35.4005933	1/5/07 6:58	Yokohama	12	0.1
139.677658	35.4003567	1/5/07 7:59	Shanghai	10.4	1
139.758910	35.2709000	1/5/07 8:59	Shanghai	10.4	13.6
139.727796	35.0962800	1/5/07 9:48	Shanghai	10.4	18.5
121.734338	31.3160067	1/8/07 7:59	Shanghai	10.1	9.9
121.647738	31.3411417	1/8/07 8:52	Shanghai	10.1	0.1
121.647720	31.3411633	1/8/07 9:55	Shanghai	10.1	0
121.647766	31.3411367	1/8/07 10:55	Shanghai	10.1	0
121.647766	31.3411367	1/8/07 11:29	Shanghai	10.1	0
121.647723	31.3411050	1/8/07 12:52	Shanghai	10.1	0
121.647933	31.3411417	1/8/07 13:58	Shanghai	10.1	0
121.647840	31.3412000	1/8/07 14:42	Shanghai	10.1	0
121.648025	31.3415150	1/8/07 15:59	Yantian	10.3	0.3
121.726748	31.3169633	1/8/07 16:46	Yantian	10.3	11.7
121.987268	31.2479250	1/8/07 17:48	Yantian	10.3	13.4
122.058365	31.2367500	1/8/07 18:04	Yantian	10.3	13.8
118.318770	23.8947467	1/9/07 18:48	Yantian	10.3	24.3

5. AIS-DAPP OVERVIEW

The AIS-DAPP includes an underlying spatial relational database structure in the PostgreSQL environment. A user interface, developed in the C# programming language allows a user to select and filter data by: polygon; port; route; vessel; vessel class, and time. Analysis capabilities include: the ability to identify routes and services; development of statistical information on arrival and departure draughts; calculation of statistics on the amount of time spent by vessels at docks; determination of vessel speeds at various points along the route; and calculation of trip shares by vessel class and route. Visualization capabilities, using Google Earth and other tools as needed include: plots of individual vessel routes; representations of vessel class share of movements by route; visualization of representation of sailing draft by route and/or route segments; and plots of routes dominated by a selected vessel class.

An automated reporting tool has also been created to allow close to a "one-click" capability to generate information about the vessel traffic at a selected port, generating a vessel call list for use with the HarborSym model.

6. PROCESSING AND VISUALIZATION

A number of tools have proven useful in the processing and initial examination of AIS data. The PostgreSQL database (http://www.postgresql.org/) is a free, open source relational database server capable of handling extremely large data files. The PostGIS extensions to PostgreSQL provide a complete set of spatial analysis capabilities for the locational data (http://postgis.refractions.net/). This allows for the development of queries such as "Identify all the vessels that come within 100 miles of the location of the Port of

Yokohama", and allowing the database to serve directly as a data source for GIS platforms such as the Quantum GIS (http://www.qgis.org/). Google Earth™ (http://earth.google.com/) provides visualization capabilities for vessel data points and tracks, once information has been formatted into the required KML file format.

An example of AIS data visualization of vessel pings for a single vessel for a few days in January 2008 using Google Earth is shown in Figure 2, and larger scale movements for the same vessel, over the course of the two years of data, are shown in Figure 3.

Figure 2: Single Vessel Ping Visualization, Eastern China Sea

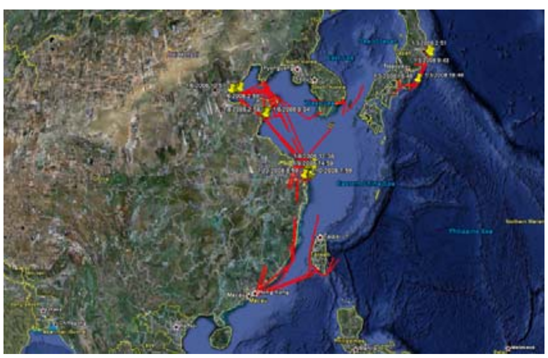


Figure 3 : Vessel Movements in Asia (single vessel, 2007-2008)

As seen in Table 1, each ping has an associated destination. A simple Python script can be used to extract the ports visited in order, as shown in Table 2.

7. TRIP SEGMENTION

AIS data, like most raw data sets includes a number of errors and omissions. Raw AIS data must be cleaned before it can be ported into the AIS-DAPP. An automated tool for cleaning the data was not developed. However, the IWR has developed detailed step-by-step instructions to transform the raw data to be compatible with the AIS-DAPP. This allows additional data that becomes available with the passage of time to be incorporated into the tool.

Table 2 : Port Visit Sample

Port Visits
Yokohama
Shanghai
Yantian
Balboa
Charleston
Norfolk
Newark
Bremerhaven
Felixstowe
Rotterdam
Le Havre
Newark
Charleston
Miami
Panama Canal
Balboa
Los Angeles

The first stage of AIS processing is to transform the positional data stream into a sequence of movements separated by points at which the vessel stops. The process of stream segmentation is a multi-step procedure consisting of stop identification, stop compression, and extraneous movement removal. To facilitate this procedure, additional data elements are introduced to the AIS data structure. In particular, three Boolean flags – Stop_pt, which is used to indicate an identified vessel stop, dest_arrival, which flags a stop as an arrival at some location, and dest_departure, which indicates the final stop point prior to a movement.

The algorithm employed for stopping point detection is a variant of the dwell time method used in Stopher's research (Stopher, et al, 2003). The data is ordered by the unique vessel ID and then by movement date/time. By default, all records are marked as non-stops. The ordered stream is then iterated over making a comparison between the current record and N subsequent records. The implemented algorithm identifies a stop as a movement ping record for a specified vessel in which neither latitude nor longitude has changed by 0.01 degrees and the vessel's velocity is less than 0.5. With a data time granularity of 60 minutes, a value of N=1 was selected to allow the detection of all vessel stops whose dwell time is greater than 1 hour 59 minutes. Examination of the raw data revealed a potential flaw in that the data gathered was not presented at a uniform sampling of 1 hour. The solution to the data gaps was to modify the algorithm to check for a standardized distance over time value. In the original test, the time element was ignored under the assumption of uniform samples. The modification determines degrees per hour moved and triggers if that value is under 0.01 degrees per hour. Analysis is currently underway to determine if the use of average velocity (degrees per hour) in addition to instantaneous reported velocity produces more accurate stop detection.

The second phase of the trip segmentation process is to identify the end points of consecutive stop records to delineate and form the actual stops. Once again, the movement records for each vessel are iterated over after being sorted by date/timestamp. If a record is marked as a stop and the previous record is not, the record is marked as an arrival. Departure records are identified by the opposite condition. Special consideration is given to the first and last records. If the first or last movement record for a vessel is identified as a stop record, a special flag is raised indicating that the actual length of time the vessel at the location is not known. If the principal or ultimate movement records are non-stop records, no special processing is required. The final phase of the trip segmentation process is data compression. The records between paired arrival and departure records are deleted as are all records not identified as stops. The result of this process is a chronologically ordered list of stops that the vessel made.

8. PORT IDENTIFICATION

While the AIS data contains a field for a vessel's current destination, this data is potentially misleading because although the vessel is physically at a particular port, the moment the vessel begins to move the destination field reports its next destination. Instead a geo-spatial process is applied to determine the identity of the stop location. The system maintains a table of stopping locations; these locations are either of type port or anchorage.

Applicable to the process of port identification of a stop is the latitude and longitude of the port along with a port specific radius of influence. The radius of influence is set using the Movement and Port Explorer portion of the analysis tool seen in Figure 4.

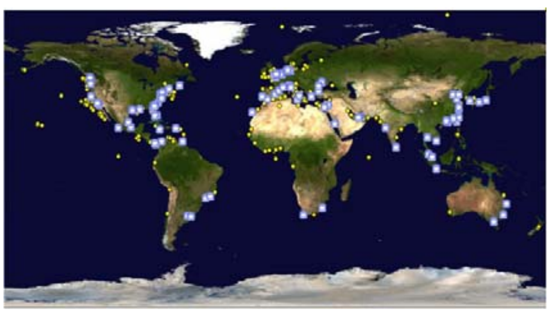


Figure 4: Port Identification Radius

The Movement and Port Explorer plots selected AIS records and defined ports along with basic geographic boundaries to assist with the analyst's geographic orientation. For each new port, the analyst can see the clusters of candidate AIS records. Using the measuring tool, a radius of influence can be determined. The port information is directly updated using the tool. The establishment of the radius is a non-trivial task when there are multiple ports within similar distances from a cluster of AIS records. Both overlapping radii and those that do not sufficiently cover one or more clusters introduce questionable results from the port identification process. Figure 5 shows the ports of San Francisco and Oakland with the associated AIS cluster's denoted.

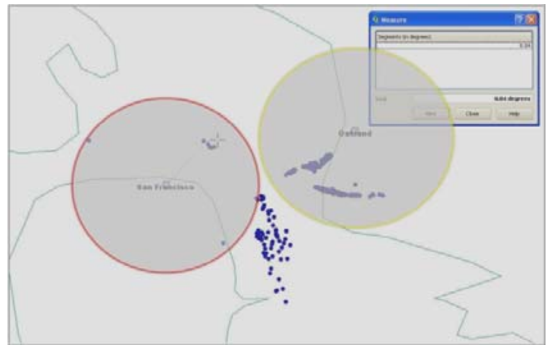


Figure 5: Radii for Ports of San Francisco and Oakland

The next step in the port identification process is the automated assignment of one or more existing ports to each AIS record when possible. This is a three phase process. The first phase is to create a Cartesian cross product between the AIS records and the defined ports where the AIS record is within the port's radius of influence. In addition, the distance from the port to the vessel is recorded. The result of this phase is a list AIS records with one or more port IDs sorted by vessel ID, MovementID, and distance to port. The list is then iterated over retaining only the first record of each set. From this list, the destination ID is set in the original segmented trip list selecting the closest port if more than one claims influence over the vessel stop. The second phase is to return to the Movement and Port Explorer with the dataset restricted to those AIS records without a valid destination ID. The analyst has the option to add new destinations with associated radii of influence to provide suitably identified destination information. These two operations are repeated until the analyst is satisfied with the coverage of identified destinations. The final phase of port identification is to remove stops that remain unidentified as they provide no relevant data.

9. REGIONS AND MULTI-LEVEL ANALYSIS

Level of detail is extremely important in exposing relevant trends in data to an analyst. Volumes of highly detailed data can mask trends that appear at higher levels. While the direct purpose of this analytical tool is to analyze vessel call trends, the nature of region definition directly affects the aggregation of the movement data and thus the level of trend visibility.

A region is defined as a collection of one or more distinct destinations or ports and the complete region list for this effort is shown in Table 3. It is important to note that a port or destination may be in, at most, one region for the aggregation to be valid. In the analysis performed, the desire was to explore vessel call trends between several geographic region in the United States and larger international regions.

Table 3: Region Names and Codes

Region Name	Region Short	Region Code
Africa	AFR	A
Black Sea	BLS	B
Caribbean / Gulf	CAR	C
Canada East Coast	CEC	D
Canada West Coast	CWC	E
East Coast South America	ECSA	F
Europe	EUR	G
US Gulf Coast	GCUS	H
Mediterranean	MED	I
Mid East	MID	J
North Asia	NAS	K
Oceana	OCE	L
Panama Canal	PAN	M
South Asia	SAC	N
South China	SC	O
Southeast Asia	SEA	P
Suez	SUEX	Q
US East Coast	ECUS	R
West Coast South America	WCSA	S
US West Coast	WCUS	T

Figure 6 shows the exploration view of the region defined as East Coast US.

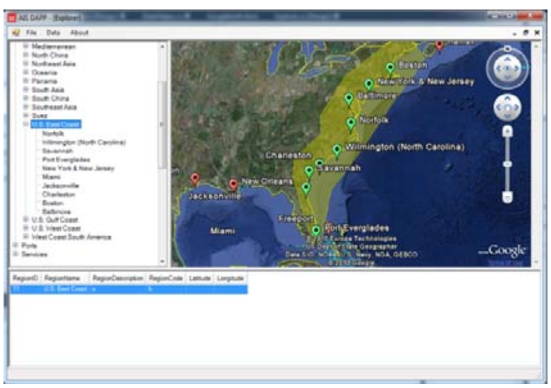


Figure 6: View of East Coast U.S. Regions

Further processing to look for patterns and development of larger spatial scale service definitions (e.g. Asia – Panama Canal – East Coast US - Europe – East Coast US – Panama Canal – West Coast US – Asia) is then carried out, together with examination of port arrival and departure draughts as indicators of vessel loading and commodity import and export.

10. SERVICE IDENTIFICATION – GENOME SEQUENCING

Genome sequencing practices were applied in the processing of AIS data. Genome sequencing is quite simply, the process of determining the order of genetic base pairs that form an organism's genetic code. In genome sequencing the functional alphabet is a simple set of four nucleotides – adenine, guanine, thymine, and cytosine. These nucleotides are coded as 4 single letters – A, G, T, and C. This simple step of nucleotide encoding serves to both simplify the representation of a genome sequence without data loss and to enhance the ability to identify patterns. An example of a DNA sequence is "ATTCGCATT". This representation of the sequence is far more compact and "observable" than fully listing the nucleotide pairs. Quick inspection of this sequence yields that there are several repeated sequences – "AT", "ATT", and "TT". This trivial observation also shows that the sequence is bounded by the "ATT" sequence and that the other two repeated sequences are possibly related to the "ATT" marker. These simple observations serve to highlight a benefit of genome sequencing – pattern and positional observation in a potentially noisy field. An example of this, paraphrased from Genome News Network (J. Craig Venter Institute, 2004) – take a phrase, remove all punctuation, remove all white space, and add random letters between the original words:

ADRYYGPRAESENSULROVAWSDCRASIPLPULL
ISSUNTGGEMELIORAWYTT

By identifying sequences or words that we know this becomes:

ADRYYG**PRAESENS**ULR**OVA**WSD**CRAS**IPL**PUL**
LISSUNTGGE**MELIORA**WYTT

Extraction of these identified words yields a sentence that still makes little sense to most.

AD PRAESENS OVA CRAS PULLIS SUNT MELIORA

Once the language of the sentence is understood (Latin), the true meaning is determined; "A bird in the hand is worth two in the bush".

There are many similarities between the problem domain of genome mapping and transportation route/service identification. The port calls of a vessel are analogous to nucleotides. Vessel movement records can alternatively be thought of as DNA sequences or chromosomes. Minor aberrations in a vessel's activities as well as actual data errors introduce extraneous noise into the DNA sequence. Given the similarities in the problem domain, this analytical tool endeavors to leverage the techniques of genome mapping in order to extract similar benefits in pattern recognition, noise reduction, and eventually, linguistic understanding of shipping services.

The primary goal of the analysis is to observe patterns and trends in inter-region call lists and to produce a set of regional services through genome sequencing. Repeated patterns of inter-region vessel calls are known as services. While the produced list of services will encompass the entire data set, the frequency of occurrence data collected will be used to show volume of movements within the genome.

The first component of this sequencing process is to obtain the DNA for each vessel in the processed AIS data. The fingerprint is in the form of a string of characters where each character represents a unique region the vessel visited in chronological order. This is done by ordering the call list for each vessel on arrival time and iterating over the resultant list. For each visit on the list, the associated region is decoded from the identified destination/port of the visit. If the decoding process yields more than one region code, an error is produced and the process stopped. If the decoding process does not find a region code, the visit is ignored. The most common result of the decoding process is one unique region code. This code is appended to the end of the string if the previous region code is not the same. This conditional appending serves to remove intra-region moves which would obscure the visibility of the inter-region movements. The result of this procedure is that each vessel in the active call list has a DNA sequence or chromosome encoding its inter-region movements over time for the analysis period.

The second component of the genome sequencing is the controlled decomposition of the chromosomes into candidate genes and gene complexes. In our problem domain a gene is a simple inter-region movement and gene complexes are a series of multiple inter-region movements. Both simple genes and gene complexes are candidates for identification as services. The data structure for this decomposition is a table with a string as the primary key which corresponds to a unique set of one or more inter-region movements as well as an integer column for accumulating the frequency of gene appearance in the dataset – the genome.

The chromosome is decomposed into candidate genes by extraction of substrings. The process starts with simple genes of length 2 and progresses up to the length of the chromosome string in full. As each gene string is extracted, the genome is checked for previous identification. If the gene string has not been previously identified, it is added to the genome with an initial occurrence count of 1. If the gene has been previously identified, the occurrence count is incremented.

The potential number of distinct genes and gene complexes in a chromosome of length n is bounded by the simple sum:

$$\sum_{i=1}^{n-1} i = \frac{n(n+1)}{2} - n = n\left(\frac{n+1}{2} - 1\right) \quad (1)$$

While this is the number of genes/gene complexes that must be examined for a given chromosome, the regional encoding will reduce the actual number of distinct entries in the genome.

The genome is then used as a source for service identification. The resultant table of services must exhibit two properties: it must be complete in that it must account for all identified inter-region movements, and the services must be mutually exclusive. Services are further defined to be cycle terminated. The rule of cycle termination defines that a service does not continue to another region after returning to a region that it has previously visited. An example of this is the following gene: “ABCAD”. This gene is not a candidate for a service as it shows a visit to region D after returning to A. The genome mapping technique used will have also identified genes “ABCA” and “AD” which would pass the rule of cycle termination. All genes that fail the cycle termination rule are culled from the candidate genome table. The desired result property of completeness is not impacted by this culling due to the genome map containing the subsections of the culled genes that do pass the cycle termination rule. The second pass of gene culling is to ensure mutual exclusivity of vessel movement observations. For each gene remaining in the candidate service genome table, the process of genome mapping is reapplied with the results being stored in a temporary location. The original gene itself is removed from the temporary store. Each remaining value in the temporary store is found in the service candidate genome and the occurrence count reduced by the count value in the temporary store. The final step is to remove any gene from the service candidate genome whose occurrence count is zero as these genes are fully accounted for in more complex genes. The resulting genome is a set of services that are mutually exclusive with respect to inter-region vessel movements and fully covering the dataset of those movements. A completely mapped service between Africa and Europe is shown in Table 4.

Table 4 : An Africa to Europe Service

Port	Country	Region	Code
Casablanca	Morocco	AFR	A
Agadir	Morocco	AFR	A
Rotterdam	Netherlands	EUR	G
Bremerhaven	Germany	EUR	G
Helsingborg	Sweden	EUR	G
Antwerp	Belgium	EUR	G
Casablanca	Morocco	AFR	A

The actual chromosome found would be AGA, indicating a service that initiates in Africa, travels to Europe and returns to Africa. Because of the string nature of the genes, and our retention of the individual vessel’s chromosomes, the analyst can find all vessels that share a common gene or, perhaps, vessels that have more than N occurrences of a specific gene.

11. CONCLUSION

The techniques described for identifying vessel trips, mapping of ports and illuminating vessel services have proved effective at uncovering valuable information from a dense yet incomplete data source. In particular, treating the vessel route as a genome sequence in order to programmatically uncover vessel services within the data provided useful insights into the operations of shippers. With this information, a plethora of informative statistics can be easily calculated for further analysis, such as:

- Ocean speeds by vessel class and service
- Vessel speeds in reach at port
- Vessel arrival drafts by port and vessel class
- Vessel departure drafts by port and vessel class
- Imputed vessel capacity used by route, route segment and vessel class.
- Identification of total vessel capacity by service
- Service length
- Imputed service volume of traffic
- Port depths on service
- Share of route capacity by vessel class
- Evaluation of share over time
- Vessel class deployment by route characteristics
- Vessel deployment over time

All of these statistics are extremely useful for analysis and simulation. A list of vessels calling at a specific port with their arrival times and draughts is also produced from the system. This vessel call list is intended to be used as input to a monte-carlo simulation model for the economic evaluation of potential port improvements such as deepening a channel to allow larger vessels to call the port.

ACKNOWLEDGEMENTS

This work was carried out as part of the navigation research being performed at the Institute for Water Resources of the U.S. Army Corps of Engineers, under the direction of Mr. Keith Hofseth. The research conducted to define appropriate regions, map ports to regions and identify current vessel services was carried out by Ms. Shana Heisey of Watertown, Massachusetts. Computer programming services and algorithm enhancements were performed by Mr. Michael Dean and Mr. William Woelbeling of CDM, Carbondale, Illinois.

REFERENCES

P&G 1983 - Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies, March 1983

Hofseth, K.D., Heisey S., Males, R.M., Rogers, C. 2006. Development of Commodity Driven Vessel Movements for Economic Analysis of Port Improvements http://www.corpsnets.us/docs/HarborSym/06-NETS-P-02.pdf

Greaves, S. and Figliozzi, M., 2008. Urban Commercial Vehicle Tour Data Collection Using Passive GPS Technology: Issues And Potential Applications. Proceeding of the 87th Transportation Research Board Annual Meeting CD rom - Washington DC. USA

J. Craig Venter Institute 2004, http://www.genomenewsnetwork.org, (*accessed June 9, 2010*)

Mathew, S. and Reddy, YV, 2008. Traffic Study of Individual Behaviour in Tiruchirapalli City Using GPS, Available online at http://www.gisdevelopment.net/application/miscellaneous/mi08_268pf.htm (*accessed August 2010*)

ESA, 2009, ESA Map Reveals European Shipping Routes Like Never Before, available online at http://www.esa.int/esaEO/SEMBDI0OWUF_index_2.html (*accessed August 2010*)

Bailey, N., Ellis, N. and Sampson, H, 2008. Training and Technology Onboard Ship: How Seafarers Learned to Use the Shipboard Automatic Identification System (AIS). Seafarers International Research Centre, Cardiff University, UK

Stopher, R. and Jones, P. 2003, Transportation Survey Quality and Innovation, Volume 2001, Emerald Group Publishing, Bingley, UK

AUTHORS BIOGRAPHY

Cory M. Rogers

Mr. Rogers is a computer scientist currently serving as the National Practice Leader for Applications Development at Camp Dresser McKee, Inc. He has over 15 years of experience in the design and development of software applications to solve complex decision making problems. He has managed teams to develop successful software applications ranging from single-user desktop applications to web-enabled systems with a user base of thousands. Prior to joining Camp Dresser McKee, Inc, he served as the Director for Software Engineering for a small consulting firm and was a founding member of the Curriculum Advisory Board for the Information Systems Technology program at Southern Illinois University. He has worked on numerous decision support software models which are currently being used to perform crucial functions such as estimating flood damages caused by coastal storms, investigate the economic feasibility of improvements to the U.S. inland waterway and port infrastructure and manage financial risk at global food and beverage companies. Mr. Rogers holds a B.S. degree in Computer Science from Southern Illinois University.

Keith D. Hofseth

Mr. Hofseth has served as an economist at the Corp of Engineers for over 25 years; conducting studies in flood control, deep draft navigation, inland navigation and hydropower. He co-authored the first guidance for major rehabilitation analysis and was a pioneer in bringing risk and uncertainty into the Corp's planning process. Mr. Hofseth started with the Corps in the Seattle district and later served as the Chief Economist for the Alaska District. He is currently the Technical Director of the Navigation Economic Technologies research program at the Institute for Water Resources and is a graduate of the Corps' Planners Associate Program. Mr. Hofseth holds a B.S. degree in Finance and Economics from the University of Montana and an M.A. degree in Applied Economics from Johns Hopkins University.

Richard (Dick) Males

Dr. Males has worked professionally in consulting since 1968, and is owner and principal of RMM Technical Services, Inc., an independent consulting firm providing technical and computer support activities to a wide range of government, business, and non-profit agency clients. Dr. Males holds a Ph.D. in Water Resource Systems Analysis from the Massachusetts Institute of Technology. Dr. Males' primary professional activities have been in the arenas of development and effective use of computer-based tools, with emphasis on water resource systems applications. Areas of work include: design and implementation of advanced planning methodologies; simulation modeling; risk-based analysis; multi-criterion decision-making techniques; data base, budgeting, tracking, and decision support systems; mathematical modeling; geographic information systems development and applications; computer graphics and CAD applications; and laboratory data systems. His recent work areas include object oriented simulation models for risk-based analysis of navigation (deep-draft harbors, inland waterways and locks); coastal shore protection modeling; Monte Carlo simulation models for repair/rehabilitation of hydropower and levees; and development of decision support systems.

SIMULATION MODEL FOR BERTH ALLOCATION PLANNING IN SEVILLE INLAND PORT

Carlos Arango[1], Pablo Cortés[1], Jesús Muñuzuri[1], Luis Onieva[1]

[1] Ingeniería de Organización. Engineering School of Seville. University of Seville. Camino de los Descubrimientos s/n 41092. Seville, Spain.
cap@esi.us.es, pca@esi.us.es, munuzuri@esi.us.es, onieva@esi.us.es

ABSTRACT

We study the current allocating berths for containerships in the port of Seville. It is the only inland port in Spain and it is located on the Guadalquivir River. This paper addresses the berth allocation planning problems using simulation with Arena software. We propose a simulation model by the identification of the main bottleneck. Allocation planning aims to minimise the total service time for each ship and considers a first-come-first-served allocation strategy. We conduct a large amount of computational experiments which validate the model.

Keywords: Berth allocation, Simulation, Port operations, Container transportation.

1. INTRODUCTION

Ports are very important to the transport logistic networks, therefore all of its operations must be optimised, according to Ambrosino *et al* (2004). Some of the main operations are: container pre-marshalling problem, landside transport, stowage planning problem, yard allocation problem, etc in Voß S and Stahlbock R (2004) and Steenken D and, Voß S. (2008) which has been one of the most complete reviews and one of the most important papers. In the Figure 1 show a classification of the port operations.

The Port of Seville is the only inland port in Spain. It is located on the Guadalquivir River, in the city of Seville and it can be accessed by rail, air, road and motorway. It has always been one of Spain's main ports due to the high frequency in small ship traffic, including RO-ROs, ferries, feeders, etc. between Seville and the Canary Islands, and other Spanish and European ports.

Seville's inland port currently has a bottleneck because there is only one lock which is for small ships. Therefore, a new lock is being built that will increase the amount of ships which can enter in the coming years. Fig. 1 shows the port's future appearance with the new lock. This lock is highly important for Seville inland port to continue being one of the main intermodal centres in the south of Spain. The new lock improves the port's performance and will double current freight traffic. However, other processes and resources must be managed to maintain its competitiveness.

The simulation presented in this paper considers the freight traffic data from the Port Authority of Seville (PAS). This data is mainly about cargo containers, because in the last 6 years this cargo type has increased greatly. It also represents additional ships arriving in the Seville port due to the new lock. The new potential bottlenecks may occur in the container terminals, because the PAS has only two quay cranes for containerships. We therefore simulated the handling operations as the ships arrived, passing through the lock, unloading/loading containers, and propose a simulation model for berth management.

As an outline for the rest of the paper, we will give the literature review in Section 2. Section 3 looks at the simulation scenario and in Section 4 we describe the freight traffic situation. Section 5 presents the simulation model constructed from such. The results appear in section 6. Lastly, main conclusions and future work are addressed.

2. LITERATURE REVIEW

Several authors have approached the BAP concept. For example, Imai A. *et al* (2001), and Nishimura E. *et al* (2001) determine the berth allocation problem (BAP) as a dynamic berth allocation problem (DBAP) which is a generalisation of the static berth allocation problem (SBAP). They propose a genetic algorithm in public berth systems which can be adapted to real world application: Park and Kim (2003), Liu *et al* (2005) and Lim A. (1997) consider BAP and quay crane scheduling problem (QCSP) as a single problem and that berth scheduling depends on the crane number that is assigned to the ship. Imai A. *et al* (2005; 2007) approaches BAP in a multi-user container terminal (MUT). In the first work they use a continuous location space approach and in the second work they solved the BAP by Genetic algorithms at a port with indented berths, where mega-containerships and feeder ships are to be served for higher berth productivity. Imai A. *et al* (2003) consider the relations between the ports and shipping lines, and when some vessel operators desire high priority services, the authors have indicated BAP as BAP with service priority.

Due to the cost and complexity involved in port and vessel operations, the simulation models have been used intensively to understand the containers terminals and test different strategies in the port operations. e.g. see (Bruzzone 1998; Chung et al. 1998; Hayuth et al. 1994). These simulators differ widely in objectives, complexy, and details. Cortés P. *et al* (2007) simulated the freight transport process in Seville's inland port, considering all existing types of cargo and testing several scenarios. They analyse the performance of the several Seville port terminals and processes. Ballis and Abacounkim (1996) developed a simulation model to evaluate different configurations, such as changes in the yard layout and equipment. (Ramani 1996; Yun and Choi 1999) developed a simulation model to analyze container port operations, evaluate the port performance and obtain estimates for terminal performance indicators. Laganá D. *et al* (2006) and Legato P. *et al* (2009) developed optimisation and simulation models by scheduling yard crane use in the Gioia Tauro port. The authors follow ranking and selection (R&S) techniques to approach the scheduling yard crane (Rubber tired gantry cranes - RTG). Others works as

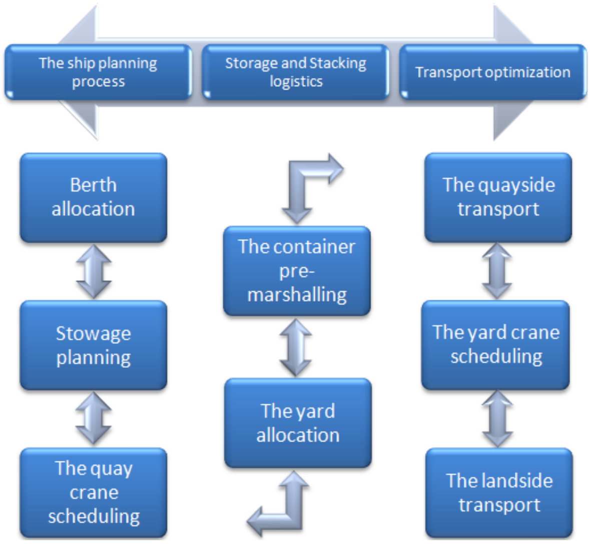


Figure 1: Operations of a container terminal

3. SIMULATION SCENARIO

PAS is a multi-purpose terminal: different types of cargo are moved through this port such as cereals, scrap metal and cement containers. The port has various specialised terminals for handling these types of cargo such as container terminals UTE Batan 1 and UTE Batan 2, TLP Esclusa cereals terminal, Holcim cement terminal, GPMA iron terminal, TLD Grupo Gallardo scrap and metal terminal and more. Our simulation scenario will only consider container terminals and the facilities needed for them to operate, the access channel and the lock. Fig 2 shows the simulation scenario model.

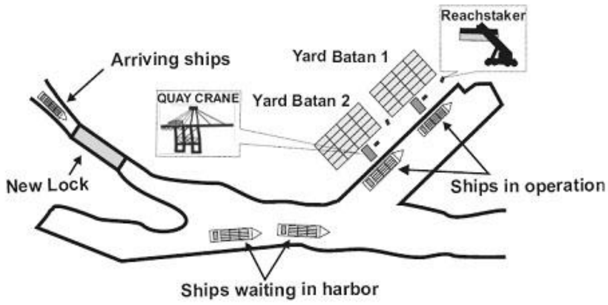


Figure 2: Simulation scenario

The container terminals Batan 1 and Batan 2 are for two different logistic operators although located in the same dock (*Centenario*). Therefore, all resources such as quay cranes, Reachsteakers and facilities are used in pairs for container handling. We therefore consider these two terminals to be one with two berths and two yards (yard Batan 1 and yard Batan 2). Table No. 1 shows the resources used in handling operations. All resources, such as the quay crane and reachsteaker must be scheduled by one terminal with two yards.

The model simulation considers information about the ship–containers' traffic through Seville port during February 2009. This simulation included data about arrival date, departure date; unload containers' number and the load containers' number by the study date.

Table 2 shows an abstract about this information, in which we can observe that 32 ships came to the port in February. The arrival frequency and the ship's country destination can also be seen. The 32 containerships transport 9954 TEUS (Twenty-foot Equivalent Unit) of which 57% is loaded in the port.

The data used in the simulation is based on the daily reports from the Port of Seville's web during February 2009. The data shows that in an ordinary month 32 containerships arrived at the Port. The Seville port is a small port, because of this it moves small amounts of containers compared with hub ports.

Table 1: Containers terminal resource

Towboat	Reachstackers	RoRo Ramp	Size Yard	Capacity yard/TEUS	Quay cranes
2	17	2	97,310m^2	150,000	2

Table 2: Ship lines

Country	Frequency	Ships month	Containers Min	Max	Average
Spain	2/Week	8	64	429	243
Morocco	1/Week	4	100	157	114
Spain	1/Week	4	54	86	75
Germany	1/Week	4	30	43	41
Spain	1/Week	4	64	86	75
UK	1/Week	4	43	430	214
Netherlands	1/Week	4	86	114	98

4. METHODOLOGY

A lot of ships arrives to the Seville inland port for load and unload containers each *t_arrive_S* hours, these ships within to the Port and wait by a free berth. When the berth is assigned to the first ship in the queue a towboat pick them up and carry them to the berth. The operations time in the berth by every ship depends of 1) Quantity of containers to load and unload; 2) the localization of these containers at the yard; 3) the reachstacker available for the operations in this moment.

The same way a lot of trucks arrives to the port each t_arrive_T minutes. The first process every truck is checking, theses trucks can load or unload container (only one operation), the operations time depend of the localization of the container at the yard.

5. SIMULATION MODEL

We are not optimising all operations in the Port of Seville, but the simulation model is formed by five module groups that represent some operations, such as 1.Truck arrivals. 2. Containership arrivals. 3. Berth assignment systems. 4. Towing vessels and 5. Berths.

5.1. Truck arrivals

We include these modules in the simulation model because truck handling operations use the reachstacker at the same time as ship handling operations. Fig 3 shows the truck modules. The truck handling operation time depends on where the containers are located in the yard: it is modelled with a module named *decide*.

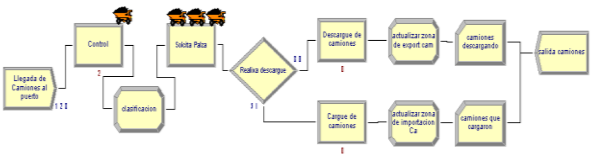


Figure 3: Truck arrival modules

5.2. Containership arrival

More than 45% of the time intervals between the arrival of one containership and another are from 0 to 15 hours. The shipping lines used for obtaining that data are shown in Fig 4 and it is modelled by the module *create*. Fig 5 shows the containers arrival modules.

The ship characteristics are assigned by a module *assign* when it arrives at the port, such as unload containers, load containers, containers located to load, etc. The ships wait in the channel access (module *Queue*) while they are waiting to be assigned a dock.

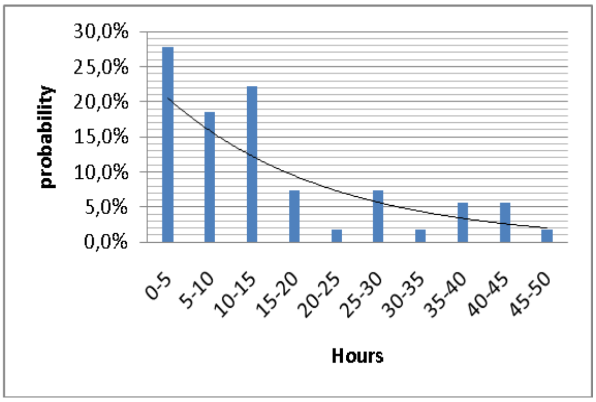


Figure 4: Intervals time between arrivals of ships

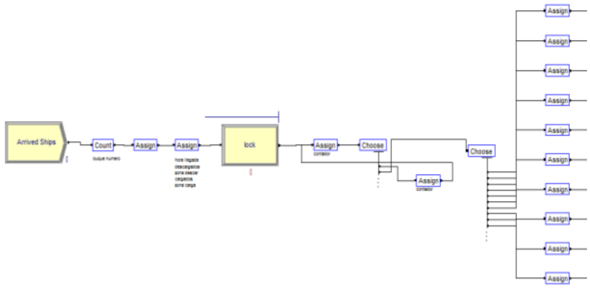


Figure 5: Containership arrival modules

5.3. Berth management system

A module *seize* and three modules *choose* were used in the study to simulate the current berth management system used in the port of Seville (Fig 6). The system used the First-come-first-served allocation strategy (FCFS) Lai K. y Shih K. (1992). Hence when a ship arrives at the port it has to wait in the queue until a berth becomes free. If there are not any other ships waiting to be serviced and the two berths are free then it is assigned the berth that is near to yard where less containers will be handled. Fig 6 shows the berths assignment modules.

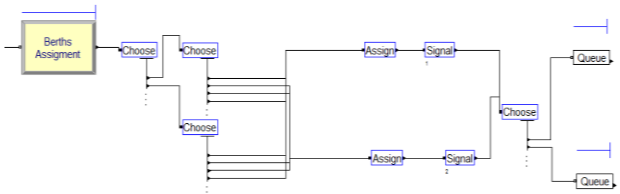


Figure 6: Berths assignment modules

5.4. Tow vessels

Two towboats are created when the simulation is started, one for each berth and it is sent to the first modules' group (Fig 8). In this group the tows are waiting for the ships, and then a signal is sent to the towboats for them to collect the ships that have been assigned to berth to pick them up and carry them to the berth. Fig 7 shows the creation the towboat.

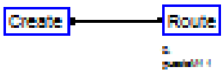


Figure 7: Creating towboat

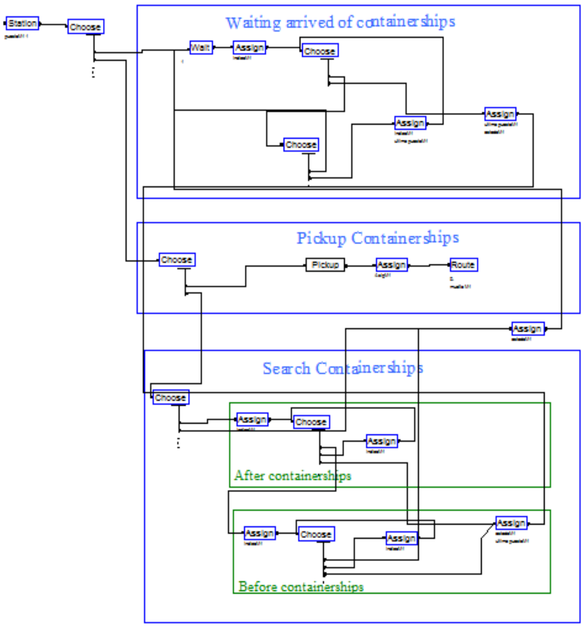


Figure 8: Tow vessels modules

5.5. Berths

The berth modules represent the handling operation time for each ship. This time depends on its characteristics and the amount of containers that need to undergo handling, containers' location and the resources available at that time. There are two berth modules which are exactly equal, one for each berth (Fig. 9). The container loading operations can only begin if the unloading operations have finished. The towboat is called again to carry the ships to the lock.

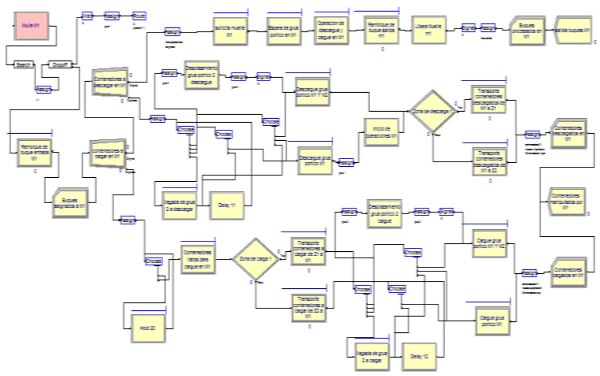


Figure 9: Berths modules

6. SIMULATION RESULTS

We have produced seven model replications presented across the previous sections, to verify and validate the simulation model proposal. Table 3 summarises the freight traffic by replication. An average of 32 containerships arrived at the port in a month in the simulation model. These ships were assigned to the berths 1 and 2 in similar quantity, this is because the container localization probability is the same by yard Batan 1 and yard Batan 2.

Table 3: Containership and container by simulation

Counters	Replications Number 1	2	3	4	5	6	7	Averg	Standar desviat.
Ships arrived	27	28	33	34	34	39	34	32,71	4,07
ships serve at Berh 1	17	12	16	15	13	18	17	15,43	2,23
ships serve at Berh 2	10	16	17	19	21	21	17	17,29	3,77
Containers unload	3497	3017	4437	3501	4021	4754	4217	3920,44	609,88
Cont. unload at Berh 1	2074	1068	1773	1322	1659	1657	2373	1703,76	436,71
Cont. unload at Berh 2	1423	1949	2664	2178	2362	3097	1843	2216,68	553,58
containers load	4317	4176	5225	4418	5557	5196	4251	4734,14	570,12
Containers load at Berh 1	2705	2031	2569	1690	2486	2213	1654	2192,59	420,40
Containers load at Berh 2	1612	2145	2655	2729	3071	2982	2597	2541,56	507,69

Table 4 show the handling time for each berth and for each model replication, we can observe that the results obtained the average handling time is 3.03 hours at the berth 1 and 3.04 hours at the berth 2 this is because the quay cranes are the same type (PANAMAX) with capacity of 30 containers/hour also the minimum and maximum handling time takes similar values in both berths because the probability that a ship has few containers to unload/load will arrive and that is located in the same yard is the same for both

Table 4: Service time

Replications Number	Handling time for each berths: handling time berth Batan 1			handling time berth Batan 2		
	Average	Min	Max	Average	Min	Max
No. 1	8,31	3,28	20,67	8,24	2,14	22,44
No. 2	6,53	3,26	14,63	7,13	3,34	23,42
No. 3	9,20	3,30	22,24	9,88	3,31	22,38
No. 4	6,76	3,30	21,93	8,10	3,31	22,37
No. 5	8,72	3,25	22,95	7,86	2,63	20,10
No. 6	8,76	2,14	30,06	9,67	3,33	22,47
No. 7	9,74	2,67	24,20	10,86	3,25	33,11
Average	8,29	3,03	22,38	8,82	3,04	23,75

Table 5 show the waiting time for each model replication, this time belong to the waiting time for each ships at the access channel (time queue) for a free berth, is very important minimise the waiting time in the container terminals because the ship lines need to go a other port as soon as possible. The average waiting time in the Seville inland port is 1,55 hours.

Table 5: Waiting time

Replications Number	Waiting time		
	Average	Minimum	Maximum
No. 1	1,28	0,00	12,06
No. 2	0,38	0,00	5,60
No. 3	1,99	0,00	27,36
No. 4	3,74	0,00	24,62
No. 5	0,33	0,00	5,69
No. 6	1,24	0,00	17,60
No. 7	1,89	0,00	20,39
Average	1,55	0,00	16,19

The information in figure 10 shows the service time in intervals of 5 hours. The simulation model shows that more than 50% of the ships with service time is between 5 and 10 hours.

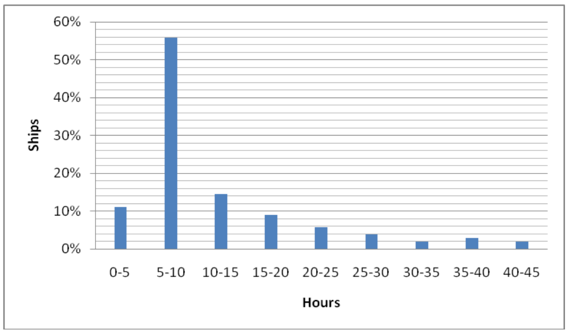


Figure 10: Ships by service time

7. CONCLUSIONS AND FUTURE WORKS

We have focused efficient planning and use of the berths to increase the port of Seville's competitiveness. By improving internal organisation and operations' management, a simulation model by supporting berth allocation has been proposed and examined.

We can conclude that the port facilities are able to serve the new freight traffic but for this to be achieved current berths systems must be improved. So is needing a system for reduced the average waiting time. The main reasons for this is because of better assignment management, improve the ships unload/load the containers in the berths closest to the yard where it is located a BAP-FCFS system would obtain a much better result.

REFERENCES

Ambrosino D, Sciomachen A, Tanfani E., 2004. Stowing a containership: the master bay plan problem. *Transport Research A*, 38, 81–99.

Steenken D, Voß S., 2008. Operations research at container terminals: a literature update. *OR Spectrum*, 30, 1–52.

Steenken D, Voß S, Stahlbock R., 2004. Container terminal operations and operations research - a classification and literature review. *OR Spectrum*, 26, 3–49.

Imai A. et al., 2001. The dynamic berth allocation problem for a container port. *Transport Research Part B* 35, 401-417.

Nishimura E. et al., 2001. Berth allocation planning in the public berth systems by genetic algorithms. *European Journal of operations research* 131, 282-292

Park Y-M. and Kim k., 2003. A Scheduling method for Berth and quays cranes. *OR Spectrum* 25, 1-23.

Liu J., Wan Y-M., Wang l., 2005. Quay Crane Scheduling at Container terminals To minimize The maximum Relative Tardiness of vessel Departures. *Naval Research Logistics* 53, 60-74.

Lim A., 1997. The berth planning problem. *Operations Research letters* 22, 105 – 110.

Imai A. et al., 2005. Berth allocation in a container port: using a continuous location space approach. *Transportation Research Part B* 39, 199 - 221

Imai A. et al., 2007. Berth allocation at indented berths for mega-containerships. *European Journal research of Operations Research* 179, 579-593

Imai A., Nishimura E., Papadimitriou S., 2003. Berth allocation with service priority. *Transportation Research Part B* 37, 437-457.

Brozzone, A.G., 1998, Harbour and maritime simulation. *Simulation* 71 (2), 72-73.

Chung, Y.G., Randhawa, S.U., McDowell, E.D., 1998. A simulation for a transtainer-based container handling facility. *Computers and Industrial Engineering* 15 (2), 113 -125.

Hayuth, Y., Pollatschek, M.A., Roll, Y., 1994. Building a port simulator. *Simulation* 63 (3), 179-189.

Cortés P. et al., 2007. Simulation of freight traffic in the Seville inland port. *Simulation Modelling Practice and Theory* 15, 256-271.

Ballis, A., Abacoumkin, C., 1996. A container terminal simulation model with animations capabilities. *Journal of Advanced Transportation* 30 (1), 37-57.

Ramani, K.V., 1996. An interactive simulation model for the logistics planning of container operations in sea ports. *Simulation* 66 (5), 291-300.

Yun, W.Y., Choi, Y.S., 1999. A simulation model for container terminal operation analysis using an object-oriented approach. *International Journal of Production Economics* 59, 221-230.

Laganá, D., et al., 2006. Solving simulation optimization problems on grid computing systems. *Parallel Computing* 32, 688 – 700.

Legato, P., Canonaco, P., and Mazza, R., 2009. Yard management by simulation and optimization. *Maritime Economics and Logistic* 11, 36 – 57.

Lai, K., and Shih, K., 1992. A study of container berth allocation. *Journal of advanced transportation* 26, 45-60.

http://www.apsevilla.com [accessed 15 May 2009]

MULTILEVEL APPROACH MODELLING FOR PORT CONTAINER TERMINAL SIMULATION

Marcos Sanz[a], Daniel Juste[b], Carlos Lozano[c], Marina Vallés[d], José Luis Navarro[e]

[(a)-(e)]Instituto de Automática e Informática Industrial
Universidad Politécnica de Valencia
Spain

[a]marsanri@ai2.upv.es, [b]dajuslo@ai2.upv.es, [c]carloga3@ai2.upv.es, [d]mvalles@isa.upv.es, [e]joseluis@isa.upv.es

ABSTRACT
In this paper, it is analyzed how to aggregate the operations carried out in a container terminal for the construction of simulation models. Also, the productivity or efficiency indexes commonly used in terminal management are related to every abstraction level, so the user will select the appropriated simulation model based on the indexes he want to obtain.

Furthermore, the models must give coherent results, so some parameters of a more abstracted (or aggregated) model can be obtained from a more detailed one using simulation. In the opposite direction, if it is known an aggregated parameter, some dependent parameters of a more detailed model can be obtained by means of a search procedure that will find the best solution for this set of parameters.
As a result of this analysis, a hierarchical multilevel model is proposed for the simulation of port container terminals.

Keywords: Container Terminal, bottlenecks, Balanced Scorecard, simulation.

1. INTRODUCTION
In recent times, the use of simulation has become in an important tool in the different logistic processes, especially those that have high cost and risks, for example simulation of a container terminal, in which exists expensive logistic equipment and very heavy (cranes, trucks, RTG's, etc.).

In our case, the simulation models are developed to assess the dynamic processes of container terminals. This allows generating and analyzing different statistics (Steenken et al. 2004), such as average productivity, mean of waiting time, etc, can also be used as a tool support to make decisions since in the field of container terminals, a small change in a terminal (e.g. add a crane in the docking line) can be a high cost in terms of money and maybe once the new element has been added to the terminal, it does not have positive changes in productivity (or other indicators to measure). Therefore, the introduction of simulation tool can help to find out if is necessary (or not) a change in the terminal.

Because of the many advantages offered by these simulation tools, the use of these has been increased in different intermodal systems and specifically in maritime environment (Rouvinen 2005; Korkealaakso et al. 2007).

Simulation models built can be used to improve many facets of a container terminal operation. In general, a simulation tool helps in our goals to increase throughput, improve equipment utilization, reduce waiting time and queue sizes, reduce bottlenecks, balance workload allocating resources efficiently and study alternate investment ideas.

To simulate it is needed simplify reality due to the high complexity of the real system, for which reason it only takes into account a number of parameters and indicators that are considered important and necessary for further analysis. However, in our model, we generate different simulation levels varying the detail level, from a more simple and generic model (level 1) to a more detailed and closer to reality (level 5) taking into account the limitations on the use of simulation.

The paper is structured as follows. In Section 2 is described the proposed hierarchical model, with 5 levels of aggregation for the container terminal. In Section 3 are detailed the different used indicators. In Section 4 is explained the model implementation and the coherence between different levels. Finally, Section 5 gives concluding remarks.

2. HIERARCHICAL MODEL
The first step for constructing the model of a system is defining the limits of the system and the objectives of the study. This step will lead us to define which are the inputs and the outputs for the model, that is, variables that are needed being defined in order to characterize the model for a specific problem. However, depending on the objective of the study, different levels of detail for the system can be defined and so, different variables are needed to be introduced.

At this work, 5 levels of model definition are proposed for the case of container terminals. The main components of the model are the yard and the intermodal links (maritime, road and rail) which are modeled with different degree of detail from the most abstract to the more detailed.

At the first level, the container terminal is modeled as a single warehouse. At level 2 operational details are added in the maritime gate. The existence of different storage areas in the yard is considered at level 3. At level 4, each area of the yard is divided in blocks. Finally, at level 5 the maximum detail of the container terminal is considered.

So, levels from 1 to 4 can only be used for simulation purposes while level 5 can be used for emulation. Definitions and comparisons between these two terms can be consulted at (Joschko et al., 2009).

Next, each of these five levels is described in detail.

2.1. Level 1: Single warehouse

At this first level all internal components of a container terminal are abstracted: the yard is modeled by a virtual store that only keeps statistics on the total number of containers and dwell time.

All transport elements (ships, trucks and trains) arrive at the terminal with an interarrival time following a statistical distribution. It also assigns a service point as element (docking, terrestrial door or railway) and remains in service for a time modeled by another distribution function. During this service containers are transferred from the terminal, modeling approximately the number of stored containers or the spent time.

The behavior of this model is determined by the distribution functions assigned to the interarrival times of transport, service times, idle times, etc.

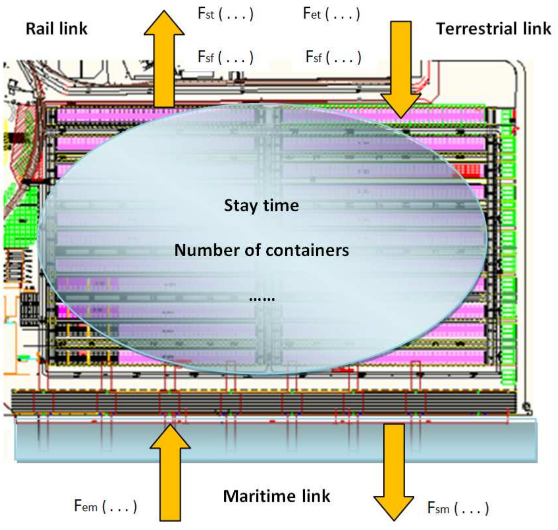


Figure 1: Level 1 scheme

In the maritime link, the ships are created by a statistical distribution that simulates the time between arrivals of the ships. The ship queue at the port entrance is modeled by a FIFO and the berth line is modeled by a discrete number of docking positions. Once the ship is moored, it will stay in the berth during a statistical service time.

In the rail link, the railroads are modeled by a finite number of ways. Once a train is assigned, it will stay a service time characterized by a distribution function. The value of this function can be affected by variables of the model: number of busy railroads, number of containers in the terminal, etc.

In the terrestrial link, there will be a FIFO queue that will model the waiting time of trucks at the entrance to the terminal. Once the truck is in the terminal, it will wait during the dwell time in the yard while the containers are unloaded and loaded.

2.2. Level 2: Maritime gate

In the second level operational details are added only in the maritime link, as has been said before.

The details of the maritime gate considered at this level are berth allocation to ships, port operations and entry docking maneuvers, allocation of cranes in the ship service (depending on this the service time) and exit maneuver port.

The critical point of this model is the determination of the distribution functions of the number of movements per hour of machines and algorithms used for the distribution of space in the berth line and the allocation of the number of cranes. So it is necessary to set more parameters than at the previous level and make available more specific information to obtain the distribution functions.

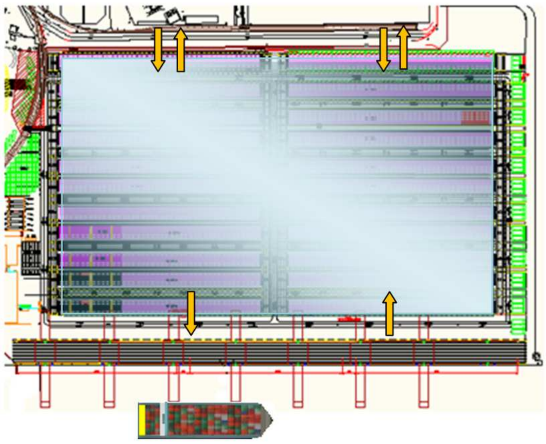


Figure 2: Level 2 scheme

The yard is modeled in the same way as level 1.

2.2.1. Ships arrival

The user could select among three options to model the load of the terminal:

- **Generic model:** it is defined "n" types of ships based on characteristics of length, width and depth. It will be used a distribution function to model the interarrival time and a discrete distribution function to define the type of the ship that arrives. The movements needed for a ship will be obtained through distribution

functions with parameters dependent on the maximum capacity of the boat. These values are stored in local variables for import and export.
- **Service model**: In this case, the arrivals of ships are modeled in accordance with a schedule to replicate the services of a specific terminal. It is added variability in arrivals (advances, delays and cancellations) using appropriate distribution functions. The service characteristics and ships will be obtained through consulting the database of the Terminal Operating System (TOS).
- **Historical model**: The traffic of the terminal will be obtained from real traffic data of the terminal. It will be added variability by distribution functions to the interarrival time, movements for each ship and alteration of the order of arrivals. It will be added a scaling factor that allows varying the traffic level in a simple way (k = 1 models the same traffic, k < 1 models a reduction of traffic and k > 1 models a proportional increase). Data will be obtained from the TOS database.

2.2.1.1. Berth allocation

For modeling the berth the real profile of the berth line of the terminal is considered and data from bollards, depth and crane work areas (if they have different characteristics) is incorporated.

For the allocation, the order of ships in the arrival queue, waiting time, required service time, movements to make, length and beam, draft and operative load of the terminal in that moment (assigned berths and available cranes) (Saurí 2009) is considered.

Some scheduling algorithms may require the use of forecast of arrivals in a determined number of hours (24, 48 hours, etc.). In that case, it would have to add a delay line between the traffic generation and the arrival to port.

The berth allocation process can be combined with the crane allocation process (ship service) that it is described in the next point, to optimize together the berthing operative and service.

Other aspects to consider in the decision process are its any-time behavior and its reactivity. Regarding the later, it should be considered the ability to re-dock planning to incidents, delays or relevant changes in the scenario.

2.2.1.2. Ship service

Once assigned the berth, the port entry time and the docking time are modeled with a distribution function of time or as an average speed and distance (using data from the port layout).

The ship service process must set the number of cranes allocated to the operations of loading and unloading. This allocation process can be built into the berth allocation algorithm or in an independent algorithm. It should be taken into account the operational features of each crane in relation to the characteristics of the ship (beam, number of bays, etc). Depending on the number of cranes that are working in the ship, it will be assigned a number of containers that should manage each one.

The operation of a crane is characterized by the number of movements per hour, and an appropriate distribution function obtained from experimental data is used. The data will include the time to be in service and the travels of the crane along the berth.

The allocation of cranes may not be static during the service time of a ship and could vary depending on the service requirements of docked ships.

Once the service is ended, it is added the undocking time and departure time from the port.
During the ship service the import containers are transferred to the yard and it is extracted the containers marked by the variable export.

2.3. Level 3: Yard partitioning

At this level the existence of different storage areas in the yard is considered. Every area has different resources and operational strategies, so time spent handling the container depends on the area where it is allocated. Internal transport elements between areas and gates are also included in the model, but the handling equipment inside the areas (RTGs, RMG, reach stacker, etc.) is not modeled.

Each area of the terminal is modeled as a homogeneous container storage that stores a particular type of container.

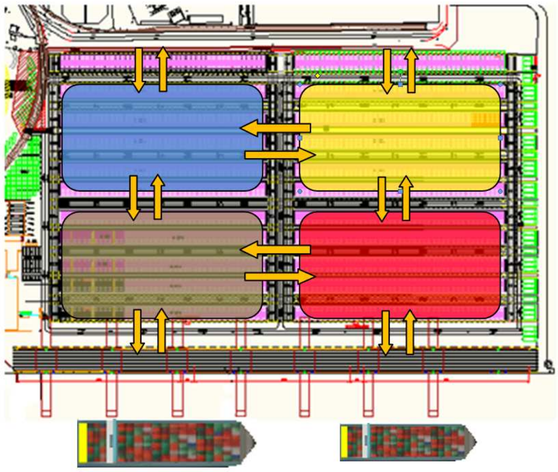


Figure 3: Level 3 scheme

In the yard it is common to use areas for import, export, empty and trans-shipment containers, but, if needed, a further subdivision can be done.

At this level, it is added data about the movements depending on the container types on each ship. For transfer containers and empty containers it is distinguished the number of loaded and unloaded containers.

2.3.1. Ship service

As at this level internal container transport is included, the service time of a crane is modeled including the interaction between the crane and the elements of internal transport, so synchronization between crane and the transport is needed.

2.3.2. Terrestrial link

Trucks that enter in the terminal should indicate the operation that they will do: leaving containers (1 or 2) and pick up (1 or 2), empty or full. After the gate, if they bring containers, they will go to a specified zone and later will go to the import zone to pick up import containers. The stay time in terminal will be set by movements within terminal and the service time in each one of the zones.

2.3.3. Model of operations in the yard areas

For each zone of the yard will be defined a stay time, that will provide the time spent managing an order for a transport element (container loading or container unloading). This time will depend on the transport operative (maritime or terrestrial), the assigned machine number to the management area, the spatial dimensions of the zone and its fill level. These functions can be obtained by simulation of more detailed level models.

There will be a manager module of the yard that it will plan all the orders of the transport elements. This plan may be global to the terminal or be oriented to the crane services that are in operation (management by human operator (Pérez 1997)).

2.4. Level 4: Block level

At this level, the details of the yard operation are increased, taking in consideration the storage yard layout, how the blocks are arranged, streets, etc. Containers will not have distinct identity within a service, so that certain operations, such as removals or housekeeping functions will be modeled by efficiency functions or by increasing service times.

For each block that enters the terminal attributes for determining the area or stack storage have to be supplied, a container location system, models to simulate the operation of the machinery responsible for managing the stack (RTG's for example), number of machines available and service areas assigned to each of them are also needed.

Figure 4: Level 4 scheme

For access to street blocks traffic directions for the streets are specified.

Each block can store containers of 20 or 40 feet. Mixed stacks will not be considered.

A block will be assigned to a preferential operational type (or exclusive): import, export, empty, transshipment. Transfers can be treated as export.

Each stack can be assigned a service, ship or destination to make easier the segregation of containers.

2.4.1. Maritime link

This level adds information regarding bays: number of bays, container movement capacity by bays. It will be differentiated 20 feet containers and 40 feet containers. So, for the allocation of cranes it will be taken into account the numbers of expected movements per bays.

2.4.2. Model of operations in the yard areas

For each area of the yard it will define a service time that will give the time spent managing an order for the transport element (loading or unloading of container). This time will depend on the operational transport (maritime or terrestrial), the number of machines assigned to the zone management, the spatial dimensions of the area and their filling level. These functions can be obtained from experimental dates or from the results obtained by more detailed simulation models.

2.5. Level 5: Terminal emulation

In the last level you get the highest degree of detail. All elements and essential operations are included in the model. Each container has all the characteristics relevant for its allocation in the terminal and its management. The simulator can be connected with the terminal operation system and interact with it in real-time or in accelerated time. This can be used for checking the operation of the TOS or see what happens when some configuration parameters are changed. But these results are valid for short time predictions because the results are very dependant of the state when the simulation starts.

3. PERFORMANCE INDICATORS

There are some well known performance indicators that are widely used in container terminal management. The proposal is to obtain these indicators from the simulation model.

Some of the indicators will be used as simulation parameters depending of the selected level. Others will be obtained from the simulation results. In this case, the indicator will be assigned to the simpler level where it can be computed (that one with the lowest number). If an indicator can be obtained in level i, then it also will be obtained in level i+k. Also, some indicators obtained in level i will be used as simulation parameters in level i-j.

At each level it must be done a comprehensive analysis to identify all the indicators that are assigned to each one. At each level we have assumed that it would need the indicators shown in the Table 1, but may be other parameters that are not indicators but necessary for the simulation.

Table 1: Indicators and parameters

Indicator/Parameter	Type	Level
Ship length	Input	1, 2
Dock length		
Docking positions		
Ship service time		
Number of gantry cranes		
Average waiting time of anchored ships	Output	
Average time from the ship arrival to port until docking ending (excluding anchoring).		
Number of access gates an available gates	Input	3
Number of trucks entering the terminal per gate number		
Number of trucks entering the terminal per gate number in rush hour		
Queue time of trucks		
Truck service time in terminal		
Traffic volume of loaded containers and unloaded container in maritime operations	Output	
Availability of trucks		
Utilization of trucks		
Number of containers per truck		
Maximum capacity of the yard	Input	4
% Utilization of the yard	Output	
Space utilization in the terminals		
RTG's utilization		

In the first column it is defined some of the indicators or parameters assumed in simulation. The second one shows if the indicator is input data (input) or whether it is a result of the simulation (output). The third one is the level where the indicator is taken into account the first time.

4. IMPLEMENTATION

The simulation tool will be usually used by technical staff of port container terminals and, commonly, they are not experts in simulation languages or tools. So, it is necessary to develop an environment for defining the terminal layout, components, its behavior, relations and parameters. Also, it is necessary to provide different tools for testing, validating and querying the terminal models using up-to-date technologies of man machine interfaces.

So, it will be helpful to use an object oriented simulation language for defining component libraries with the models of terminal interfaces, handling equipment, scheduling operations, etc. Also, it will be useful to use graphical 3D representation of simulation objects (figure 5) for showing how the terminal objects interacts and helping in model validation stages.

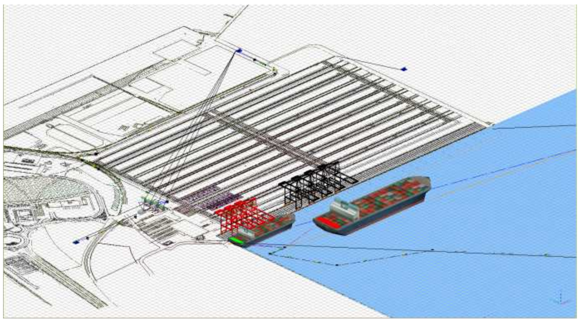


Figure 5: Simulator preview

In our case, the program used to implement the simulation is Flexsim® Simulation Software, a fully 3D simulation software environment. This software is a multipurpose simulation tool that has been used in manufacturing industry, health-care, or communications. The choice of this simulator is based on the following characteristics:

- Open structure to programming.
- Intuitive interface.
- Direct insertion of 3D elements.
- Works under OpenGL®, free graphics library.
- Programming in C/C++ and a proprietary scripting language (flexscript).
- Use of sequenced tasks for the coordination of object operations.
- Scheduling of movements based on kinematics parameters.

In addition, this simulation tool has a library for container terminals (FlexsimCT), that incorporates some the most common equipment and operations found in container terminals. But it has not been used in this development because it is a end-user library and it is not possible to include all the extra functionality presented in this paper.

Every hierarchical level is implemented as a different simulation model, that it is automatically generated using a terminal editing tool, because the simulation code is more efficient. Also, different instances of the model can be run in parallel, speeding the results.

Another critical issue in constructing simulation models for container terminals is the acquisition of object parameters from equipment specification, from real exploitation data or from both. As the model is more detailed it will be necessary to use an increased number of parameters. On the contrary, as more abstract is a model, less parameters, but there is more imprecision or uncertainty in the results. So, it is necessary to select the simulation level that best fits the performance indexes that we are interested in. This is usually the more abstract level (simpler one) that obtains those indexes as results.

But the data must be also coherent between the simulation levels: statistical density functions can be used to represent a complex behavior of different parts of the terminal operation. Then, the simulation results of all the levels must be similar (if not equal) for all these functions. Two cases can be met:

- Abstracting: the statistical functions used in level i can be obtained from simulation of model of level i+1. In this case, it is only needed to simulate the model of level i+1, record the statistical results and incorporate these to the level i as parameters.
- Detail increase: in this case, the known information is the functions of level i. Then, values of some parameter of level i+1 must be found in order to statistical results of both levels will be similar. This is a harder problem that can be solved using optimization. For measuring the similarity between statistical functions it can be used differences in mean values and variances or, even, histograms.

All the functions described here are schematized in figure 6. The user edits the terminal layout, equipment and defines the abstraction levels in the editor. Then, simulation models can be automatically generated. Parameters hint and validation tool can be used for aiding in the introduction and validation of simulation parameters. Finally, runtime scheduler and monitor are used to launch different simulation instances in parallel and collect the results.

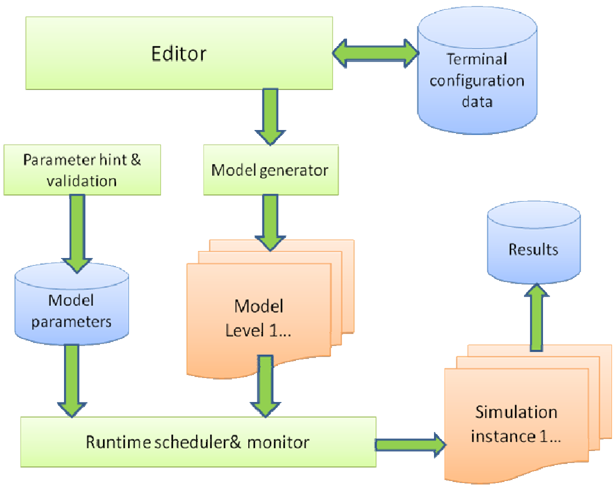


Figure 6: Simulation tool components

5. CONCLUSIONS

In this paper a proposal for the construction of hierarchical simulation models for container terminals has been presented.

The complexity of every model agrees with the results that will be obtained from simulation and, actually, they are a subset of the performance indexes used in container terminals for monitoring strategic, tactical or operations levels. This produces a simpler simulation model with less parameters and the simulation run can be more efficient and faster.

Also, a global structure of the simulation tool has been presented and, at this moment it is being developed.

ACKNOWLEDGMENTS

This work was supported by the project 19/08 –Ayudas a Proyectos I+D en Transporte e Infraestructura del Ministerio de Fomento from Spanish Government.

REFERENCES

Joschko, P., Brandt, C., Page, B., 2009. Combining Logistic Container Terminal Simulation and Device Emulation Using an Open-Source Java Framework. *In Proceedings of the International Conference on Harbor, Maritime & Multimodal Logistics. Modeling and Simulation*.

Korkealaakso, P. M., Rouvinen, A. J., Moisio, S. M. and Peusaari, J. K., (2007). Development of a real-time simulation environment. *Multibody System Dynamics*, 17:177-194.

Pérez Fiaño, J., 1997. Optimización del Proceso de Asignación del Trabajo Portuario en las Terminales de Contenedores. *Tesis Doctoral. Departamento de Transporte y Territorio. Universidad Politécnica de Cataluña.*

Rouvinen, A. (2005). Container gantry crane simulator for operating training. In Publishing, P. E., editor, *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics*, volume 219, pages 325-336.

Saurí Marchán, S., 2009. Operaciones y colas de los barcos en los puertos. *Departament d'Infraestructura del Transport i del Territori. Universitat Politècnica de Catalunya.*

Steenken, D., Voss, S., Stahlbock, R., 2004. Container terminal operations and operations research – a classification and literature review. In: *OR Spectrum 26*, pp. 3-49. Berlin, Heidelberg, New York: Springer.

SIMUL9: APPLYING UML TO A METRO SIMULATOR

J. Montero[(a)], A. Guasch [(b)], D. Huguet[(c)] and J. Figueras[(d)]

[(a)] LogiSim-LCFIB, Universitat Politècnica de Catalunya
[(b)] LogiSim, Universitat Politècnica de Catalunya
[(c)] Siemens, Mobility Division
[(d)] LogiSim, Universitat Politècnica de Catalunya

[(a)] jordi.montero@upc.edu, [(b)] toni.guasch@upc.edu, [(c)] david.huguet@siemens.com and [(d)] jaume.figueras@upc.edu

ABSTRACT
Custom-designing a simulator in a graphic environment requires use of two methodologies: one for software engineering and one for modeling of real systems. UML is a methodology geared to the design and specification of software that enables visualization, specification, construction and documentation of a system; therefore, it is ideally suited to modeling of real systems. Herein are described UML components that proved invaluable for modeling a real system, namely, for developing a simulator of Line 9 of the Barcelona metro.

Keywords: metro simulation, manless train operation (MTO), fixed block

1. INTRODUCTION

Conventional metro control systems, known as automatic train protection (ATP) systems, are based on the use of a fixed block that ensures a safe distance between two consecutive trains on the same track. Advances in contemporary control systems, combined with automation of certain processes, have reduced the role of a human operator: thus, at increasing levels of train automation (i.e. automatic, driverless or manless train operation [ATO, DTO or MTO]), the responsibilities—and indeed, the mere presence—of an operator become less and less significant.

Simulations of ATP systems can be run quite synthetically, as a chain of events in the route between stations combined with the simulator's coordination of train departures from a given station (in function of accessibility to the fixed block). However, these models cannot be extrapolated to MTO, in which trains are allowed to circulate with a variable block (i.e. a variable distance between two trains traveling in the same direction, which varies in function of the trains' respective accelerations and decelerations).

Herein are described the design, scheduling events, and experimental validation of a simulator that was specifically developed for the study entitled "Optimization and Simulation of Barcelona Line 9".

2. L9: BARCELONA'S NEW AUTOMATED METRO LINE

Line 9 (L9) is slated to be Europe's longest subway line. Spanning 47.8 km, it will link the cities of Santa Coloma de Gramenet, Badalona, Barcelona, L'Hospitalet de Llobregat and El Prat de Llobregat.

Line 9 will serve neighborhoods that currently lack metro service, such as Bon Pastor, Llefià, La Salut, Singuerlín, Pedralbes and Zona Franca, connecting residents of the five cities that it will pass through. Moreover, it will link strategic hubs, logistics centers, and major infrastructure or services areas, such as El Prat airport; Zona Franca; La Fira convention center; the Barcelona Port extension; the City of Justice judicial complex; the Diagonal university campus; Sagrera high-speed train (TAV) station; Sant Pau Hospital; Park Güell; Camp Nou; and Ciutat del Bàsquet basketball complex. It will encompass 52 stations, including 20 transfer stations that will further improve transport within the metropolitan area of Barcelona, namely, through connections with other branches of the local railway network: Rodalíes RENFE suburban rail; high-speed rail (TAV); other metro lines (Lines 1, 2, 3, 4 and 5); FGC suburban rail (Lines 6, 7 and 8), and the Trambaix and Trambèsos tram lines.

Line 9 will be completed by 2014. Transit studies have predicted an average daily ridership of 350,000 passengers, equivalent to 130 million passengers per year.

3. SIMUL9

SimuL9 is a custom-made simulator that runs on Windows XP (SP3) and Framework.Net 2.1. It is a specific, object-oriented simulator based on an event-scheduling methodology that combines discrete simulation (temporal management of periodic events) with continuous simulation (train traction).

Owing to its various advantages, including scalability, reusability and parallel task operation, the Model-View-Controller programming paradigm was chosen for development of SimuL9. This paradigm enables separation of a business model's logic from its view, via a controller which communicates the events that occur.

3.1. Control Elements in MTO

Line 9 of the Barcelona metro, like most automated lines, will be equipped with an array of logic and physical elements to guarantee control and tracking of the automated trains. These include:

- Controller zone (CZ)
- Automatic train supervisor (ATS)
- Automatic train control (ATC)
- Supervisory control and data acquisition (SCADA) systems

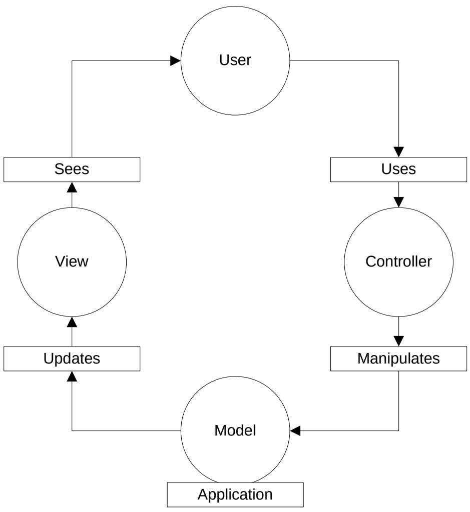


Figure 1: Schematic of the Model-View-Controller programming paradigm

Furthermore, L9 will feature sensors and odometric elements to enable teledetection of the position of different trains circulating on the same track. Obviously, L9 will also require a backup system to ensure correct operation in the event that the primary system fails.

Simul9 was designed expressly to behave exactly as an MTO control system would behave.

4. UML

Developing a specific simulation model requires a firm grasp of the domain to be modeled; the deeper the programmer's knowledge on the domain, the easier the programming of the simulator.

Unified Modeling Language (UML) is geared towards the design and specification of software that enable visualization, specification, construction and documentation of a system.

Design by UML is built around a series of diagrams and documentation practices, including conceptual and relational models, class diagrams, use-cases sequences, and collaboration diagrams.

4.1. Conceptual model

The UML conceptual model (Figure 2) is used to identify the major concepts in the subject domain.

Based on the objectives defined for the simulator, the significant elements for the simulator's conceptual model are established.

The final objectives for SimuL9 enabled the railway infrastructure to be treated as a single simulation object (Railway) which would contain all of the railway segments (Tracks), have the correct parameters, and dictate the logic of the queries from the remaining simulation elements.

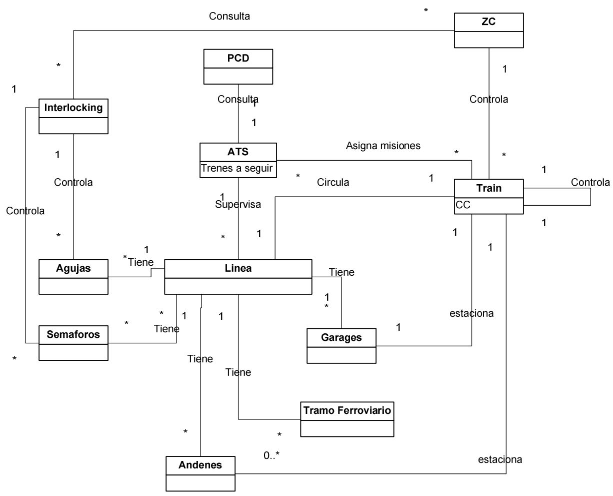


Figure 2: Conceptual model

Connecting all of the railway segments yielded a plot which enables dynamic breakdown of the trains according to operation time.

4.2. Relational model

The UML relational model is used to establish the logic that rules the system's constituent elements.

The relational model for SimuL9 proved invaluable in communication the simulator to the client, from whom accreditation of the model is pending.

This model was devised by combining the simulator's conceptual model with the use cases for each element, which generated a list of responsibilities and obligations for each simulator element.

4.3. Class diagram

Generalizing the aforementioned models provided a class diagram, and consequently, the objects that had to be encoded such that, once queried, they could enable specific simulations to be run (in this case, of L9 or any other automatic train under the same Siemens control system).

Interestingly, objected oriented design facilitates the scalability and specialization of the current model, meaning that other train control systems could be integrated into an expanded version of SimuL9 through specific coding of new simulation elements.

4.4. Application architecture

After the definition of the programming paradigm and the specification of the data model, the application architecture has been developed.

The application has a central database where all data is stored, from physical model of the network to simulation results. As the system uses a MVC schema, there are different modules for each activity. They are: the simulation kernel, the physical model of the rail network, the statistics module and the representation module. All of them are linked with the database and, of course, with the Graphical User Interface (GUI). All these elements are described in Figure 3.

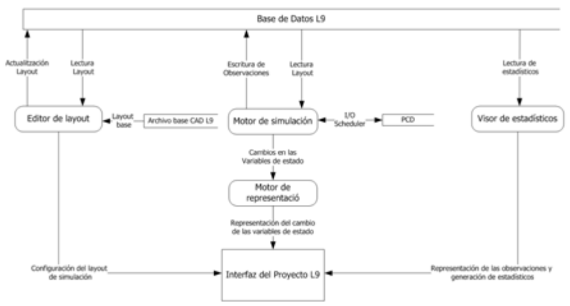


Figure 3: Application architecture

The physical model module is also in charge of the conversion of CAD models to logic ones and the simulation kernel also uses operation plan to control the rail system.

5. SIMULATION MODEL

The UML specification enables definition of all the components required to develop the simulator, as well as of the logic that dictates the interactions among them.

To complete the simulation model, a series of discrete and continuous simulation events had to be managed and linked together. These events were needed to allow temporal evolution and state-variable value changes in the model.

5.1. Traction, system continuity, control, and supervision model

The system is controlled and supervised at two levels:

1. Simulation of train dynamics with the advantages offered by use of a mobile block;
2. Use of interlocking, which guarantees transit safety on a given train route.

5.1.1 Metro dynamics

The basic continuous equations used to model the metro dynamics are:

$$T - R = m \cdot a$$
$$R = A + B \cdot v + C \cdot v^2 \tag{1}$$

Whereby T is the traction effort; R is the resistance to the train's movement; m is the train's mass; and a is the train's acceleration. The coefficients A, B and C depend on the mechanical resistance, aerodynamic drag and grade resistance, respectively. Using these equations, the acceleration in traction mode is given by:

$$a = \frac{1}{m}\left[T - (A + B \cdot v + C \cdot v^2)\right] \tag{2}$$

The Barcelona metro L9 network uses a moving block control system. Under these systems, computers calculate a safe zone around each moving train, which no other train is allowed to enter. The system requires knowledge of the exact location, speed and direction of each train, which is determined by a combination of several sensors, namely, active and passive markers along the track, plus onboard tachometers and speedometers. With a moving block, lineside signals are not required, and instructions are passed directly to the trains. This has the advantage of increasing track capacity by allowing trains to run closer together while maintaining the required safety margins.

5.1.1. Interlocking

When trains circulate over a system of tracks, they generate circuit routes that must be carefully protected. In SimuL9, this protection was achieved by dynamically creating petitions from circulating trains. These petitions are managed by the controller zone (CZ), which is responsible for receiving circulation notifications (i.e. variations in the circuit route) sent to it by the trains over the course of the simulation. Thus, when the CZ detects a set of available segments, it proceeds to exclusively assign the transit segments requested by a given train. Likewise, this same train notifies the CZ once it has abandoned a given segment, such that the CZ can then determine when the interlock will be available. Efficient management of these interlocks enables safe control of the circulating trains in the simulation.

5.2. Discretization of the system

Discrete simulation of L9 is achieved through temporal events associated to a daily operations schedule known as *PCD*, namely, mission start (see below), and passenger boarding and exiting services, and to events in Emergency Mode, which enables simulation of line failures.

5.2.3 PCD

A single PCD encompasses all required daily operations. The PCDs are defined based on the service missions and lines. A mission is a sequence of stations and transit segments in which a train must complete a series of operations (e.g. stopping for passengers or traveling without stopping).

Initiating a mission at a given point in time generates a services line in which the service time for each passing point is provided; each mission start can be considered a valid PCD operation.

5.2.4 Safety operations

Safety operations in SimuL9 are simulated in Emergency Mode, through a special interface that enables the user to define *PCDs* and line operating incidents.

Operating incidents are described according to the time that they occur, the track segments that they affect, and their duration.

Each event associated to an operating incident that affects a given train is linked to a service recovery event for that train.

6. EXPERIMENTATION

SimuL9 can run simulations of L9 under daily operations schedule (PCD), as well as in emergency scenarios, such that the line's operations can be evaluated in terms of train service time and frequency in each experiment.

6.1. Emergency Mode

Emergency Mode was developed to allow the user to select the type of safety operations strategy to adopt (*i.e. bypass* or *split*) in the event of an operating incident (Figure 4).

1. In bypass, or VUT, operation, trains switch tracks in order to avoid the affected train while preserving the service line.
2. In split operation, the system divides all of the service lines in order to provide full service along the entire L9 route.

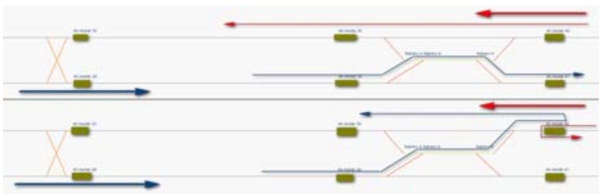


Figure 4: Bypass/VUT (top) and split (bottom) safety operations

6.2. Case studies

Examples of cases being evaluated in the final phase of SimuL9 include:

- Extra service for sporting or other large events (e.g. for FC Barcelona games at Camp Nou or for the Mobile World Congress at the Fira de Barcelona convention center).
- Sequencing missions with passenger service at alternating stations.
- Simulation of the full L9 and L10.

7. SIMULATION RESULTS

This section reports on some of the results obtained from simulations run under Standard Mode; however, results from simulations run with optimized PCPs are not described.

Analysis of the simulations of missions with passenger service at alternating stations reveals time savings of roughly 10% for covering the entire route, equivalent to approximately 7 minutes per trajectory. This reduction in time opens the possibility of introducing more trains over the course of the day, and consequently, the chance to increase the total number of kilometers covered daily.

Running simulations in Emergency Mode with various periodic operating incidents provided a table of service frequencies that ensure proper transit along the line without any losses in train circulation and enable determination of which emergency option (bypass/VUT or split) is the best suited according to the location of the operating incident.

Interestingly, bypass/VUT operation generally provided better performance than split operation, given that the latter penalizes transit at the point of return, as revealed in Figure 5, below. The illustration shows that when Train B begins its return maneuver, Train A must slow down, and ultimately, stop.

Figure 5: Transit is penalized at the point of return

8. GUI

The graphic user interface (GUI) in SimuL9 was designed to meet three objectives, all of which are necessary for developing a specific simulator:

- Verify that the simulator is working correctly, through experimentation and execution of different encoded processes, including:
  1. Generation of missions, assignment of a train to a service line from the PCD, etc.;
  2. Transit control, safety system, etc.;
  3. Management of operating incidences.
- Validate train circulation operations under optimized PCPs and in Emergency Mode;
- Establish credibility for the simulation model.

The interface in SimuL9 comprises the essential elements of any Windows application: a menus system, toolbar, properties windows, and graphics views.

8.1. Menus system and toolbar

The menus system and the toolbar in SimuL9 are the first element of interaction between the user and the application. They enable the user to:

1. Create simulation scenarios;
2. Configure transit tracks;
3. Configure Emergency Mode;
4. Define experimental *PCDs*;
5. Control the simulation.

8.2. Properties window

The properties window allows configuration of the simulation's general parameters, including:

- The integration step;
- Parameters such as friction, masses, kinematics, etc.
- Generic parameters, such as a simulation's interval of representation.

8.3. Graphics views

Lastly, SimuL9 features two graphics views, Pane and Zoom, which enable tracking of train movement and operating incidences at two different levels of magnification: total and partial.

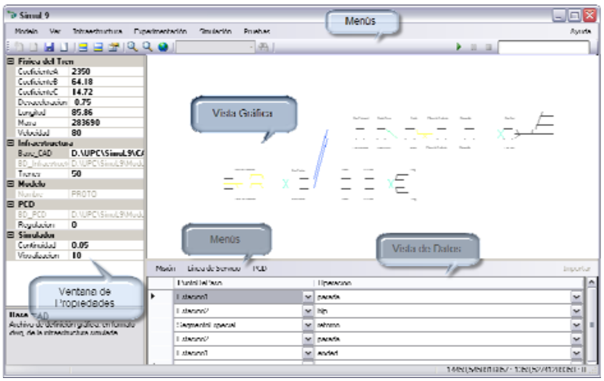


Figure 5: SimuL9 GUI

9. CONCLUSIONS

Unified Modeling Language (UML) is a specification language that facilitates developer's work for a specific simulator, namely, by enabling clear identification of a conceptual data model and direct relation of this model to a conceptual simulation model.

In the case reported here, development of the train simulator SimuL9, UML elements such as case-use diagrams and relational models allowed specification of the logic that dictates the simulation objects integrated into the model.

Unified Modeling Language has proven essential for attaining credibility for SimuL9 from the client, by enabling the client to actively participate in the initial phases of the simulator's development.

ACKNOWLEDGMENTS

This work is being funded by the *Departament d'Innovació Universitat i Empresa* (*Generalitat de Catalunya*, Spain) and the *Ministerio de Industria, Turismo y Comercio* (Spain). The authors thank the master students Joan Antoni Navarro and Alvaro Sanchez-Muro for their contributions to this project.

REFERENCES

L.B. Arief, N.A. Speirs, Proceedings of the 2nd International Workshop on Software and Performance. pp. 71-76; 2000; Ottawa, Canada

Fries R., Chowdhury M., Brummond J., Transportation Infrastructure Security Utilizing Intelligent Transportation Systems, John Wiley & Sons Inc.

Object Management Group. Unified modeling language superstructure specification - v2.0. 2005.

Ortúzar J., Willumsen L., Modelling Transport, 3rd Edition, John Wiley & Sons Inc., 2001

J. Pachl. Railway Operation and Control. VTD Rail Publishing, New Jersey, 2004.

Man Hon Y., Kollmann M. Simulation and Verification of UML-based Railway Interlocking Designs, Automatic Verification of Critical Systems (AVoCS 2006); Nancy, France

AUTHOR BIOGRAPHIES

Born in 1968, Jordi Montero earned his BS in Computer Science in 1998, and has worked as a PAS at UPC since 2000. His research interests include discrete simulation systems. He has worked on several projects for various companies (*e.g.* Aena, Agbar, Almirall Prodesfarma, Damm, Indra and Siemens) from diverse sectors (*e.g.* airport, transport, manufacturing and pharmaceuticals).

Born in 1958, Dr. Antoni Guasch is a research engineer focusing on modeling, simulation and optimization of dynamic systems, especially continuous and discrete-event simulation of industrial processes. He received his PhD from UPC in 1987. After a postdoctoral stay at the California State University, Chico (USA), he became a professor at UPC. He is now Professor in the department called *Ingeniería de Sistemas, Automática e Informática Industrial*. Since 1990, Prof Guasch has led 35 industrial projects related to modeling, simulation and optimization of processes for the nuclear, textile, transportation, auto manufacturing and steel industries. Prof. Guasch has also served as scientific coordinator and researcher on seven scientific projects. He has also helped organize local and international simulation conferences. For example, he was the Conference Chairman of the European Simulation Multi-conference held in Barcelona in 1994. He recently published a modeling and simulation book that is now being used in many Spanish university classrooms. Prof. Guasch's current research project, sponsored by Siemens, is related to the development of power management optimization algorithms for Barcelona's new subway Line 9. Line 9 will be the first driverless metro in Spain and one of the largest (45 km) and most advanced driverless lines in the world. Prof. Guasch is also contributing to the development of tooPath (www.toopath.com), a web server system for free tracking of mobile devices.

Born in 1975, Dr. David Huguet is currently a Project Research Manager in the Mobility Division of Siemens. His work focuses on the simulation and modeling of metros and tramways to optimize their kinematic profile and to reduce traction energy. Dr. Huguet is currently a professor in the Department of Mechanical Engineering at UPC, where he received his PhD in 2005 for his work on Fluid Mechanics. He is presently working on the SIMUL9 and TRAM projects in collaboration with UPC researchers.

Born in 1974, Jaume Figueras earned his Degree in Computer Science in 1998. His research is in automatic control and computer simulation & optimization. He designed and developed CORAL, an optimal control system for sewer networks, used in Barcelona, Spain; and PLIO, an optimal control system and planner for drinking water production and distribution, used in Santiago de Chile, Chile, and Murcia, Spain. He is currently collaborating on different industrial projects, including the power-consumption optimization of tramway lines in Barcelona, in conjunction with TRAM and Siemens, and the development of tooPath (http://www.toopath.com), a free web tracking system of mobile devices. Jaume Figueras is also the local representative of OSM (http://www.openstreetmap.org) in Catalonia and participates in different FOSS projects.

MODELLING AND ANALYSIS OF MECHANICAL STEEL HANDLING PROCESSES IN SEAPORTS

B. Scholz-Reiter[(a)], J.T. Tervo[(b)], M. Görges[(c)], R. Matthies[(d)]

[(a), (b), (c)] BIBA – Bremer Institut für Produktion und Logistik GmbH
Hochschulring 20, 28359 Bremen
Germany

[(d)] BLG Cargo Logistics GmbH & Co. KG.
Neustädter Hafen, Schuppen 22 / Senator-Borttscheller-Straße, 28197 Bremen
Germany

[(a)] bsr@biba.uni-bremen.de, [(b)] ter@biba.uni-bremen.de, [(c)] goe@biba.uni-bremen.de, [(d)] rmatthies@blg.de

ABSTRACT

Despite the actual financial crisis the quantities shipped in international seaports are assumed to increase during the next years. Due to spatial and capacity restrictions many modern seaports have limited possibilities for expanding their current infrastructure. Hence, seaports need to use their particular resources in a more effective manner, in order to fulfil the demand. In this context novel approaches and processes for material handling may help to increase the effectiveness of the entire maritime logistic chain. This paper will focus in particular on the handling of steel sheets, which are determined for the export, in an exemplary case at a German seaport. It focuses on modelling the underlying business processes by event-driven process chains (EPC). These EPCs are analysed in order to identify major weak points and improvement potentials. On the basis of these potentials an innovative magnetic handling process will be discussed. It will be shown how this magnetic device may help to use the identified potentials and to overcome the weak points.

Keywords: maritime logistics, handling processes, magnet technology, event-driven process chains

1. INTRODUCTION

During the last years an intensive growth of cargo traffic in seaports world-wide was recorded. Especially, the world-wide maritime traffic profited from this development strongly (Stopford 2009, Amerini 2007). However, on the one hand there is a need to serve these increasing cargo quantities. On the other hand, efficient handling and warehousing processes have to be offered to customers, in order to stay competitive (Zondaga et al. 2010). Additionally, the actual financial crisis has intensified this competitive pressure. In this context technological process innovations are promising. Especially, with regard to the limiting factors, e.g. spatial restrictions, which reduce possibilities to upgrade existing infrastructure and capacities, the implementation of new technologies is necessary. The development of such novel technologies increases the competitive advantage of enterprises in the maritime business. But also, these innovations may affect the whole sector (Metcalfe and Ramlogan 2008, Roper et al. 2008). Regarding steel handling in seaports this means, that the whole industry sector may be affected positively by the implementation of new efficient handling technologies and unified processes.

The handling of steel products is a classical load handling process with a low degree of automation. It is characterized by mechanical load handling devices like hooks, chains, ropes and belts. Usually, these devices are attached manually to the steel sheets. Therefore, this process offers potential for technological improvements.

This paper will present a detailed analysis of a steel handling process in an exemplary business case, which mainly focuses on the handling of steel sheets at BLG Cargo Logistics GmbH & Co. KG. in Bremen, Germany. Based on an event-driven process chain model of the entire process its weak points will be identified and classified. These weak points will be investigated with regard to aspects of process quality, process stability, economic potentials and safety of workers. Furthermore, a magnetic traverse for steel sheet handling will be discussed as a possible solution for the identified weak points.

Therefore, this paper is structured as follows: section 2 presents the perspective of modelling maritime processes with event-driven process chains. Subsequently, section 3 presents the detailed model of all process steps involved in the whole handling process. The corresponding weak points are discussed in section 4. In section 5 a possible solution for this process by using a magnetic handling device is discussed. Finally, section 6 gives a summary and provides an outlook with further research directions.

2. MODELLING BUSINESS PROCESSES USING EPC

The analysis of material handling processes should not be limited to a pure analysis of single handling functions. Rather the entire logistic process should be investigated, in order not to breach interdependencies between logistic target measures (Arora and Shinde 2007).

The event-driven process chain is a commonly used method for business process modelling (BPM) (Rosemann and van der Aalst 2007). It is a graphical representation of processes, which divides the total process into sequences of functions and events. These elements (functions and events) are modelled as nodes, which are connected by arrows. Logical distinctions of processes can be modelled by applying logical connectors. Functions in an EPC are denoted by rounded rectangles. These functions describe tasks, which have to be performed by an organisational unit. In this context functions are time-consuming procedures. In contrast, events do not consume any time. They are passive elements, which occur as a result of one or more functions at a particular point in time. In the graphical EPC-representation events are denoted as hexagons. Logical connectors can be used to model different kinds of distinctions in the process. These different types are 'AND', 'OR' and 'XOR' connectors. They denote when a function leads to two or more events, when two or more functions start one event and both vice versa (Scheer 1999).

Modelling business processes by EPCs is widely spread among researchers and practitioners. Nevertheless, this method has besides its several advantages certain disadvantages. Kesari et al. (2003) point out in their survey on BPM some of them, which mainly concern the possibility of over-analysis, developer-biasedness and misinterpretations. An over-analysis means that the modeller sets the wrong focus. Highly detailed models which do not focus the main aspects of the processes are a possible consequence. Moreover, this kind of over-analysis leads on the other hand to possible misinterpretations of third parties. Some authors identified another reason for possible misinterpretations. They argue, that the semantics and syntax of the EPC are not well defined (van der Aalst 1999, Kindler 2004). But due to their simple notation and their intuitive interpretability (Ko et al. 2009, Scheer et al. 2005) EPC models are used in this paper.

3. PROCESS MODEL

3.1. General process description

In the presented case a particular handling process of steel sheets at BLG Cargo Logistics GmbH & Co. KG. in Bremen, Germany is investigated. Usually the steel sheets are delivered by rail to the seaport and are stored for further export shipment. Starting from this point, the investigation focuses physical handling processes concerning the loading procedure of ships for export. Hence, port internal storage and handling processes are included in this study.

The complete steel handling process in the case at hand can be divided into three parallel running sub processes:

1. Pick-up from storage
2. Transfer to ship
3. Placing timber

In the first sub process a reach stacker or a fork lifter takes out material from stock in the 'storage area' and places it on a trailer. Notice that multiple steel sheets are moved as a ply to the trailer. The amount of sheets per ply depends mainly on the weight of the steel sheets and varies between two to four. After pick-up from the 'storage area', the trailer drives directly to the 'adjustment area', where a second fork lifter adjusts the steel sheets interlocking by pushing them in a predefined position. This is necessary because the crane can only pick up steel plies with a plain geometry. Afterwards the trailer transports the steel sheets to the 'crane area'. It has to wait in this area until the crane picks up the steel sheets. In this moment the trailer starts driving and completes its round course with arriving at the storage area again. Meanwhile, the crane turns and releases the steel sheets into the ship. After this, workers inside the ship have to place timber beams on the top of the latest ply of sheets. This step is indispensable for the unloading procedure in the port of destination. Without placing the dunnage there is no jacking point for the steel handling device in this port. In this particular case the mechanical load handling device consists of four claws mounted on chains, which are connected to a traverse at the crane. The claws have to be fixated on predefined positions at the steel ply to ensure a correct transportation.

The amount of trailers circulating between storage and crane area depends mainly on the distance between mooring place of the ship and storage area. Usually it varies between two and five trailers. The particular number of trailers is determined by a task-dispatcher case-by-case. Further resources involved are two fork lifters, four manual workers on the land side and four manual workers on the water side. These resources are schematically depicted in figure 1.

The following provides a detailed model of this steel handling process in terms of event-driven process chains.

3.2. Detailed EPC-Model

The overall EPC model in figure 2 depicts the total process and the dynamic interplay between all involved sub processes. For the focus of this paper the general EPC model is aggregated to the form of the model in figure 2. In particular the functions 'pick up of steel sheets' and 'crane turns load into the ship' are aggregated representations of sub processes.

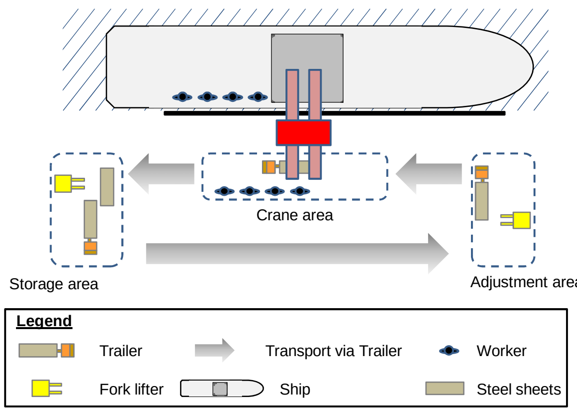


Figure 1: Schematic view of the handling process

In order to investigate the mechanical handling process, this paper presents only the underlying process of the first sub process ‘pick up of steel sheets’ in figure 3.

The general process shown in figure 2 can be divided into three strands, which represent the three sub processes described before. The process starts with an initial event, which indicates that all necessary resources (e.g. cranes, fork lifters or trailers) are in the right set-up state to start the process. Then, the first strand describes the transfer of the steel sheets to the ship. The interdependency between this sub process and the sub process ‘placing timber’ can clearly be seen in figure 2. There is a loop for the ‘placing timber’ process, which starts after the crane placed the steel sheets in the hatchway. On the other hand the next ply of steel sheets can be transferred, if all timber beams are in the right place. This interplay of both processes is indicated by the multiple ‘AND’ connectors between these process steps. In the same way the interdependency between the sub processes ‘transfer to the ship’ and ‘pick-up from storage’ is modelled. As indicated in the verbal description, the trailer drives directly after ‘pick-up’ back to the storage area. In the EPC model this is represented by an ‘AND’ connector. Similar to ‘placing timber’ this sub process has a loop back to the ‘transfer to ship’ process. The loops determine the temporal interdependency of all three sub processes. In occurrence of an unforeseen disturbance in one of these processes the total process stops. In this context, the manual handling process in the crane area is the temporal bottleneck of this process. Thus, a detailed EPC diagram is given in figure 3. It represents the activities in the aggregated function ‘Pick-up of steel sheets’ in figure 2.

Almost all activities in figure 3 can be modelled as a linear sequence of functions and events. The crane turns the chains to the workers, who finally attaches the chains and the claws to the ply of steel sheets. Subsequently, the workers have to press manually against the claws until the crane lifts the sheets slightly.

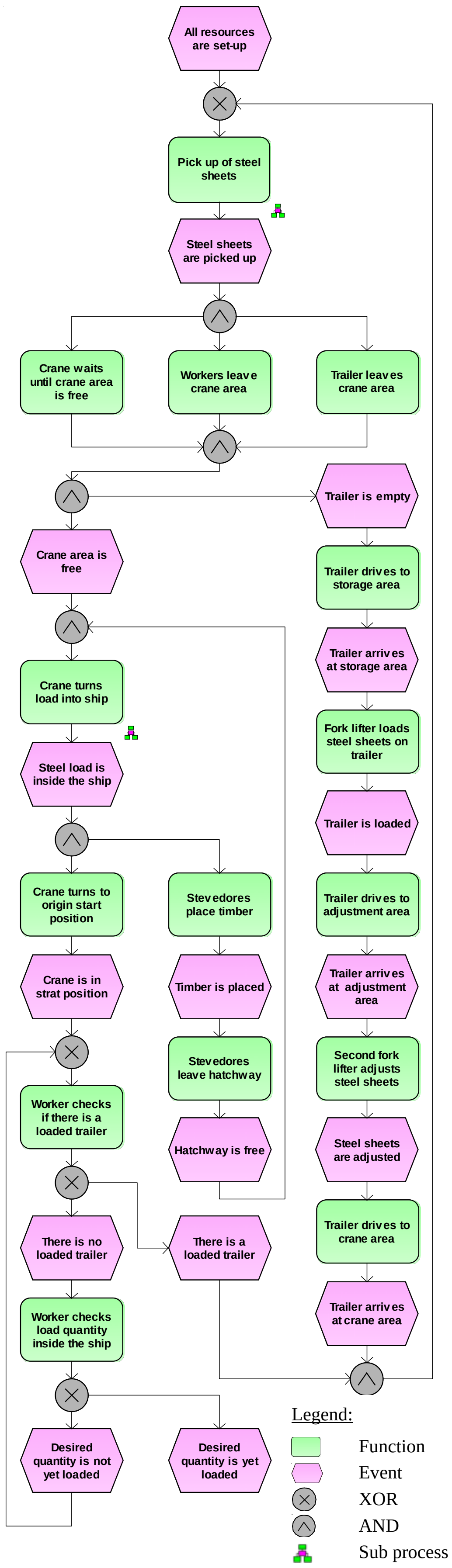


Figure 2: EPC Model of the steel handling process

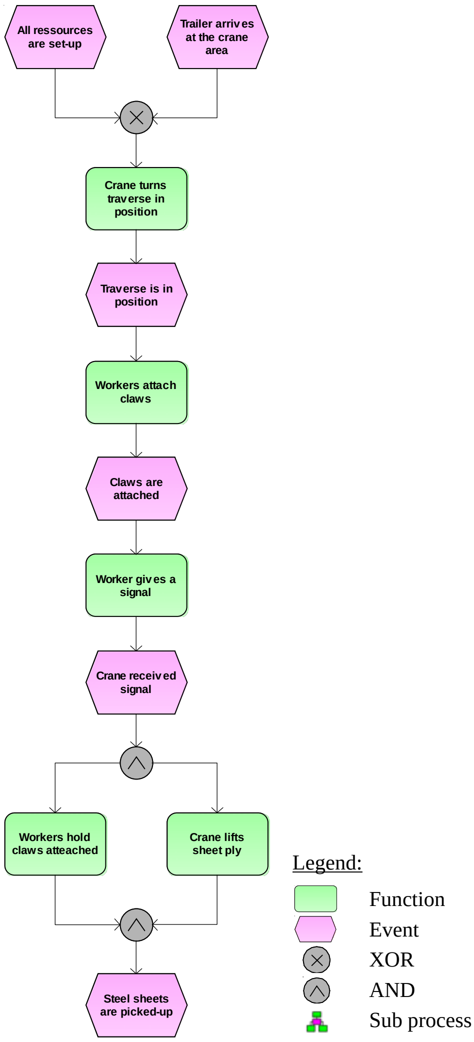


Figure 3: EPC sub model crane turns load into the ship

Only after this slight lifting of the steel ply the correct mechanical force transmission can be guaranteed. Finally, after these steps the process continues at the first 'AND' connector in figure 2. In the next process step all workers have to leave the crane area for safety reasons. Thus, as indicated in figure 2, the process interrupts until the crane area is free. Due to the modelled loop in figure 2 the total process is repeated until the pre-defined quantity of steel sheets is loaded into the ship.

4. WEAK POINT ANALYSIS

A detailed analysis of the handling process led to four major weak points regarding the safety, quality, stability and efficiency of the process. They appear especially in the sub-process of mounting the handling device to the steel sheets.

4.1. Safety

As shown in figure 3, workers have to attach claws to the steel sheets manually. Afterwards, they have to hold them in the right position while the crane is lifting the handling device until all chains are tight. This is necessary to ensure the correct fixing of the claws at the steel sheets. It is obvious that during this process workers can easily bruise fingers or a hand by accident. In general bruises are besides fractures a common type of injuries in the maritime sector (Ellis et al. 2010). Due to the weight of the claws and the occurring forces during the lift process, this may lead to serious injuries.

Furthermore, the claws need to be mounted at predefined positions at the steel sheets. If they are located at a wrong place, e.g. in the border area or in the middle of the sheets, the steel sheets will bend. Thus, they cannot be handled and transported correctly. In the worst case scenario, the claws can loosen and the steel sheets would fall down. Due to the physics of such sheets, they would not fall down straightly but float down like a sheet of paper. This may lead to damage of surrounding infrastructure or to serious or lethal injuries of workers.

4.2. Quality

Generally, the use of claws in the handling process leads to the danger of damaging the steel sheets. While the claws are put on, there is a risk of scratching the sheets. This causes a reduction of the product quality. Also, like described above, the incorrect mounting of claws leads to a bending of the steel sheets. This also reduces product quality. In the worst case scenario, when the steel sheets fall down, they are generally completely damaged.

4.3. Stability

The sub-process of mounting the claws at the steel sheets was described in section 3.2 in detail. An analysis of the process steps showed a certain instability of process times. The weight of the claws and the monotonous activity lead to rising fatigue of workers. Therefore, process times exhibit a higher mean value and a higher variance the longer this tiring activity is performed. The sub-process becomes more and more unstable. Since there is a strong interaction between all sub-processes the overall process times also increase and vary.

4.4. Efficiency

In the described handling process there are four workers needed on landside and on seaside, respectively. As detailed above, the workers at landside have the task to mount the handling device to the steel sheets. The remaining time within the process is waiting time for the next handling steps and can be used for recovery. Likewise, workers at seaside within the ship have a similar task. They loosen the claws from the steel sheets and place timber beams. In total, approximately only 20% of the whole process time is working time, whereas 80% is waiting time. This shows a low efficiency of this sub-process.

5. PROPOSED SOLUTION

The proposed solution to resolve the mentioned weak points within the handling process of steel sheets is the use of a magnetic traverse. Actually, there are three different possible magnet technologies which can be used here. These are an electromagnetic, an a-stable permanent magnetic and a bi-stable permanent magnetic system. The functionality as well as the advantages and disadvantages were shown by Scholz-Reiter et al. (2008).

Due to safety reasons an electromagnet system needs to be constructed redundantly. If one systems fails, the other one can take over the task. Thus, the weight of the whole traverse would be too large. Regarding the maximum load of the crane only one steel sheet could be moved per lift. Detailed calculations and simulations of the remaining two systems have shown that an a-stable permanent magnet system has the highest force/weight ratio. Furthermore, its capability to change the magnetic force continuously makes it the preferable choice.

At present, a magnetic traverse is being developed using this technology. Eight single magnet systems will be attached to a traverse and be equally distributed over the surface of the steel sheets. The solution has to be able to handle up to three stacked steel sheets with the dimensions 12m x 4,38m x 19mm each. Since there are air gaps between the single steel sheets, it is extremely challenging to develop this magnetic system, so that it complies with German safety standards in seaports.

The magnetic traverse will strongly change the here presented process of handling steel sheets in different points. Especially, the new process will exhibit the potential to resolve the presented weak point within the actual handling process.

Due to the process automation it will be possible to save labour. Depending on the final configuration and design of the traverse up to six workers might become free for further tasks in the seaport area. The automation also leads to a better stability of the process as a whole. The influence of tired workers on the process times can be reduced significantly. It can be estimated that the variance and the mean of the process times will decrease. Thus, the stability of this sub-process will positively influence the interaction of all three sub-processes.

With the substitution of the manual load handling attachments by a magnetic system many manual activities of workers become obsolete. Thus, possible injuries of workers when mounting the claws to the steel sheets can be avoided. Furthermore, the well defined position of the single magnet systems on the traverse ensures the correct and planar handling of the steel sheets. This prevents the sheets from being damaged or falling down.

6. SUMMARY AND OUTLOOK

Before the financial crisis, quantities shipped in international seaports increased and will in future again increase even more. Due to spatial restrictions in seaport areas, it is important to use the existing infrastructure effectively to stay competitive. Nowadays, the steel handling process in seaports is mostly performed with manual load handling devices.

To investigate the weak points of this handling process a detailed process analysis was performed in the seaport of BLG Cargo Logistics GmbH & Co. KG. in Bremen, Germany. A process model using EPCs was developed. Based on this, four major weak point could be identified regarding safety, quality, stability and efficiency of the process. The proposed solution to resolve these weak points is the use of a magnetic traverse. It can be estimated, that the four presented weak points can be optimized in this way. At present a model of the developed magnetic system is built to examine the real behavior of such a system. Based on the gathered results a magnet traverse will then be built.

To evaluate the impact of the solution a profitably analysis is being performed. It contains at present the actual situation of the process presented in this paper. Future work will contain a simulation study to approximate the benefits using a magnet traverse. To be later able to substitute the simulation data with real data, the developed magnet system will be installed to a crane in the port of the operator. Extensive field tests will then be performed to be able to finalize the profitably analysis.

ACKNOWLEDGMENTS

This research is funded by the German Ministry of Economics and Technology (BMWi) based on a decision of the German Parliament. The project “Advanced stowage and handling technology for steel products (ISUS - Intelligente Stau- und Umschlags-technologie für Stahlprodukte)” is situated in the funding programme Innovative Seaport Technologies II (ISETEC II).

REFERENCES

Amerini, G. 2007. Maritime Transport of Goods and Passengers 1997 - 2005. *Statistics in focus* 94/2007. London: Eurostat.

Arora, K.C. and Shinde, V.V, 2007. *Aspects of materials handling.* New Delhi, Boston: Laxmi cop.

Ellis, N., Bloor, M. and Sampson, H., 2010. Patterns of seafarer injuries. *Maritime Policy & Management*, 37(2), 121 - 128.

Gudehus, T., 2005. *Logistik: Grundlagen, Strategien, Anwendungen*. Berlin: Springer.

Kesari, M., Chang, S. and Seddon, P.B., 2003. A content-analytic study of the advantages and disadvantages of process modeling. *ACIS 2003 Proceedings.*

Kindler, E., 2004. On the semantics of EPCs: a framework for resolving the vicious circle. *Proceedings of 2nd International Conference, BPM*, Potsdam.

Ko., R.K.L., Lee S.S.G. and Lee E.W., 2009. Business process management (BPM) standards: a survey. *Business Process Management Journal* 15(5), 744-791.

Metcalfe, S. and Ramlogan, R., 2008. Innovation systems and the competitive process in developing economies. *The Quarterly Review of Economics and Finance* 48(2), 433-446.

Roper, S., Du, J. and Love, J.H., 2008. Modelling the innovation value chain. *Research Policy* 37(6), 961-977.

Rosemann, M. and van der Aalst, W.M.P., 2007. A configurable reference modelling language. *Information Systems* 32(1), 1-23.

Scheer, A.-W., Thomas, O. and Adam, O. 2005. Process modelling using event-driven process chains. In: Dumas, M., Aalst, W., Hofstede, A.H.M. eds. *Process-aware information systems*. Hoboken: Wiley-Interscience.

Scheer, A.-W., 1999. *ARIS – Business Process Frameworks*. Berlin: Springer.

Scholz-Reiter, B., Hinrichs, U. and Tervo, J.T., 2008. Advanced handling of steel products in seaports using magnet systems. In: Bruzzone, A., Longo, F., Merkuriev, Y., Mirabelli, G., Piera, M. eds. *11th International Workshop on Harbour, Maritime and Multimodal Logistics Modeling and Simulation (HMS2008)*, 202-207.

Stopford, M., 2009. *Maritime Economics*, Taylor & Francis.

van der Aalst, W.M.P., 1999. Formalization and verification of event-driven process chains. *Information and Software Technology* 41(10), 639-650.

Zondaga, B., Buccia, P., Gützkowb, P. and de Jongc, G., 2010. Port competition modeling including maritime, port, and hinterland characteristics. *Maritime Policy & Management* 37(3), 179-194.

AUTHORS BIOGRAPHY

Prof. Dr.-Ing. Bernd Scholz-Reiter is head of the department Planning and Control of Production Systems at the University of Bremen and managing director of the BIBA - Bremer Institut für Produktion und Logistik GmbH at the University of Bremen. He is Editor of the professional journals Industrie Management and PPS Management. Prof. Scholz-Reiter is a corresponding member of C.I.R.P., the International Institution for Production Engineering Research and also a member of the Scientific Advisory Board of Bundesvereinigung Logistik e.V. He is also vice president of the German Research Foundation (DFG).

Dipl.-Phys. Jan Topi Tervo works as a research scientist at the BIBA - Bremer Institut für Produktion und Logistik GmbH at the University of Bremen in the division Intelligent Production and Logistic Systems.

Dipl.-Wi.-Ing. Michael Görges works as a research scientist at the BIBA - Bremer Institut für Produktion und Logistik GmbH at the University of Bremen in the division Intelligent Production and Logistic Systems.

Ralf Matthies leads the Profitcenter West at BLG Cargo Logistics GmbH & Co.KG in the Neustädter Hafen in Bremen, Germany.

TOWARDS THE INTEGRATION OF BERTH ALLOCATION AND CONTAINER STACKING PROBLEMS IN MARITIM CONTAINER TERMINALS

Miguel A. Salido[(a)], Mario Rodriguez-Molins[(b)], Federico Barber[(c)]

[(a), (b), (c)] Institute of Control Systems and Industrial Computing (Technical Univ. of Valencia, Spain)

[(a)]msalido@dsic.upv.es, [(b)]mrodriguez@dsic.upv.es, [(c)]fbarber@dsic.upv.es

ABSTRACT
Services provided by the container terminals are being further optimized due to the competitiveness between the different terminals. In this research, the combined problem of Container Stacking and Berth Allocation in container terminal's management is investigated. On the one hand, each container allocated in the yard should be easily accessible before vessel's arrival (demanded by terminal operators). On the other hand, an immediate berthing is expected for each incoming vessel (by ocean carriers). Thereby, we present an artificial intelligence based-integrated system to relate these problems. Berth Allocation Problem is solved by a metaheuristic algorithm which generates an optimized order of vessels to be moored; and we develop a domain-oriented heuristic planner to give a sequence of movements to allocate containers in the appropriate place according a given berth ordering of vessels. Through these optimized solutions together with the developed system, terminal operators can be assisted to decide the most appropriated solution in each particular scenario.

Keywords: Berth Allocation, Container Reshuffling, planning and scheduling, decision support system.

1. INTRODUCTION

During the last decade, worldwide container transportation has grown considerable, being the Container Terminals one of the key factors within global logistic network. This growth has rise to a more exhaustive analysis to ensure reliability, delivery dates or handling times as well as to increase container throughput from quay to landside and vice versa, etc. (Henesey, 2006). (Stahlbock and Voβ, 2008) provides a survey of the issues which must be optimized in Container Terminals.

Container terminals are mainly interested in reducing the berthing time of vessels. This objective is dependent on different interrelated problems: berth allocation, yard-side operation, storage operation and gatehouse operation. In the literature, these problems are managed independently of others due to their exponential complexity. However, these problems are clearly interrelated so that an optimized solution of one of them may not lead to a good solution in another.

The problems we take into account in this paper are Berth Allocation Problem (BAP) and Container Stacking Problem (CStackP) (see Figure 1). BAP consists of assigning a berthing position, a berthing time and cranes to incoming vessels under several constraints and priorities (length and depth vessels, number of containers, distance from storage yard blocks, etc.). On the other hand, CStackP arises when a vessels berth, since export containers to be loaded in this vessel should be on top of the stacks of the container yard. Thereby, CStackP consists on avoiding unnecessary movements of the yard-crane relocating containers at the time of loading. The relationship among these two problems is very clear since an optimal berth allocation plan may generate a large amount of relocations for export containers given a yard-state. However, a suboptimal berth allocation plan could require fewer movements given the same yard-state.

In this paper, we develop a system to optimize these two problems integration by means of a set of intelligent techniques for solving each one of them in order to achieve a mixed-solution. To this end, we present a heuristically-guided planner for generating a rehandling-free intra-block remarshaling plan for container yards. Furthermore, we introduce a meta-heuristic approach for solving the BAP as an independent problem. Finally, we integrate optimization of both problems. Terminal operator should ultimate decide which solution is the most appropriate one in relation to a multi-objective function: to minimize the waiting times of vessels and to minimize the amount of relocations of containers.

2. A DOMAIN-BASED PLANNER FOR THE CONTAINER STACKING PROBLEM.

In Container Terminals, almost all the operations are related to the container yards, where containers are stacked on top of each other awaiting further transport. A container yard is composed of several blocks, each one of them among 20 or 30 yard-bays (Figure 2). Each yard-bay contains multiple (usually 6) rows (or stacks) and each row has a maximum allowed tier (usually 4 or 5 tiers for full containers).

Loading and offloading containers on the stack is performed by cranes following a 'last-in, first-out' (LIFO) criteria. Containers are stacked in the order they arrive. However, in the loading process of vessels, to access a container which is not at the top of its pile, those above it must be relocated. This remarshaling process is required since the stacking order depends on the order in which ships unload or containers have been stacked. Furthermore, this process also reduces the productivity of cranes and its optimization would minimize the moves required.

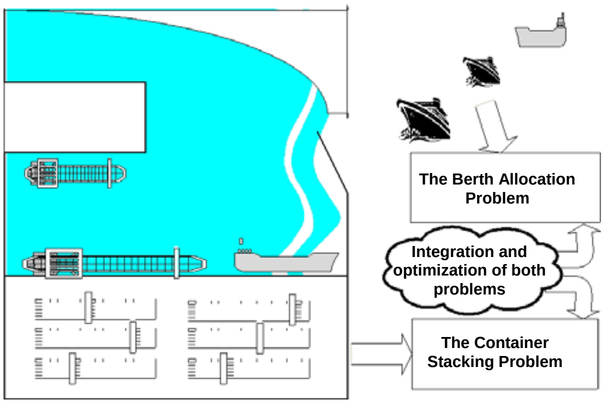


Figure 1. Integrated Remarshaling and Berthing problems in Maritime Terminals.

For safety reasons, it is usually prohibited to move the gantry crane while carrying a container (Lee and Hsu, 2007), therefore these movements only take place in the same yard-bay. In addition, there exist a set of hard/soft constraints regarding container moves or locations where can be stacked, for example, small differences in height of adjacent yard-bays, dangerous containers must be allocated separately by maintaining a minimum distance, etc.

The CStackP is a well known NP-complete combinatorial optimization problem and different approaches has been proposed (Park et al., 2009; Kim and Hong, 2006; etc.). In (Salido et al., 2009), a planning system for remarshaling processes was proposed. This system obtains the optimized plan of reshuffles of containers in order to allocate all selected containers at the top of the stacks, or under another selected containers, in such a way that no reshuffles will be needed to load these outgoing containers.

The proposed planner was specified by means of the standard Planning Domain Definition Language (PDDL, Ghallab, 1998) and it was developed on the well-known domain-independent planner *MetricFF* (Hoffmann, 2003). The developed domain file contains the common features of the problem domain: (i) the domain objects: containers and rows, (ii) the relations among them (propositions), (iii) allowed moves to change the status of the problem (actions), and (i) the goal: each export container must be allocated at the top of the stacks or under other export containers. The problem file describes each particular instance: (i) the initial layout of the containers in the yard (Initial state), (ii) the export containers (goal), and (iii) the function to optimize (minimizing the number of relocation movements).

More details can be seen in (Salido et al., 2009) and as it was anticipated, the Metric-FF-based initial planner was improved by integrating a domain-dependent heuristic (H1) in order to achieve efficiency. (Salido et al., 2009a). H1 computes an estimator of the number of container movements that must be carried out to reach a goal state, which it is used to guide search of solutions.

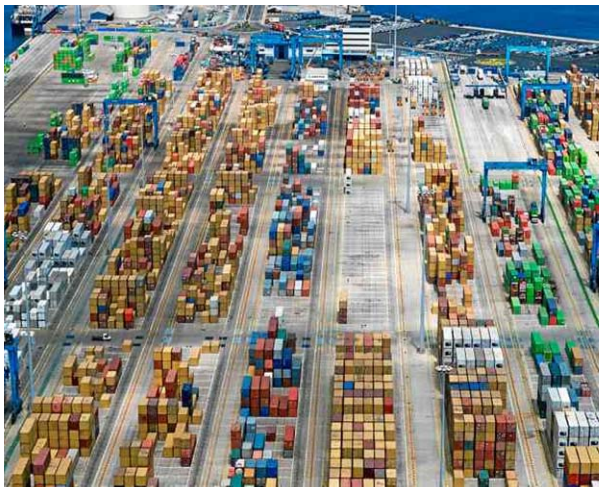


Figure 2. A container yard (left, Puerto de la Luz Terminal).

Moreover, new constrains and optimization criteria have been included in order to take into account real-world requirements:

1. Reducing distance of the goal containers to the cargo side.
2. Increasing the range of the move actions set for the cranes allowing moving a container to 5th tier.
3. Balancing the number of stacked containers within the same bay in order to avoid sinks.

The improved planner can manage a full container yard. The container yard is decomposed in yard-bays, so that the problem is distributed into a set of subproblems. Thus, each yard-bay generates a subproblem. However, containers of different yard-bays must satisfy a set of constraints among them. Therefore, subproblems are sequentially solved, so that each subproblem (yard-bay) takes into account the set of constraints with previously solved subproblems. This decomposition requires taking into account these new added constraints. With these new added constraint and criteria, the developed planner can solve more real-world based problems:

1. Balancing contiguous yard-bays: rows of adjacent yard-bays must be balanced in order to avoid sinks inter yard-bays (CB).
2. Dangerous containers must maintain a minimum security (Euclidian) distance among them (DC).

3. THE BERTH ALLOCATION PROBLEM

The BAP is one of the major problems directly related to productivity in the management of container terminals. Several models are usually considered (Theofanis et al., 2009):

- All vessels to be served are already in the port queue at the time that scheduling begins (static BAP).
- All vessels to be scheduled have not yet arrived but their arrival times are known (dynamic BAP)
- The quay is viewed as a finite set of berths, and each berth is described by fixed-length segments (Discrete BAP).
- Vessels can berth anywhere along the quay (Continuous BAP)

The objective in BAP is to obtain an optimal distribution of the docks and cranes to vessels waiting to berth. Thus, this problem could be considered as a special kind of machine scheduling problem, with specific constrains (length and depth of vessels, ensure a correct order for vessels that exchange containers, assuring departing times, etc.) and optimization criteria (priorities, minimization of waiting and staying times of vessels, satisfaction on order of berthing, minimizing cranes moves, degree of deviation from a pre-determined service priority, etc.).

The First-Come-First-Served (FCFS) rule can be used to obtain an upper bound of the function cost in BAP (Lai and Shih, 1992). On the other hand, several methods have been proposed for solving BAP. Usually, these methods are based on heuristic (Guan and Cheung, 2004) or metaheuristic (Cordeau et al., 2005), (Cheong et al., 2009), etc., approaches. In (Theofanis et al., 2009), a comparative analysis is provided.

Our approach takes into account as a whole the Quay Crane Assignment Problem (QCAP) and the Berth Allocation Problem (BAP) and we use the metaheuristic Greedy Randomized Adaptive Search Procedure, also known as GRASP (Feo and Resende, 1995) in order to obtain optimized solutions efficiently.

Next, let's introduce the notation used in this section: $a(V_i)$ indicates the arrival time of the vessel V_i at port; $m(V_i)$ is the moored time of V_i. At this time, all constraints must hold; $c(V_i)$ is the number of required movements to load and unload containers of V_i; $q(V_i)$ is the number of assigned Quay Cranes (QC) to V_i. The maximum number of assigned QC by vessel depends on its length since a security distance is required. Let's assume that the number of QC does not vary along all the moored time. Thus, the handling time of V_i is given by (where MovsQC is the QC's moves per unit time): $(c(V_i) / (q(V_i) \times MovsQC))$; $d(V_i)$ indicates the departure time of V_i, which depends on $m(V_i)$, $c(V_i)$, and $q(V_i)$; $w(V_i)$ shows the waiting time of V_i from it arrives at port until it moors ($w(V_i) = m(V_i) - a(V_i)$); $l(V_i)$ denotes the length of V_i. There is a distance security between two moored ships: let's assume 5% of their lengths; and, the vessels' priority is $pr(V_i)$.

In order to simplify the problem, let's assume that mooring and unmooring does not consume time and every vessel has a draft lower or equal than the quay. In each case, simultaneous berthing is allowed.

The goal of the BAP is to allocate each vessel according existing constraints and to minimize the total weighted waiting time of vessels:

$$T_w = \sum_i w(V_i)^\gamma \times pr(V_i)$$

The parameter γ ($\gamma \geq 1$) prevents lower priority vessels are systematically delayed. Note that this objective function is different to the classical tardiness concept in scheduling.

3.1. A meta-heuristic method for BAP

BAP can be solved through different methods. We have developed three different methods to solve it; two of them are direct but inefficient solutions. Firstly, we applied the simplest solution, following the FCFS criteria: $\forall i,\ m(V_i) \leq m(V_{i+1})$. A vessel can be allocated at time t when there is no vessel moored in the berth or there are available quay length and cranes at this time t (Algorithm 1).

Data: V: set of ordered incoming vessels; b: state of the berth
Result: Sequence for V
$V_{last} \leftarrow \varnothing$;
$V_m \leftarrow \varnothing$;
foreach $V_i \in V$ **do**
  $t \leftarrow \max(e(V_{last}), a(V_i))$;
  $inst \leftarrow insertVessel(V_i, t, b)$;
  if $!inst$ **then**
    $T \leftarrow d(V_j) | V_j \in V_m \wedge d(V_j) > t$;
    while $t_k \in T \wedge !inst$ **do**
      $inst \leftarrow insertVessel(V_i, t_k, b)$;
    end
  end
  $update(b)$;   /* state of the berth b */
  $V_last \leftarrow V_i$;
  $V_m \leftarrow V_m \cup V_i$;
end

Algorithm 1: Allocating vessels using FCFS policy.

Data: V_i
Result: V_i could moor
if $empty(b)$ **then**
  $m(V_i) \leftarrow a(V_i)$;
  $q(V_i) \leftarrow \min(\texttt{maxQC}_\texttt{V}, l(V_i)/\texttt{distQC})$
  $d(V_i) \leftarrow m(V_i) + \frac{c(V_i)}{q(V_i) \times movsQC}$;
  return true;
else
  $\texttt{freeQC} \leftarrow QC(b) - \sum q(V_i) | t \geq a(V_i) \wedge t < d(V_i)$;
  $\texttt{freeL} \leftarrow l(b) - \sum l(V_i) | t \geq a(V_i) \wedge t < d(V_i)$;
  if $\texttt{freeQC} > 0 \ \wedge \ l(V_i) <= \texttt{freeL}$ **then**
    $q(V_i) \leftarrow \min(\texttt{freeQC}, l(V_i)/\texttt{secQC})$ $m(V_i) \leftarrow t$;
    $d(V_i) \leftarrow t + \frac{c(V_i)}{q(V_i) \times movsQC}$;
    if *checkDisponibility*$(V_i, m(V_i), d(V_i))$ **then**
      return true;
    else
      return false;
    end
  else
    return false;
  end
end

Algorithm 2: Function insertVessel. Allocating one vessel in the berth at time t.

We also have implemented a complete search algorithm for obtain the best (optimal) mooring order of vessels: the lowest T_w (lower bound of the function cost). This algorithm uses the *Function insertVessel* (Algorithm 2) to know whether a vessel can be allocated at time t (the required data are: V_i: Vessel for allocating; t: actual time; b: state of the berth at time t).

However, with a complete search, only a limited number of vessels can be taken into account since search space grows exponentially. Therefore, we developed a meta-heuristic GRASP algorithm for berth allocation (Algorithm 3). This is a randomly-biased multistart method to obtain optimized solutions of hard combinatorial problems in a very efficient way. The parameter ρ (0≤ρ≤1) allows tuning of search randomization.

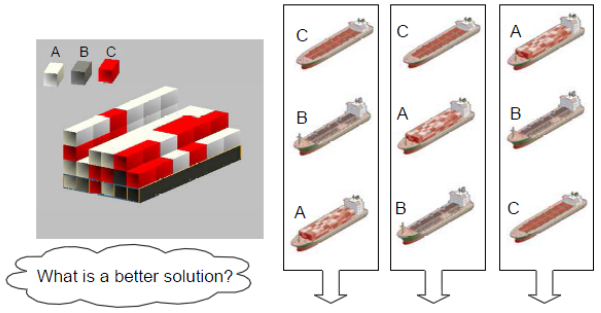
```
Data: ρ factor; E elements; b: state of the berth at t_0
Result: Solution s
/* current time at which algorithm is performed          */
T_assig ← t_0;
V ← {V_i};
T_exit ← {};
while V ≠ ∅ do
    /* V_i which can be allocated in available quay       */
    SV ←
    {V_i}|checkDisponibility(V_i, max(T_assig, a(V_i)), d(V_i)) = True;
    if SV ≠ ∅ then
        T_assig ← first(T_exit) ;    // Time of the next exiting
        vessel
    else
        foreach V_i ∈ SV do
            Allocate(V_i) ;              // Procedure allocate V_i
            Cost(V_i) ← 0;
            foreach V_j ∈ SV|V_i ≠ V_j ∧
            max(T_assig, a(V_i)), max(T_assig, a(V_i)) + d(V_i) ∩
            max(T_assig, a(V_i)), max(T_a ssig, a(V_i)) + d(V_i) ≠ ∅ do
                Cost(V_i) ← Cost(V_i)+
                pr(V_j)((max(T_assig, a(V_j)) + d(V_j)) −
                max(T_assig, a(V_j)))^γ;
            end
            MaxCost ← max_{V_i∈SV}(Cost(V_i));
            MinCost ← min_{V_i∈SV}(Cost(V_i));
            V_assig ← {V_i ∈ SV|Cost(V_i) ∈
            {MinCost, MinCost + ρ(MaxCost − MinCost)}};
            V_k ← random(V_assig);
            insertVessel(V_k, max(T_assig, a(V_k)), b);
            update(b) ;          // update the state of the berth
            remove(V_k, SV);
            T_exit ← T_exit ∪ d(V_k);
        end
    end
end
;                     // All waiting vessels have been allocated
```

Algorithm 3. Allocating Vessels using GRASP metaheuristic.

4. AN INTEGRATED APPROACH FOR CONTAINER STACKING AND BERTH ALLOCATION PROBLEMS

In previous sections, BAP and CStackP have been studied and solved separately through different intelligent techniques in an efficient way. However, no systems have been developed to relate and optimize both problems in an integrated way. Only some works integrate the BAP with the QCAP, for instance (Giallombardo et al., 2010) which follows to minimize the yard-related house-keeping costs generated by the flows of containers exchanged between vessels. However, there also exists a relationship between the optimization of maritime and terminal-sides operations (BAP, QCAP, container stacking problem, etc.).

Figure 3 shows an example of three berth allocation plans and a block of containers to be loaded in the vessels. Containers of type A, B and C must be loaded in vessels A, B and C, respectively. In the first berth allocation plan the order of vessel is A-B-C, the waiting time for this plan is 205 time units and the number of reshuffles needed to allocate the white containers at the top of the stacks is 110. The second berth allocation plan is B-A-C. In this case the waiting time for this plan is 245 time units and the number of reshuffles is 260. Finally, the third berth allocation plan is C-B-A, the waiting time for this plan is 139 time units and the number of reshuffles is 450. The question is straightforward: what is a better solution? A solution that optimizes the BAP problem could not be the more appropriate for the CStackP (and vice versa).



Waiting Time	205 Time Units	245 Time Units	139 Time Units
N. Reshuffles	110	260	450

Figure 3. Three different plans for the BAP: What is better?

Given a waiting queue of vessels to be allocated and a given state of the containers in the container yard, each solution for the BAP ($SBAP_i$: a feasible sequence of mooring), requires a different number of container's re-locations in the associated CStackP solution ($SCStackP_i$) in order to put on top the containers to be loaded according to the order of berthing. We can associate a cost to each $SBAP_i$ related to the total weighted waiting time of vessels of this berthing order (T_w). Likewise, we can associate a cost to each $SCStackP_i$ as the number of required container relocations. Therefore, we can qualify the optimality of each global solution (Sol_i) of BAP and CStackP as a lineal combination of the quality of each partial solution:

$$Cost(Sol_i) = \alpha * Cost(SBAP_i) + \beta * Cost(SCStackP_i) \quad (1)$$

The best decision will depend on the policy of each maritime terminal (α and β parameters). Thus, by combining the planning and berth allocation solutions (they obtained by the systems developed in Sections 3 and 4), we can assess the cost to the global solution Sol_i.

The applied method is: First, both the BAP and the CStackP data are loaded in the integrated system. Next, the BAP is solved to achieve a solution ($SBAP_i$) based on their constraints and criteria. Then, the CStackP is solved by taken into account the berthing order of vessels obtained in $SBAP_i$. The CStackP planner is applied sequentially for each vessel in $SBAP_i$, according the state of the container yard in each moment. Thus, the optimized remarshaling plan for the berthing order of vessels of $SBAP_i$ is obtained ($SCStackP_i$). After this step, the cost of the global solution (Sol_i) can be calculated by using the previous expression (1). By iterating this integrated process, the operators can obtain a qualification cost of each feasible Sol_i, as well as the best global solution (Sol_i), according the given α and β parameters. A branch and bound method has been also applied in the integrated search of the best global solution (Sol_i), so that the search can be pruned each time the current solution does not improve the best solution found until this moment.

5. EVALUATION.

In this section, we analyze the performance of the algorithms developed in the paper. The experiments were performed on random instances. For the CStackP, containers are randomly distributed in blocks of 20 yard-bays, each one with six stacks of 4 tiers. A random instance of a yard-bay is characterized by the tuple < *n*, *s* >, where '*n*' is the number of containers and '*s*' ($s \leq n$) is the number of selected containers in the yard-bay. A random instance for the BAP has '*k*' vessels with an arrival exponential distribution with vessel's data randomly fixed (lengths, drafts, moves and priorities).

Table 1: Performance of real-world criteria in CStackPs.

	Metric-FF Planner	H1	CB	DC	CB + DC
Reshuffles	3.98	3.60	5.68	4.30	6.53
Sinks	24.33	32.67	0	33.33	0
Non-Safe Dangerous	15.33	7.67	8.00	0	0

For the developed planning system to solve CStackPs (Section 2), Table 1 shows the performance of the introduced real-world criteria. These experiments were performed on instances < 15, 4 >. The results shown in Table 1 are the average of the best solutions found in 10 seconds and they represent the average number of reshuffles, the average number of sinks generated along the block, and the average number of unsatisfied dangerous containers. It can be observed that H1 outperforms the general purpose Metric-FF-based initial planner in the number of reshuffles and the new introduced criteria (CB, DC) avoid undesired situations.

Table 2: Computing time elapsed (seconds) for BAP.

No. Vessels	Complete search	GRASP
5	< 1	1
10	112	8
12	11830	10
13	57462	12
15	-	15
20	-	30

Table 2 shows the computational times (in seconds) required for solving BAP by using a complete search against the GRASP method with 1000 iterations. As it can be observed, complete search is impracticable from 12 vessels (more than 3 hours). However, the GRASP method takes around 30 seconds to solve a schedule of 20 vessels.

Table 3: Total waiting time elapsed.

No. Vessels	FCFS	CS
5 (separate arrival times)	73	46
10 (separate arrival times)	256	136
5 (closest arrival times)	117	80
10 (closest arrival times)	586	351

Table 3 shows the average waiting times using FCFS and Complete Search (CS) methods described for the BAP, with two different inter-arrival distributions (temporal separation among arriving vessels). Through these data, it is demonstrated that FCFS criteria results a schedule which is far away from the best one (CS).

Using as minimization function the total weighted waiting time (T_w), Figure 4 shows the results given by the FCFS criteria, and the GRASP procedure (with 1000 iterations) respect to the value of ρ. The optimum value is ρ=0,3, which indicates the suitability of the cost function used in the GRASP procedure (Algorithm 3). A total of 20 vessels are allocated, with two different inter-arrival distributions (separate and closest arrival times) among them.

As it was expected, the GRASP procedure obtains a lower T_w than the FCFS criteria. It is also remarkable that using GRASP is more profitable when the inter-arrival distribution of the vessels is closer. It is not possible to know the optimal T_w due to the exponential computational time required by a complete search with 20 vessels.

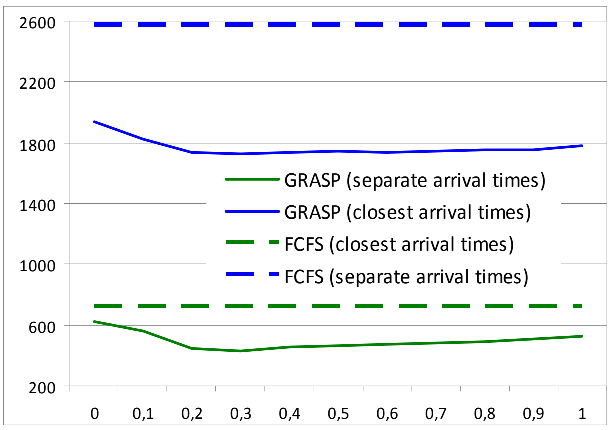


Figure 4: Weighted waiting time (Tw) with FCFS and GRASP procedures.

Finally, Figure 5 shows the combined function cost $Cost(Sol_i)$, introduced in (1) which relates: (i) The normalized total weighted waiting time of vessels, $Cost(SBAP_i)$, and (ii) the number of its required container relocations, Cost(SCStackP$_i$); for ten different scenarios. In each one of this ten cases, the arrival times and data of vessels, as well as the initial state of the container yard, have been randomly generated. Figure 5 represents the combined function cost, Cost(Sol$_i$) with three different weights of the parameters α and β. We can see that better (or worst) berthing orders can require larger (or smaller) number of container relocations.

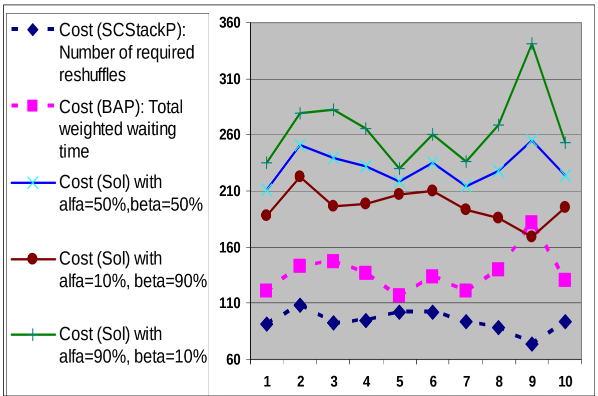


Figure 5. Relating the costs of BAP and CStackP.

6. CONCLUSIONS

This paper presents an efficient way of solving Berth Allocation and Container Stacking Problem, respectively. The former is solved by means of a metaheuristic called GRASP; the latter is solved by an improved planning system used to obtain optimized plans for remarshaling process. Furthermore, an integrated system is studied to provide mixed-solutions for both problems. This system is also oriented to assist to the terminal operators' decision between different feasible alternatives. Several evaluations on randomized scenarios have been performed and we can conclude that a better ordering of vessels does not imply a minimum number of container relocations. As future work, we plan improve GRASP method and adequate the parameters (α, β and γ) to real-world practical decisions and expert knowledge. Then, the developed system, as a computer-based aid system, could assist container terminal's operator to simulate, evaluate and compare different feasible alternatives.

ACKNOWLEDGMENTS

This work has been partially supported by the research projects TIN2007-67943-C02-01 (MEC, Spain-FEDER) and P19/08 (M. Fomento, Spain-FEDER).

REFERENCES

Cheong, C.Y., K.C. Tan and D.K. Liu (2009). Solving the berth allocation problem with service priority via multi- objective optimization. In: *Computational Intell. in Scheduling, 2009. CI-Sched '09. IEEE Symposium on*. pp. 95 –102.

Cordeau, J.F., G. Laporte, P. Legato and L. Moccia (2005). Models and tabu search heuristics for the berth-allocation problem. *Transportation science* 39(4), 526–538.

Feo, T.A. and M.G.C. Resende (1995). Greedy randomized adaptive search procedures. *Journal of Global Optimization* 6(2), 109–133.

Ghallab, M., A. Howe, C. Knoblock, D. McDermott, A. Ram, M. Veloso, D. Weld and D. Wilkins (1998). PDDL - the planning domain definition language. *AIPS-98 Planning Committee*.

Giallombardo, Giovanni, Luigi Moccia, Matteo Salani and Ilaria Vacca (2010). Modeling and solving the tactical berth allocation problem. *Transportation Research Part B: Methodological* 44(2), 232 – 245.

Guan, Y. and R.K. Cheung (2004). The berth allocation problem: models and solution methods. *OR Spectrum* 26(1), 75–92.

Henesey, L. (2006). Overview of Transshipment Operations and Simulation. In: *MedTrade conference, Malta, April*. pp. 6–7.

Hoffmann, Jörg (2003). The metric-ff planning system: translating "ignoring delete lists" to numeric state variables. *J. Artif. Int. Res.* 20(1), 291–341.

Kim, K.H. and G.P. Hong (2006). A heuristic rule for relocating blocks. *Computers & Operations Research* 33(4), 940–954.

Lai, KK and K. Shih (1992). A study of container berth allocation. *Journal of Advanced Transportation* 26(1), 45–60.

Lee, Yusin and Nai-Yun Hsu (2007). An optimization model for the container pre-marshalling problem. *Computers & Operations Research* 34(11), 3295 – 3313.

Park, K., T. Park and K.R. Ryu (2009). Planning for remarshaling in an automated container terminal using cooperative coevolutionary algorithms. In: *Proceedings of the 2009 ACM symposium on Applied Computing*. ACM. pp. 1098–1105.

Salido, M., O. Sapena and F. Barber (2009). The Container Stacking Problem: an Artificial Intelligence Planning-Based Approach. Procc. Of *The Int. Workshop on Harbour, Maritime and Multimodal Logistics Modelling and Simulation* HMS'2009. pp:127-131 (2009)

Salido, M., O. Sapena, M. Rodriguez and F. Barber (2009*a*). A planning tool for minimizing reshuffles in containers terminals. *ICTAI 2009: 21st International Conference on Tools with Artificial Intelligence*.

Stahlbock, R. and S. Voß (2008). Operations research at container terminals: a literature update. *OR Spectrum* 30(1), 1–52.

Theofanis, S., M. Boile and M.M. Golias (2009). Container terminal berth planning. *Transportation Research Record: Journal of the Transportation Research Board* 2100(-1), 22–28.

CLASSIFICATION OF DYNAMICAL PATTERNS IN AUTONOMOUSLY CONTROLLED LOGISTIC SIMULATIONS USING ECHO STATE NETWORKS

B. Scholz-Reiter[(a)], T. Lensing[(b)], M. Görges[(c)] , L. Dickmann[(d)]

[(a-c)] BIBA GmbH, University of Bremen, Germany
[(d)] Research Group Digital Media, University of Bremen, Germany

[(a)]bsr@biba.uni-bremen.de, [(b)]leg@biba.uni-bremen.de, [(c)]goe@biba.uni-bremen.de, [(d)]dickmann@tzi.de

ABSTRACT
The concept of autonomous control aims at improving the robustness and performance of logistic systems in a dynamical environment. In this context logistic objects are able to make and execute routing decisions autonomously. On the one hand this enables logistics systems to react promptly on dynamic changes and disturbances. On the other hand autonomous control causes an inherent dynamic systems behavior, which depends mainly on decision logic and initial system states. In order to analyze the interplay between these internal dynamics and the overall systems performance, new approaches for describing and classifying the observed behavior are needed. This paper presents an approach, based on Echo State Networks, for identifying and comparing different dynamics, gained by a simulation model of an autonomous controlled production network. It will be shown, that echo-state networks are able to distinguish different patterns of this exemplary autonomously controlled production network.

Keywords: production networks, autonomous control, echo-state networks

1. INTRODUCTION

Production networks are characterized by company or cross company owned facilities, which aim at an integrated planning of geographical dispersed logistic processes and the usage of common resources (Wiendahl and Lutz 2002). In production networks with geographical dispersed production plants, additional tasks for production planning and control (PPC) arise, e.g. the assignment of jobs to plants or the planning of transports. Thus, the coordination of transport and production processes gets more and more important (Sauer 2006). Conventional incremental planning and control methods have shortcomings to cope with these additional tasks (Ivanov 2009). In this context decentralized approaches, e.g. autonomous control, appear to be promising. Autonomous control aims at improving the logistic performance of a system by coping with complexity in a distributed and flexible manner. According to this concept, single objects are able to make and execute routing decisions by themselves (Windt 2006). One can assume that an integrated autonomous control of both, production and transport processes may increase the logistic performance of production networks (Scholz-Reiter et al. 2009b). However, the implementation of autonomous control does not per se lead to the desired dynamical effects. Different dynamics, e.g. oscillating behavior or unpredictable fluctuations were observed for an autonomous controlled production system with varying start parameters (Scholz-Reiter et al. 2007). In order to get a deeper understanding of the underlying dynamics caused by autonomous control, novel methods of analysis, which go beyond a sole comparison of aggregated data like mean values and standard deviations are necessary. This kind of classical evaluation neglects dynamical aspects (e.g., periodicity), which are also of interest in production planning and control. In this context approaches that are able to classify different dynamics can be used to analyze the link between control logic, dynamic system's behavior, and system's performance. In the case at hand, we deal with output from a simulation model in the form of time series data. The output data exhibits characteristic patterns, which we intend to classify. Echo state networks (ESN) appear to be promising for this task. They denote a relatively novel approach from the domain of reservoir computing (RC) where the hidden layer of a recurrent neural network (RNN) is seen as a dynamical reservoir (DR). In contrast to other RNN approaches, the weights of units inside the hidden layer are not trained here. Instead training is performed by linearly combining signals from the hidden layer using linear regression, which is computationally cheap and guaranteed to converge. It has been shown that ESN are well-suited for time series classification due to their inherent short-term memory capabilities.

This paper presents an approach for analyzing time series data gained by discrete event simulations of an autonomously controlled production network. For this purpose an exemplary production network scenario is modeled. The material flow on the shop-floor-level and on the network-level is controlled autonomously by a pheromone based approach. This paper will show that dynamics caused by the pheromone approach can be classified using echo state networks. We present a cascaded network setup consisting of multiple ESNs for classifying different patterns in time series data of dynamics exhibited by the simulation model. Finally, we discuss the results of our classification experiments and outline the implications of our findings for future research.

2. AUTONOMOUS CONTROL

The collaborative research centre 637 "Autonomous cooperating Logistic Processes: A Paradigm Shift and its Limitations", which is founded by German research foundation, gives the following wide definition of autonomous control: "Autonomous control describes processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions independently. The objective of autonomous control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity" (Windt and Hülsmann 2007). According to this the general definition of autonomous control, the concept can be understood as decentralized coordination of intelligent logistic objects and routing through logistic systems by the intelligent objects themselves (Windt et al. 2008). Hence, the main idea of autonomous control is a shift of decision making capabilities from the overall system to single elements. These autonomously acting elements, i.e. intelligent logistic objects, are able to gather information about local system states and to make and execute decisions on the basis of this information. The term intelligent logistic object is broad defined. It covers physical objects (e.g. machines, jobs, etc.), as well as immaterial objects like production orders (Windt 2006). In the context of production logistics the decision making capability is transferred to the jobs, which are allowed to decide about routes through the entire production system. It has already been shown, that autonomous control may improve the handling of dynamic complexity and increase the logistic target achievement of production systems (Scholz-Reiter et al. 2009a). Moreover comparative studies remarked that the dynamic performance of different autonomous control methods depends mainly on the scenarios parameters, e.g. arrival rate (Hülsmann et al. 2008).

As far as production networks are concerned several autonomous control approaches have already been formulated. Similar to production systems autonomous control leads to promising results (e.g., Scholz-Reiter et al 2009a, Scholz-Reiter et al. 2010). Nevertheless, these studies confirmed the interdependences between dynamical systems behavior and internal and external parameters. Due to the high degree of structural complexity, these networks may be even more sensitive to these effects: compared to single plants, production networks include many more factors (e.g., transport mode, distances or transport schedules), which affect the dynamical behavior of the system. As a consequence, the analysis of the dynamics of autonomously controlled production networks has to cover a broad range of possible impact parameters.

Moreover, autonomous control methods often offer some degrees of freedom, in terms of facultative parameters, which also have a major impact on the systems behavior.

3. ECHO STAE NETWORKS

Echo state networks (ESN) as proposed by Jaeger (2001) denote a special kind of architecture and supervised learning principle for recurrent neural networks. In contrast to feed forward networks ESNs are able to naturally cope with continuous inputs and exhibit a fading memory of the input history in the network's reservoir. In the recent past ESNs have *inter alia* been successfully employed for speech recognition (Skowronski et al. 2007), robot control (Hertzberg et al. 2002), and time series prediction (Webb 2008).

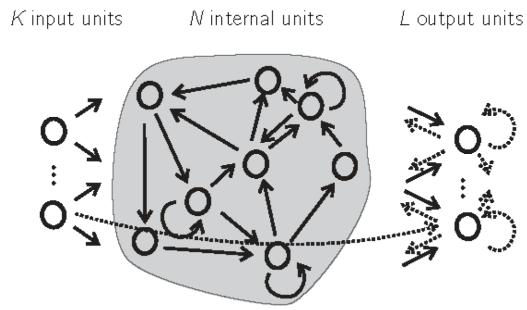


Figure 1: ESN architecture: an ESN has three layers. Solid arrows indicate mandatory types of connections, dashed arrows are optional connections. Figure reproduced and adapted from Jaeger (2001)

The typical architecture of a standard ESN is illustrated in figure 1. In an ESN the hidden layer containing the internal units is seen as a dynamical reservoir (DR), which is "tapped" using an attached linear readout module. In contrast to conventional RNN approaches only the linear readout is trained. This boils down to a linear regression task from a mathematical point of view, which is computationally cheap and guaranteed to converge. The hidden layer can be seen as a possibly high dimensional non-linear combination of the input signal, hence the name "dynamical reservoir" (Jaeger 2001). In order for the approach to work the DR must exhibit a special type of "damped" dynamics. A DR that exhibits this dynamics is attributed to have the echo state property, thus enabling a network based on that DR to be an echo state network. The echo state property basically ensures that for every internal signal there exists an echo function which maps input and output histories to the current state. That is, the network's DR does not exhibit chaotic dynamics that are independent of input or output. Echo state networks exhibit a form of short term memory, which can be seen as a consequence of the fact that echoes (possibly variations) of the input signal determine the current network state due to the echo state property. A thorough explanation of the architecture, setup and mathematical properties of ESNs is beyond the scope of this paper. However, for a very well-written introduction to the overall topic we would like to refer the reader to Jaeger's ESN tutorial (Jaeger 2005).

Echo state networks can be set up with different neuron types, different connectivity patterns and with or without output feedback connections. Generally, ESN setup parameters have to be chosen task-specifically. A common methodology here is to estimate network setup parameters manually following the intuition and experience of the experimenter as described by Jaeger (2005). What is more, numerous extensions and modifications for improving different aspects of the standard ESN architecture have been proposed in the literature. In the scope of this work, we utilize one of these, namely the delay&sum readout as proposed by Holzmann (2008). This extension to the ESN readout module allows for improved handling of long-term dependencies, which appears crucial in our experiments.

4. SCENARIO

A scenario with six different plants on four network stages is considered, similar to Scholz-Reiter (2009b). On stage one and on stage four there is only one plant. On stage two and three there are two collocated plants, respectively. Additionally, each plant consists of a shop floor with three parallel production lines and three machines per production line. Figure 2 shows the general structure of the scenario:

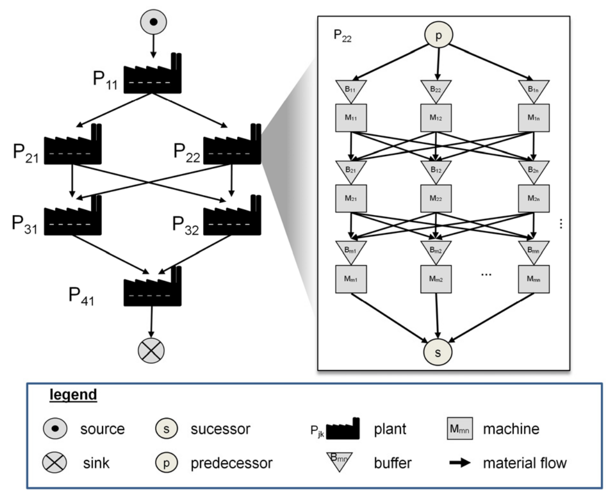


Figure 2: Production network scenario

There are three different job types. These job types differ in their processing times on the shop floor level. The processing times are set as summarized in Table 1:

Table 1: processing times

Plant	P_{11}; P_{41}			P_{21}; P_{22}; P_{31}; P_{32}		
Type / Line	1	2	3	1	2	3
Type A	2:00	3:00	2:30	4:00	5:00	4:30
Type B	2:30	2:00	3:00	4:30	4:00	5:00
Type C	3:00	2:30	2:00	5:00	4:30	4:00

The jobs arrive in plant 1 at stage 1 with a certain arrival rate. In order to model a dynamic seasonal demand, this arrival rate $\lambda(t)$ is set to a sine function:

$$\lambda(t) = \lambda_m + \beta \cdot \sin(t + \varphi) \tag{1}$$

This function has a phase shift φ of a period for each job type, so that the maximal arrival rates of all job types do no cumulate. The variable λ_m defines the mean of the arrival rate and is set to 0.4 1/h in all simulation runs. The second variable β determines the intensity of the arrival rate fluctuation.

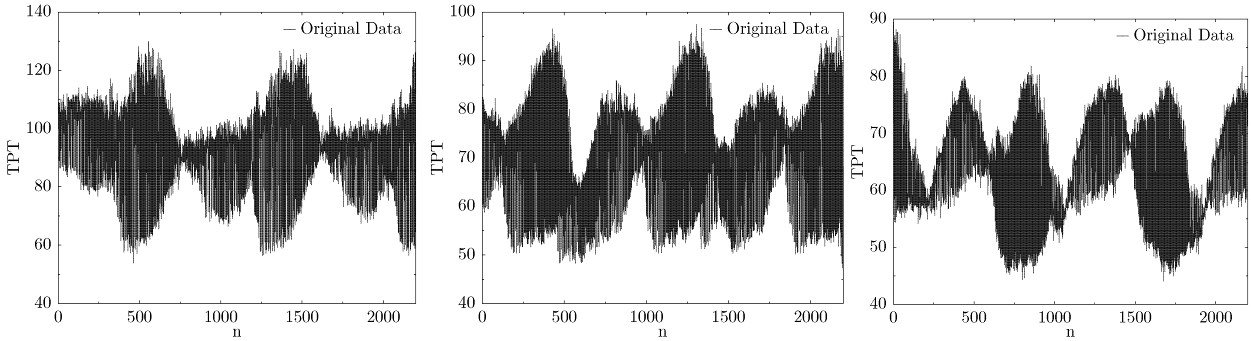
Transports between plants are triggered by a “go when full policy” (as described by Crainic 2002). This means, that a transport from one plant to the next plant starts as soon as a predefined amount of jobs has been finished in one plant. This transportation policy is commonly used in door to door transports (Crainic 2000). For this scenario the truck capacity q is set to 5 jobs. The distances between the plants D are 140 km each. The velocity of all trucks is set to 70 km/h. Hence, a transport from one plant to the next takes 2 hours.

Jobs in this scenario are able to decide about routes on the network and on the shop floor level, autonomously.

5. PHEROMONE-BASED METHODS

In order to route themselves through the scenario all jobs have two major decision problems: on the one hand the allocation to a plant has to be conducted. On the other hand they have to decide about routes within the respective plant. For both decision types a pheromone based approach is modeled, in order to reduce the throughput time of jobs through the entire network.

The pheromone approach is based on the idea to imitate the process in which ants mark possible routes to food sources in nature. Ants leave pheromone marks between their formicary and potential food sources. Other ants can detect those pheromones and will follow the tail with the highest concentration of pheromone (Parunak 1997). On the shop-floor-level this is done similarly (Armbruster et al. 2006): During the production process the jobs leave information about their processing and waiting times at a corresponding machine.



(a) (b) (c)

Figure 3: Excerpt plots (throughput time (TPT) against simulation steps n for characteristic patterns of original data retrieved from the simulation for different values of L (evaporation parameter). (a) pattern A with $L=50$, (b) pattern B with $L=150$, and (c) pattern C with $L=250$. Note: the plots reflect the first 2200 samples of data points from each dataset after stripping data from initial attack times

Following jobs entering a stage on the shop floor compare this artificial pheromone concentration by computing an average value of the waiting time data of the last five jobs and then choose a production line. Thus, the pheromone concentration depends on waiting and processing times of previous jobs. To model the evaporation process of natural pheromones, a moving average of waiting time data is used.

What is more, on the network level the time spent to pass the transport system has to be considered. This time span is denoted as $T_{o,i}^{s,k}$, where i is the index of i th job which passed the plant k on stage s. Each plant has a vector $\overline{T}_o^{s,k}$ where o represents the product type. Whenever a job i leaves a plant, the waiting time for transports and processing times are appended to the corresponding $T_{o,i}^{s,k}$, see equation 2. The value $T_{o,i}^{s,k}$ of the last job i is appended at the first position.

$$\overline{T}_o^{s,k} = \begin{pmatrix} T_{o,i+1}^{s,k} \\ T_{o,i}^{s,k} \\ \vdots \\ T_{o,1}^{s,k} \end{pmatrix} \tag{2}$$

After processing in one plant the job has to choose a succeeding plant. Therefore a moving average over the last L jobs as an artificial pheromone (3) is calculated. Similar to the shop-floor-level the moving average is used to emulate the evaporation of natural pheromones.

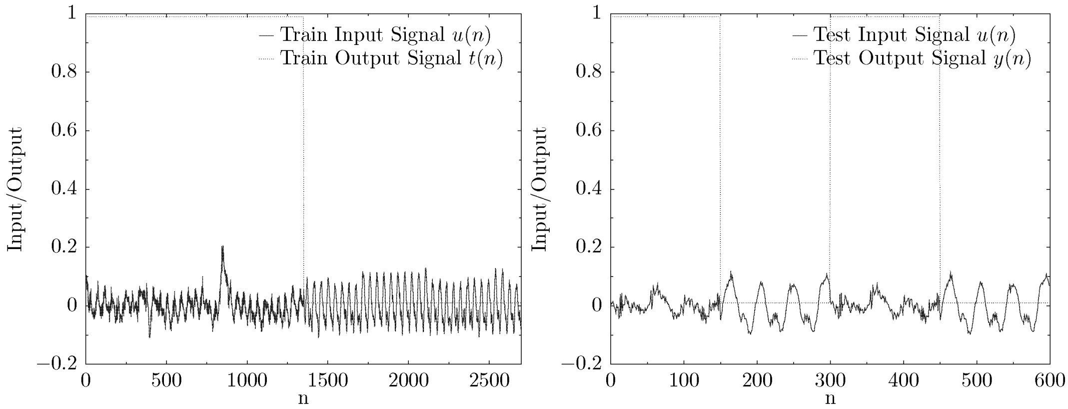
$$PHE_{s,k} = \frac{\sum_{i=1}^{L} T_{o,i}^{s,k}}{L} \tag{3}$$

After calculating the concentration of artificial pheromones, the job chooses the succeeding plant with the lowest average transportation and processing times. The scenario presented above is modeled by a discrete event simulation model. The pheromone method is implemented to this model for both: allocation decisions of jobs to plants on the network level and to production lines on the shop-floor-level. It is assumed that the evaporation parameter L has a major impact on the logistic performance and on the general dynamic behavior of the production network. In order to analyze the impact of parameter L, different simulation runs with varying values of L were conducted. Thereby, the logistic performance of the production network is recorded in terms of throughput times (TPT). This means the time span of each job to pass through the entire system from the source to the sink. The throughput times of every job are recorded as a time series.

Figure 3 shows three characteristic plots of TPT against simulation steps n for different values of L ($L=50$, $L=150$, $L=250$). A visual comparison of these results shows that the curves follow different dynamic patterns. This indicates that the dynamic behavior differs in each case. With regard to the mean logistic performance these three time series cannot be distinguished that clearly. Only the simulation run with $L=50$ differs distinctly from the others. The mean value of TPT for the simulation run with $L=50$ is $TPT_{mean}=92.87h$. While the mean TPT values of the other simulation runs are: $TPT_{mean}=70.31h$ for $L=150$ and $TPT_{mean}=64.32h$ for $L=250$. In order to investigate and classify the differences in the dynamic patterns of the time series an ESN is used.

6. SETUP AND RESULTS

In what follows, we describe our experimental setup as to classify two different characteristical patterns from the simulation runs. That is, in the scope of this work, we simplify the given problem to a binary classification task. Afterwards, we outline implications for possible further experimental setups, which aim at classifying more than two pattern classes in a multi-class network.



(a) (b)

Figure 4: ESN input and output signal plots for classification experiment with patterns A and C. *n* denotes ESN-based signal time steps (a) training signals (solid line: input, dotted line: output for teacher forcing), (b) testing signals (solid line: input, dotted line: output)

6.1. Data processing

To allow for utilization with the ESN approach, output datasets from the simulation runs must be normalized and further preprocessed.

We outline our approach as to perform adequate data preprocessing in the case at hand as follows:

1. As a first step, data from initial attack times resulting from the simulation runs are stripped from each dataset. This is done to ensure that the ESN is not trained with chaotic patterns occurring only at the beginning of data collected from each simulation run.
2. Afterwards, we determine the global maximum ($g_{\max}$) and minimum ($g_{\min}$) values of all data that are to be utilized as an input signal to the ESN. This subsumes both training and testing data from all datasets used for the experiment.
3. We then normalize each dataset to range $[0,1]$ by the calculation of the term $d_{norm}(n) = (d(n) - g_{\min}) / (g_{\max} - g_{\min})$, where $d_{norm}(n)$ denotes the normalized data value and $d(n)$ represents the original data value at index n.
4. Subsequently, we shift the normalized data down by its mean, so that the represented signal oscillates around zero. This is done by calculating $d_{ms}(n) = d(n) - d_{mean}$, where d_{mean} is the arithmetic mean of the normalized dataset and $d_{ms}(n)$ denotes the final mean-shifted signal. Note that we chose to mean-shift each dataset on its own, i.e. each dataset is first shifted and later datasets are concatenated for training and testing using an ESN. This has been done to allow for commensurability with respect to the way ESN experiments are carried out later on.
5. In order for the ESN approach to work, the data must exhibit useful patterns at appropriate time-scales, which can be captured with limited short term memory inherently available in the network. Since we deal with very fine-grained original output data, each dataset is thus super-sampled in order to reduce the number of data points. This is done by segmenting the dataset into segments of $s = 20$ data values each, then calculating the average of each segment and finally storing the concatenation of all consecutive segment averages as a result in a newly created dataset. The value of s was determined empirically and may vary with different simulation scenarios.

6.2. Signal Composition

Finally, datasets are partitioned for training and testing as illustrated in figure 4. As is common practice in the machine learning domain, we use 90 percent of the data for training and the remaining 10 percent for testing. In the case at hand, we partition datasets so that the first 90 percent of the signal are devoted for training and the last 10 percent are utilized for testing. The datasets are then used for composing input signals $u(n)$ and output signals $y(n)$ for training and testing the ESN as explained in the following.

For training the ESN, two training datasets D_A and D_B with lengths l_A and l_B are chosen that exhibit a characteristical pattern, which is supposed to be recognized by the ESN. The training input signal $u(n)$ is then composed by concatenating training set D_A and D_B. The training output signal $t(n)$ is created of a block of ones (1.0) with length l_A following a block of zeros (0.0) with length l_B.

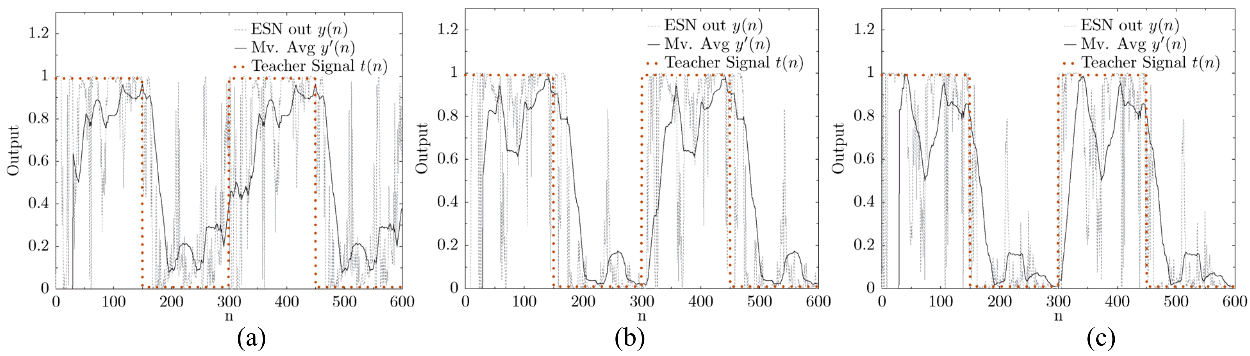


Figure 5: ESN output and test signal (dotted line: ESN output signal, solid line: moving average over ESN output signal, reddish thick dotted line: test signal for comparison of ESN output with ground truth

The training output signal can be considered a step signal, which is designed to train the ESN to vote for class C_A (1.0) or class C_B (0.0) depending on the underlying input signal at time step n. For testing the ESN the same scheme is applied, but this time the testing partitions of the respective datasets are employed and output $y(n)$ is used only for evaluation purposes. Figure 4 shows plots (a) of the resulting overall training signal and (b) of the testing signal.
Note that the testing signal was repeated once to improve illustration of the ESN output signals (see section 6.4).

6.3. Network setup

Table 1 gives an overview of the ESN configuration employed in the scope of this work. It contains all relevant parameters and values for the ESN used in the case at hand.

Table 2: Overview of the ESN setup for the classification experiments

Parameter	Value
Number of DR neurons N	400
DR connectivity	10%
Spectral radius α	0.4
Input connectivity	10%
Input scaling	6.0
Internal activation function	sigmoid: tanh
Output activation function	sigmoid: $\frac{1.0}{(1.0+e^t)}$

An echo state network is set up with one input signal $u(n)$ and one output signal $y(n)$. Internal units use the tanh activation function while output units use the logistic sigmoid activation function. The number of internal units is set to $N = 400$. The network size was determined empirically, i.e. increasing the network size had no significant effect on performance while decreasing it led to considerably worse performance. The DR's spectral radius is set to $\alpha = 0.4$ in order to account for a required tradeoff between memory capacity and other factors influencing classification performance. The DR's connectivity parameter is set to 10 percent. Inputs are re-scaled by factor 6.0, thereby yielding input weights sampled from a uniform distribution in range $[-6.0, 6.0]$. The input unit is connected to 10 percent of the DR's internal units. Output feedback is completely omitted as to the nature of our classification experiments. We utilize a modified readout, namely the delay&sum readout as proposed by Holzmann (2008), which is not part of the ESN standard as proposed by Jaeger.

The delay&sum readout allows for taking into account long-term dependencies in the ESN's input signal without increasing network size beyond the limits of current computer hard- and software. We use the delay&sum readout with generalized cross correlation (GCC) and a maximum delay of 10 simulation steps. Training is done with a special pseudo-inverse algorithm with respect to estimating delays in the readout module as described by Holzmann (2008). ESN-based simulation (testing) is done with additional squared states as described by Jaeger (2003).

6.4. Results

Figure 5 shows ESN outputs for simulation runs on (a) pattern A and B, (b) pattern A and C, and (c) pattern B and C. The dotted graphs for each run represent the output signals generated by the ESN (trained with 2700 training samples) and tested on 600 test samples (300 samples repeated twice). During training the first 100 samples were omitted to washout chaotic dynamics induced by the random initialization of the ESN. Table 3 lists the results of the simulation runs performed with the ESN on the different training and testing sets in terms of the normalized root mean square error (NRMSE), which is commonly employed for ESN performance evaluation.

Table 3: ESN normalized root mean square errors for training $NRMSE_{Train}$ and testing $NRMSE_{Test}$ on each simulation run

Run	$NRMSE_{Train}$	$NRMSE_{Test}$
(a) A vs. B	0.325	0.804
(b) A vs. C	0.224	0.768
(c) B vs. C	0.214	0.596

6.5. Discussion

The NRMSE results suggest that both fitting on training data and correctly predicting testing data was not achieved with satisfactory performance. The best case can be seen in (c) where patterns B and C are classified with test performance $NRMSE_{Test} = 0.596$ while the worst result is achieved for (a) pattern A vs. B with $NRMSE_{Test} = 0.804$.

However, even though NRMSE result values indicate fairly bad performance of the network in this particular case the ESN output signals plotted in figure 5 indicate that it appears possible to perform a successful classification when we apply some post-processing. A fairly simple approach that turned out to be quite effective is applying a moving average with window size $w = 30$ (determined empirically) on the ESN output signal. Figure 5 illustrates this moving average with a solid black graph plotted above the original ESN output during testing. It can be seen that this adequately compensates for spikes to the wrong output value and enables partitioning of the output range to sub-ranges $(0.5, 1.0]$ for the first class and $[0.0, 0.5]$ for the second class respectively. A binary readout attached to the moving average output $y'(n)$ of the ESN could thus determine crisp output class predictions $C(n)$ as indicated in equation 4:

$$C(n) = \begin{cases} true \ if \ y'(n) > 0.5 \\ false \ if \ y'(n) \le 0.5 \end{cases} \tag{4}$$

Looking at figure 5 we can state that the described approach of post-processing the ESN output signal does at least hold for cases (b) and (c). Case (a) appears to be harder to handle for the ESN, which might be caused by the similarity of patterns A and B.

Concluding, it can be stated that we were able to successfully classify dynamical patterns retrieved from the logistics simulation using an ESN. An advantage of this method over e.g. the Fourier transform applied in Scholz-Reiter (2007) is that, as soon as a suitable ESN configuration is found, it can be applied very easily and without much manual effort.

7. CONCLUSION

In order to improve the robustness and performance of logistic systems in a dynamical environment we applied the concept of autonomous control in an exemplary simulation model scenario. In this context we introduced a pheromone-based approach for routing within such scenario. We identified the need for a more sophisticated analysis of the interplay between internal dynamics and the overall system's performance in such autonomously controlled environments. In order to enable an analysis going beyond a sole comparison of aggregated data like mean values and standard deviations, we presented an approach, based on Echo State Networks, for identifying and comparing different dynamics, gained by a simulation model of an autonomous controlled production network. We have shown that echo-state networks are able to distinguish different patterns of an exemplary autonomous controlled production network with varying initial parameters.

8. FUTURE RESEARCH

In the scope of this work, we have demonstrated that classifying different time series patterns retrieved from an exemplary autonomously controlled logistics simulation model with varying parameters is possible using an ESN. In the context of logistics research it is of interest to utilize and further develop methods like the one presented in this paper in order to gain a deeper understanding of algorithms and methods used in simulation models. For instance, our approach could be extended to identifying aspects of autonomous control methods that manifest in output patterns and may have influence on the logistics system's performance.

ACKNOWLEDGMENTS

The research presented in this paper was supported by the German Research Foundation (DFG) as part of the Collaborative Research Center 637 “Autonomous Cooperating Logistic Processes.”

REFERENCES

Armbruster, D., de Beer, C., Freitag, M. Jagalski, T. and Ringhofer, C., 2006. Autonomous control of production networks using a pheromone approach. In: *Physica A*: Statistical Mechanics and its Applications, 363(1), pp. 104–114

Camarinha-Matos, L.; Afsarmanesh, H. (2003): Elements of a base VE infrastructure. In: Computers in Industry 51, 139–163

Crainic, T.G., 2000. Service network design in freight transportation. In: *European Journal of Operational Research* 122(2),pp. 272-288

Hertzberg, J., Jaeger, H. and Schönherr, F., 2002. Learning to Ground Fact Symbols in Behavior-Based Robots. In *ECAI*, pp. 708– 712

Holzmann, G., 2008. Echo State Networks with Filter Neurons and a Delay and Sum Readout with Applications in Audio Signal Processing, Master’s thesis, 2008.

Hülsmann, M., Scholz-Reiter, B., de Beer, C. and Austerschulte, L., 2008. Effects of Autonomous Cooperation on the Robustness of International Supply Networks - Contributions and Limitations for the Management of External Dynamics in Complex Systems,In: *LogDynamics International Conference*, pp. 241–250, Berlin, Springer.

Ivanov, D., 2009. An adaptive framework for aligning (re)planning decisions on supply chain strategy, design, tactics, and operations, In: *International Journal of Production Research*, (907681677), pp. 1–19

Jaeger, H., 2001. The ”echo state” approach to analysing and training recurrent neural networks, Technical report, GMD - German National Research Institute for Computer Science

Jaeger, H., 2003. Adaptive nonlinear system identification with echo state networks’, in Advances in Neural Information Processing Systems, MIT Press, Cambridge, MA, pp. 593–600

Jaeger, H., 2005. ‘A tutorial on training recurrent neural networks, covering BPPT, RTRL, EKF and the “echo state network” approach, Technical report, Fraunhofer Institute for Autonomous Intelligent Systems (AIS)

Parunak, H.V., 1997.Go the ant: engineering principles from natural multi agent systems. *Annals of Operations Research* 75, pp. 69–101

Sauer, J., 2006. Modeling and Solving Multi-Site Scheduling Problems. In: Meystel (ed.):*Planning in Intelligent Systems: Aspects, Motivations and Methods*, Wiley, pp. 281–299

Scholz-Reiter, B., de Beer, C., Freitag, M. and Jagalski, T., 2007. Analysing the Dynamics caused by Autonomously Controlled Logistic Objects. In: *Proceedings of 2nd International Conference on Changeable, Agile, Reconfigurable and Virtual Production*, El- Maraghy, H.A. and M. F. Zaeh (eds) , pp. 273–280,

Scholz-Reiter, B., Görges, M. and Philipp, T., 2009a. Autonomously controlled production systemsInfluence of autonomous control level on logistic performance. In: *CIRP Annals - Manufacturing Technology,* 58(1), pp. 395–398

Scholz-Reiter, B., Görges, M., Jagalski, T. and Mehrsai, A., 2009b. Modelling and Analysis of Autonomously Controlled Production Networks. In: *Proceedings of the 13th IFAC Symposium on Information Control Problems in Manufacturing*, pp. 850–855

Scholz-Reiter, B., Mehrsai, A., Görges, M., 2010. Handling the Dynamics in Logistics - Adoption of Dynamic Behavior and Reduction of Dynamic Effects. In: *Asian International Journal of Science and Technology in Production and Manufacturing Engineering (AIJSTPME)*, 2(2009)3, pp. 99-110

Skowronski, M.D. and Harris, J.G., 2007. Automatic speech recognition using a predictive echo state network classifier, In: *Neural Networks* 20, pp. 414–423

Webb, R., 2008. Multi-Layer Corrective Cascade Architecture for on-Line Predictive Echo State Networks, *Applied Artificial Intelligence*, 22(7), pp. 811–823

Wiendahl, H.P. and Lutz, S., 2002. Production in Networks, *CIRP Annals – Manufacturing Technology*, 51(2), pp. 573–586,

Windt, K. and Hülsmann, M. 2007. Changing Paradigms in Logistics – Understanding the Shift from Conventional Control to Autonomous Cooperation and Control. In: Understanding Autonomous Cooperation & Control - The Impact of Autonomy on Management, Information, Communication, and Material Flow. Hülsmann, M. and Windt, K. (eds), pp. 4–16

Windt, K., 2006. Selbststeuerung intelligenter Objekte in der Logistik. In: Selbstorganisation - Ein Denksystem für Natur und Gesellschaft. Vec, M., Hütt, M. and Freund, A. (eds), pp. 271–314

Windt, K.; Böse, F.; Philipp, T., 2008. Autonomy in Production Logistics - Identification, Characterisation and Application. In: International Journal of Robotics and CIM, 24(4), pp. 572-578

AUTHORS BIOGRAPHY

Prof. Dr.-Ing. Bernd Scholz-Reiter is head of the department Planning and Control of Production Systems at the University of Bremen and managing director of the BIBA - Bremer Institut für Produktion und Logistik GmbH at the University of Bremen. He is Editor of the professional journals Industrie Management and PPS Management. Prof. Scholz-Reiter is a corresponding member of C.I.R.P., the International Institution for Production Engineering Research and also a member of the Scientific Advisory Board of Bundesvereinigung Logistik e.V.

M.Sc. Tobias Lensing works as a research scientist at the BIBA - Bremer Institut für Produktion und Logistik GmbH at the University of Bremen in the division „Intelligent Production and Logistic Systems.

Dipl.-Wi.-Ing. Michael Görges works as a research scientist at the BIBA - Bremer Institut für Produktion und Logistik GmbH at the University of Bremen in the division „Intelligent Production and Logistic Systems.

M.Sc. Lutz Dickmann works as a doctoral canidate at Research Group Digital Media at the University of Bremen.

DESIGNING A SOFTWARE TOOL TO PLAN FIGHT ACTIONS AGAINST MARINE POLLUTIONS

Jean-Marc MERCANTINI, Claudia DETRAUX, Diégo DANTAS DE FREITAS

Laboratoire des Sciences de l'Information et des Systèmes (UMR CNRS 6168)
Université Paul Cézanne (Aix-Marseille 3)
Avenue Escadrille Normandie-Niemen
13397 Marseille cedex 20

jean-marc.mercantini@Lsis.org, claudia.serey@Lsis.org, diegodfreitas@gmail.com

ABSTRACT

The purpose of the paper is to present the design of a software tool to plan fight actions against marine pollutions. In particular such tool has to assist crisis management staff to minimise pollution impact due to maritime accident. From a methodological point of view, the paper shows the importance of developing ontologies (i) for structuring a domain (at a conceptual level) as its actors perceive it and (ii) for building computer tool for aid solving problems in that domain.

Keywords: ontology, decision support system, marine pollution, crisis management

1. INTRODUCTION

Although the Mediterranean is only one hundredth of the sea surface it supports thirty percent of the volume of international maritime traffic (2200 ships are sailing continuously): either through exchanges between the 305 ports scattered along its coasts, or the use of its transit routes. An estimated 50% of goods transported could present a risk to different degrees.

A study on shipping accidents in the Mediterranean sea (REMPEC 2002), conducted between 1977 and 2003 identified 376 accidents involving hydrocarbons and 94 accidents involving hazardous and noxious substances (HNS). These accidents have resulted in a total discharge of 305,000 tons of hydrocarbons and 136,000 tonnes of HNS. These events highlight the criticality of the risk induced by transport activities in that region.

Marine pollution has always had a strong impact on coastal populations. Coastal water polluted leads inexorably to a disruption of ecosystems and significant risks to people. The economic losses to the affected area are often important because of damage suffered by the tourism, fisheries and aquaculture.

In general, the strategy of fight against marine pollution from hydrocarbon following shipping accident is divided in two complementary stages: (i) recovery of the maximum volume of hydrocarbon on the sea surface and when the pollutant reached the coast (ii) cleaning the polluted coastline. There are many intervention techniques to combat pollution and their effectiveness depends on the situations in which they are implemented. Thus, it appears that the choice of a fight technique in a response plan is not trivial and requires taking into account a large number of parameters.

The project CLARA 2 (Calculations Relating to Accidental Releases in the Mediterranean) brings responses to these problems. It aims to develop and implement a computer tool to assist management crisis resulting from a maritime accident having caused a spill of pollutants. To carry out this national project (funded by the Research National Agency), a consortium of 13 partners was formed (CLARA 2 Consortium 2006). The purpose of this paper is to focus on the elaboration process of the GENEPI module (GENEration de Plan d'Interventions) from CLARA 2, which aims to plan fight actions against marine pollutions.

The current work lies in the following research fields: (1) from the maritime field perspective, the paper presents a software tool to assist crisis management staff to minimise pollution impact and (2) from a methodological perspective, the paper shows the importance of developing ontologies (i) for structuring a domain (at a conceptual level) as its actors perceive it and (ii) for using these ontologies to build computer tools for aid solving problems in that domain.

An overview of the CLARA 2 project is presented in section 2 and section 3 presents the functioning principles of the GENEPI module. Section 4 describes the methodological approach and the process used to build the GENEPI module. In the section 5 the implementation of the process is developed and exemplified. Section 6 presents the architecture of the GENEPI module. Section 7 presents the conclusions.

2. THE CLARA 2 PROJECT

The CLARA 2 project aims to provide a tool for managing crises induced by marine pollution, whether of chemical or petroleum. This tool should facilitate the rapid establishment of relevant exclusion zones to alert, but also to protect people, goods and environment, to mobilize appropriated fighting means and to anticipate critical situations. It also provides information on the capabilities of bio-accumulate in the food chain substances released and a preliminary approach to risk in terms of toxicological effects on humans is proposed in case of atmospheric dispersion of toxic gases.

The software tool (Figure 1) is based on a simulator designed to predict the location of a pollutant (Hydrodynamics Module / Meteorological data Module), and changes in its concentration in the sea (Product behaviour Module) and in the atmosphere (Atmospheric Dispersion Module) following a massive spill. It helps to know the distance effect in the case of a fire (Fire Module), provides information on the bioaccumulation capacity of some marine organisms (Module Impact Assessment) and provides sensitivity indicators according to the polluted areas (Vulnerability Maps). In addition, CLARA 2 generates plans on the steps to take and methods of intervention to implement (the generation module of intervention plans: GENEPI). The relevance of results provided by the different models is based on the relevance of the database (Product Physical-Chemical Database) of physico-chemical and eco-toxicological substances, which are the most representative (in terms of tonnage and frequency) of the Mediterranean maritime transport.

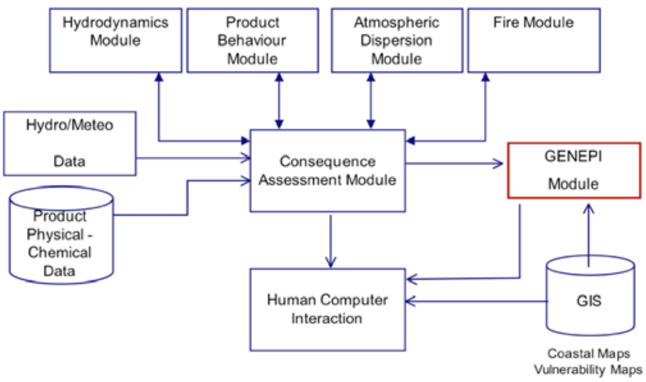


Figure 1: architecture of the CLARA 2 software tool

3. THE GENEPI MODULE

The fighting plans generated by GENEPI take account of the accidental situations and their changes over time. The set of methods and intervention techniques that could be mobilized have been classified and suitability criteria with situations have been established and associated to each of them. Figure 2 shows the functioning principle of this module.

Access to the GENEPI module is done through an observation vector of a real situation (Vreel_sit) and / or an observation vector of a simulated situation (Vsim_sit) resulting from another CLARA 2 Modules. Based on this observation vector and the suitability criteria associated with each fight (intervention) action, the selection system (Selection of Intervention Actions) accesses to the Action Classification to extract the most relevant ones. The selection is based on the analysis of suitability criteria associated with each intervention technique. The result is a set of fight action called "candidates actions". It will serve as the basis for generating fight Plans. Each Plan can be simulated to be validated. Its users can operate this module automatically or in a coordinated and controlled way.

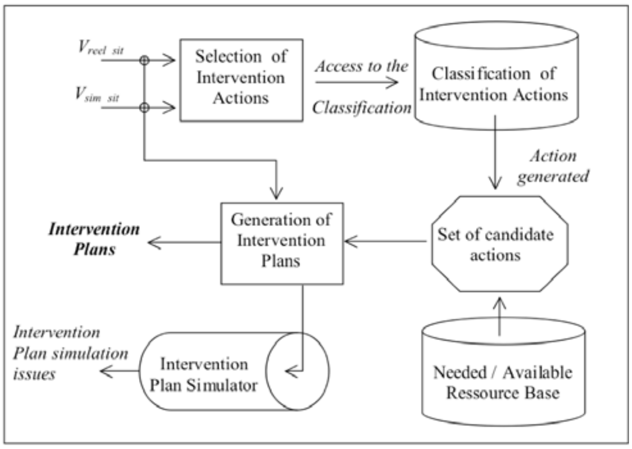


Figure 2: Functioning principle of the GENEPI Module

4. METHODOLOGICAL APPROACH

4.1. Analysis of the problem

One of the main problems arising during the conception of new computing tools to assist the resolution of safety problems is linked to the stability of the terminology. This problem is symptomatic of semantic and conceptual distances within actors of the community for which computing tools are intended. These distances can emerge within critical situations and lead to accidents or to increase accident consequences. The notion of ontology and works currently developed by the scientific community of the knowledge engineers can bring interesting answers to this problem. One of the objectives of ontology is to facilitate the exchanges of knowledge between human beings, between human beings and machines as well as between human beings through machines (Uschold and Grüninger 1996).

The advantages in developing ontologies to solve problems arising in the field of safety and risk management are the following: (i) they structure a domain in highlighting concepts and semantic relations that are linking these concepts and, (ii) they can be used to be the base for new computer tool design. Tools so built are carrying knowledge shared by the actors of the domain, what makes them more effective within critical or crisis situations.

The followed methodological process is based on the "Knowledge Oriented Design" (KOD) method (Vogel 1988) (Mercantini 2007). KOD belongs to the family of methods coming from Cognitive Engineering and designed to guide the engineer (or the knowledge engineer) in its task of developing knowledge based systems. This method was designed to introduce an explicit model between the formulation of the problem in natural language and its representation in the formal language chosen. The inductive process of KOD is based on the analysis of a corpus of documents, speeches and comments from expert domain, in such a way to express an explicit cognitive model (also called conceptual model).

4.2. The KOD method

KOD is based on an inductive approach, which requires to explicitly express the cognitive model (also known as the conceptual model) based on a corpus of documents, comments and experts' statements.

The main features of this method are based on linguistics and anthropological principles. Its linguistics basis makes it well suited for the acquisition of knowledge expressed in natural language. Thus, it proposes a methodological framework to guide the collection of terms and to organize them based on a terminological analysis (linguistic capacity). Through its anthropological basis, KOD provides a methodological framework, facilitating the semantic analysis of the terminology used to produce a cognitive model (conceptualisation capacity). It guides the work of the knowledge engineer from the extraction of knowledge to the development of the conceptual model.

The employment of the KOD method is based on the conception of three types of successive models: the practical models, the cognitive model and the software model, as represented in Table 1. Each of these models is conceived according to the paradigms: <Representation, Action, Interpretation>. The Representation paradigm allows to model the universe such as an expert represents it. This universe is made of related concrete or abstract objects. The Action paradigm allows modelling the behaviour of active objects that activate procedures upon the receipt of messages. In consequence, action plans devised by human operators as well as by artificial operators will be modelled in the same format. The Interpretation / Intention paradigm allows modelling the reasoning employed by the experts in order to interpret situations and to elaborate action plans related to their intentions (reasoning capacity).

The practical model (PMi) is the representation of a speech or a document of the corpus, expressed in the terms of the domain by means of taxemes (static representation of objects), actemes (object activity representation) and inferences (at the basis of the task cognitive structure). The cognitive model is built by abstracting the practical models. It is composed of taxonomies, actinomies and reasoning patterns. The software model result from the formalization of a cognitive model expressed in a formal language, and is independent of programming languages.

Table 1. KOD, the three modelling levels.

Paradigms / Models	**Representation**	**Action**	**Interpretation**
Practical	Taxeme	Acteme	Inferences
Cognitive	Taxonomy	Actinomy	Reasoning Pattern
Software	Classes	Methods	Rules

4.3. The ontology building process using KOD

Research work in Ontology Engineering has put in evidence five main steps for building ontologies (Gandon, 2002)(Aussenac-Gilles and al. 2000) (Dahlgren 1995)(Uschold 1996; Uschold *et al*. 1995) (Fernández-López 1999; Fernández and al. 1997):

1. *Ontology Specification*. The purpose of this step is to provide a description of the problem as well as the method to solve it. This step allows one to describe the objectives, scope and granularity size of the anticipated ontology.
2. *Corpus Definition*. The purpose is to select among the available information sources those that will allow the objectives of the study to be attained.
3. *Linguistic Study of the Corpus*. This step consists in a terminological analysis of the corpus in order to extract the candidate terms and their relations. Linguistics is specially concerned to the extent that available data for ontology building are often expressed as linguistic expressions. The characterization of the sense of these linguistic expressions leads to determine contextual meanings.
4. *Conceptualization*. Within this step, the candidate terms and their relations resulting from the linguistic study are analyzed. The candidate terms are transformed into concepts and their lexical relations are transformed in semantic relations. The result of this step is a conceptual model.
5. *Formalization*. The purpose of this step is to express the conceptual model with a formal language.

The projection of the KOD method on the general approach for developing ontology shows that KOD guides the corpus constitution and provides the tools to meet the operational steps 3 (linguistic study) and 4 (conceptualization).

Under previous researches, the KOD method has been already implemented (Mercantini et al., 2003; 2004; 2007) in the domains of road safety, safety of urban industrial sites and study of conduct errors of industrial plants.

Table 2. Integration of the KOD method into the elaboration process of ontology

Elaboration process of Ontology	KOD process	Elaboration process of ontology with KOD
1. Specification		1. Specification
2. Corpus definition		2. Corpus definition
3. Linguistic study	1. Practical Model	3. Practical Model
4. Conceptualisation	2. Cognitive Model	4. Cognitive Model
5. Formalisation		5. Formalisation
	3. Software Model	6. Software Model

5. ELABORATION OF THE ONTOLOGY

5.1. Corpus Definition

This phase's objectives are to identify, within the problem domain, the relevant knowledge for the GENEPI module. It requires a well-defined and well-delimited problem domain.

In our study, two important phenomena that define the field and the problem to be addressed are: (i) maritime accidents and (ii) interventions to contain the consequences of the accident. Thus, the corpus has been established on the basis of documents from CEDRE (le Centre de Documentation, de Recherche et d'Experimentation sur les pollutions accidentelles des eaux) and REMPEC (the REgional Marine Pollution Emergency Response Centre for the Mediterranean Sea) in respect of accidents that have already occurred as well as the implementation of emergency plans. The types of documents that make up this corpus are the following:

- Documents relating to the evaluation of each fight technique or method,
- General documents about the organization of emergency plans (plan ORSEC, « Organisation de la Réponse de SEcurité Civile", Organization of Civil Security Response),
- Return on experience documents about the major maritime disasters such as that of the Erika, Prestige, etc..
- Return on experience documents about maritime accidents of lower magnitudes.

5.2. Practical models

This phase consists in extracting from each document belonging to the corpus, all the elements (objects, actions, and inferences) that are relevant to accident representation and fight action implementation.

5.2.1. Extracting taxems

To obtain taxems, the linguistic analysis is performed in two steps: the verbalization and the modelling into taxems. The verbalization step consists in paraphrasing the corpus documents in order to obtain simple phrases, which allow qualification of the terms employed during document analysis. Thus, some terms appear as objects, others appear as properties, and yet others appear as relations between objects and values. The modelling step consists of representing the phrases in the format of taxem: <object, attribute, value>.

The taxem characterizes an object from the real world by means of a relation (attribute), which links the object to a value. There are five types of relations: classifying (is-a, type-of), identifying (is), descriptive (position, failure mode, error mode, cause…), structural (composed-of) and situational (is-in, is-below, …).

The example that follows illustrates the process employed to obtain the taxems from one phrase extracted from the "Prestige" accident.

"... On November 13th, 2002, the Prestige oil tanker flying the Bahamian flag, sends an emergency message from the Finisterre Cape ..."

Paraphrases

1. The Prestige is a oil tanker
2. The Prestige flies the flag of the Bahamas
3. On November 13, The Prestige is located at the Finisterre Cape
4. On November 13, the Prestige sends an emergency message

Taxems

1. <Prestige, IS A, oil tanker>
2. <Prestige, FLAG, Bahamas>
3. <Prestige, LOCATION, Finisterre Cape>
4. <Prestige, DATE, November 13th>

The last paraphrase is related to an action, so it will be modelled by means of an actem. The extent of this analysis at the Corpus, have allowed obtaining the set of taxems needed for the representation of the universe described by the corpus of documents. An object of the real world is modelled by the sum of related taxems extracted from the set of documents of the corpus.

5.2.2. Extracting actems

In order to obtain the actems, the linguistic analysis consists on identifying verbs that represent activities performed by actors during marine pollution or object behaviour. In general terms, an activity is performed by an action manager, by means of one or more instruments, in order to modify the state (physical or knowledge) of the addressee. The action manager temporarily takes control of the addressee by means of instruments. Occasionally the action manager can be the one who directs the activity and at the same time is also subjected to the change of state (example: knowledge acquisition). The following example illustrates how to extract actems from the Corpus.

"... the Prestige sends an emergency message..."

The activity is "SENDING an emergency message". Once identified, the activity is translated into a 7-tuple (the actem):

<Action Manager, Action, Addressee, Properties, State1, State2, Instruments>,

Where: the Action Manager performs the action; the Action causes the change; the Addressee undergoes the action; the Properties represent the way the action is performed; State 1 is the state of the addressee before the change; State 2 is the state of the addressee after the change; Instruments, is one or a set of instruments representing the means used to cause the change.

The actem "SENDING an emergency message" is, thus, represented as following:

<Prestige Commandant, SENDING an emergency message, CROSS MED, (date, location, duration), CROSS MED (do not know), CROSS MED (know), Radio>.

Where CROSS MED means "Centre Régional Opérationnel de Secours et de Sauvetage en Méditerranée », which is the French organism that receives any emergency messages from ships in difficulties. Figure 3 illustrates this actem and figure 4 illustrates the case of a fight action where it has been necessary to extend the actem formalism to take in account suitability criteria:

<Action Manager, Action, Addressee, Properties, Suitability Criteria, State1, State2, Instruments>

Actems model the task activity. It is composed of textual items extracted from the reports, which describe the state change of an object as described by the domain experts. Each element of the 7-tuple (or 8-tuple for fight actions) must be previously defined as a taxem.

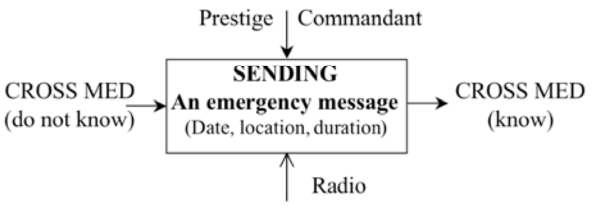


Figure 3: Representation of the Actem "SENDING An emergency message".

FLUSHING	
Components	**Values**
Action Manager Operator	{Human Means}
Addressee Substratum	{Sand, Stone, Concrete, Rock, etc.}
Addressee State1 State	{Polluted, Cleaned}
Addressee State2 State	{Polluted, Cleaned}
Instruments	{Pump + Water Hose + Recovery Means}
Properties	Efficiency
Suitability Criteria	Site_Acces, Viscisity_Pollutant, Pollution_level, Kind_Of_Substratum, etc.

Figure 4: Representation of the Actem "FLUSHING" in a table form.

5.3. The cognitive model

This phase consists on the analysis and abstraction of all the Practical Models built in the previous phase. The objective is to build the domain ontology. In other words, the aim is to classify the used terminology and thus obtain the KOD Cognitive Model

5.3.1. Building the Taxonomies.

Term Analysis: the analysis consists in solving problems induced by homonym and synonym terms, with the objective to build a common terminology.

Concept Identification: This step is based on the analysis of the taxems and consists in highlighting the nature of the attributes, which characterize each object. The attribute nature is the basis for the construction of the taxonomies (relations 'kind-of' and 'is-a') or other tree type structures (relations: 'is-composed-of', 'position', 'is-in', 'is-below', 'is-above', etc.).

As an example, from the analysis of the set of taxems it was found that the term "Skimmer" is meaningful and thus it deserves the status of a concept. It is significant of a set of recovery devices (modelled by means of taxems). As a result of the analysis of the terms related to "Skimmer", the taxonomy of the figure 5 has been built and the "Skimmer" concept is defined through his attributes as follow:

The Skimmer Concept

<Type, Flow, Quantity, Storage Location, City, Dimension, Weight, Performance Limit, Selectivity, Recovery Rate>

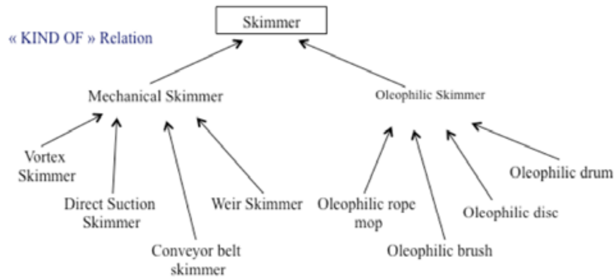


Figure 5: The Skimmer taxonomy

All the taxems of the corpus are organized in taxonomies and each concept has been defined as shown in the example.

5.3.2. Actems abstraction

One result of the actem analysis is that actems can be devided into five main action categories:

- Actions related to pollutant behaviour,
- Actions related to accidented ship behaviour,
- Actions related to reasoning patterns,
- Actions related to CLARA 2 services.
- Actions related to operations against pollution,

Amongst actions related to pollutant behaviour we can cite: Evaporation, Dissolution, Drift, Emulsion.

Amongst actions related to accidented ship behaviour, we can cite: Listing to starboard, Sinking, Sending an emergency message, Requesting evacuation.

The actions related to reasoning patterns such as « Choosing the shoreline clean-up methods » are used to select or to plan fight actions. To be performed, they use the suitability criteria associated to each actem.

The actions that belong to the CLARA 2 services category are implemented to improve the GENEPI functionalities. As examples we can cite: Coastal Mapping, Evaluating the Pollution Movement, Evaluating the Pollution Impact.

The actions of the last category are fight actions. They are divided into two main classes: (i) the shoreline clean-up methods and (ii) the clean-up methods on the sea. The set of actems from this category has been structured by means of a Taxonomy. Figure 6 is an extract of this taxonomy.

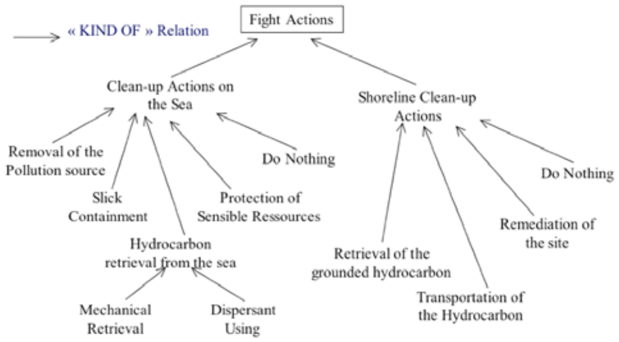


Figure 6: Extract of the Fight Action Taxonomy

Some actems of this category can be organized in a structural and temporal way to form actinomies. The interest of this kind of structure is that actions are already planned.

6. ARCHITECTURE OF THE GENEPI MODULE

The architecture of the GENEPI module (Figure 7) has been designed around the ontology enriched with the instances of the concrete classes. The association of the ontology with instances constitutes a knowledge base (Maedche 2002).

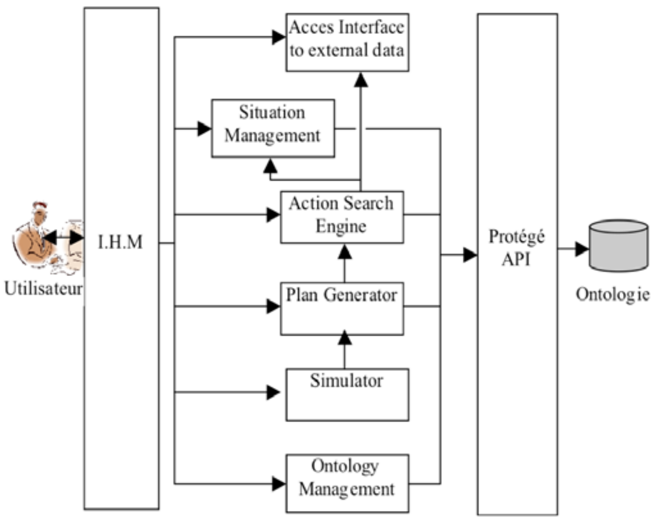


Figure 7: Architecture of the GENEPI module

6.1. The notion of Situation

The analysis of accident stories from the corpus, shows that each accident has its own characteristics and that for a particular accident, the circumstances and context change from one moment to another. To take this into consideration, we defined the notion of Situation. A Situation consists of a set of attributes (S) that characterizes the accident and its context. The set of these attributes is a superset of the set of suitability criteria (Ca) associated to fight actions. Thus, attributes common to Ca and S have the same types.

Instances of the Situation are obtained from data delivered by the access interface to external data (coming from others CLARA2 modules), and from data supplied by the user.

6.2. The Action Search Engine

The search engine receives as input the Situation and the Domain in which searching the fight actions in the ontology. The domain is identified by the name of the class that characterizes it into the taxonomy of the fight actions (Shoreline Clean-up Actions, Mechanical Retrieval, etc.). As results, it provides four sets of fight actions:

- The set A, which contains the actions where all criteria are verified,
- The set B, which contains the actions where at least one of the criteria could not be assessed by lack of information in the situation,
- The set C, which contains the shares of which at least one criterion was not satisfied,
- The set D, which contains the actions of the set B enriched by criteria not assessed.

6.2.1. The selection rules of actions

The rules for selection of fight actions are based on the suitability criteria and the values taken by the corresponding attributes of the situation.
The rules are of the form:

$$c1 \wedge c2 \wedge ... \wedge cn \rightarrow \text{True / False}$$

With c1, c2, ... cn, the criteria associated to a fight action. The conclusion of the rule is about the possibility whether or not to select the action. A criterion is satisfied if the value taken by the corresponding attribute of the situation is compatible the criterion constraints.

6.2.2. The algorithm for selecting actions

Upon the receipt of the Situation, the algorithm analyzes the actems involved in the Search Domain. From each ACTEM, it extracts the criteria and it applies the selection rules previously presented. According to the results obtained, the actem is placed in the corresponding set (A, B, C or D).

After running the algorithm, if the user is not satisfied with the result, it can enrich the situation to assess the criteria that have not been. This new running should reduce the size of the B set, putting the actions which were either in the set A or in the set C.
The algorithm is independent of changes in the ontology.

6.3. The ontology management module

This module provides users with the functions needed for maintenance (updating, adding and deleting classes, attributes and instances) and consultation (searching knowledge) of the ontology.

7. CONCLUSION

The paper presents the first results about the design of a software tool (the GENEPI module) to plan fight actions against marine pollution. The GENEPI module is a part of a wider research program: CLARA 2.

The methodological process to build GENEPI is based on the elaboration of an ontology. The purpose of that ontology is to structure the domain (maritime accidents) according to the problem to solve (to plan fight actions) and to the problem solving method.

The ontology was obtained through a cognitive approach, which consisted in applying the KOD method, which has proven to be adequate.

The Situation Management module, the Ontology Management module and the Action Search Engine are in service. The Plan Generator module and the Simulator are currently in progress.

REFERENCES

Aussenac-Gilles N., Biébow B. and Szulman S., 2000. Revisiting Ontology Design: a method based on corpus analysis. *EKAW-2000*, *Proceedings of the 12th International Conference on Knowledge Engineering and Knowledge Management*, R. Dieng et O. Corby (éd.), LNAI 1937, Springer, pp. 172-188.

CLARA 2 Consortium: École des Mines d'Alès, le Cèdre, IFREMER, Météo France, IRSN, TOTAL, EADS, Géocéan, UBO, INERIS, SDIS 30, Préfecture Maritime de la Méditerranée, le CEPPOL, LSIS. Projet ANR, 2006-2010.

Dahlgren, K., 1995. A Linguistic Ontology. *International Journal of Human-Computer Studies*, vol. 43, n°5, pp. 809-818.

Fernández-López M., 1999. Overview of methodologies for building ontologies. *Proceedings, IJCAI-99 Workshop on Ontologies and Problem-Solving Methods (KRR5)*, pp. 4-1 to 4-13. August 2, 1999. Stockhom, Sweden.

Fernández M., Gómez-Pérez A. and Juristo N., 1997. METHONTOLOGY: From ontological art towards ontological engineering. *Proceedings AAAI-97 Spring Symposium Series, Workshop on ontological engineering*, pp. 33-40. Stanford (California).

Gandon F., 2002. Ontology engineering: a survey and a return on experience. *Research Report n° 4396*. INRIA Sophia-Antipolis, mars 2002.

Mercantini J.M., Capus L., Chouraqui E., Tourigny N., 2003. Knowledge Engineering contributions in traffic road accident analysis. In: Ravi K. Jain, Ajith Abraham, Colette Faucher, Berend Jan Van der Zwaag, eds. *Innovations in Knowledge Engineering*. pp 211-244

Mercantini J.-M., Turnell M.F.Q.V, Guerrero C.V.S, Chouraqui E., Vieira F.A.Q et Pereira M.R.B, 2004. Human centred modelling of incident scenarios. *IEEE SMC 2004, Proceedings of the International Conference on Systems, Man & Cybernetics*, pp. 893-898. October 10-13, The Hague, The Netherlands.

Mercantini, JM., Tourigny, N., Chouraqui, E., 2007. Elaboration d'ontologies à partir de corpus en utilisant la méthode d'ingénierie des connaissances KOD. *1ère édition des Journées Francophones sur les Ontologies (JFO 2007)*, n° ISBN : 978-9973-37-414-1, pp 195-214, 18 – 20 Octobre 2007, Sousse (Tunisie).

Rempec, 2002. *Guide pour la lutte contre la pollution marine accidentelle en Méditerranée*, *Partie D, Fascicule 1*. Avril 2002.

Uschold, M. and King, M., 1995. Towards a Methodology for Building Ontologies. *Proceedings of the IJCAI-95 Worshop on Basic Ontological Issues in Knowledge Sharing*, Montréal (Canada).

Uschold, M., and Grüninger, M., 1996. Ontologies: Principles, methods and applications. *Knowledge Engineering Review*, volume 11, n° 2, 1996, pp. 93-136.

Vogel, C., 1988. *Génie cognitif*, Paris, Masson (Sciences cognitives).

ANALYSIS AND OPTIMIZATION OF AN HIGHLY SEASONABLE WAREHOUSE: CASE STUDY UNIFRIGO GADUS S.P.A.

Andrea EMINENTE[(a)], Teresa MURINO[(b)], Giuseppe NAVIGLIO[(c)]

[(a)] Unifrigo Gadus S.p.a.
[(b)] Department of Materials Engineering and Operations Management
University of Naples "Federico II" P.le Tecchio – 80125 Napoli ITALY
[(c)] Department of Materials Engineering and Operations Management
University of Naples "Federico II" P.le Tecchio – 80125 Napoli ITALY

[(a)]andrea.eminente@hotmail.it, [(b)]murino@unina.it, [(c)]giuseppe.naviglio@unina.it

ABSTRACT
The paper deals with a highly seasonable warehouse, owned and managed by Unifrigo Gadus Spa, a firm operating in the field of the salted fish supply.
This warehouse represents a crucial point for the whole salted fish supply chain in Italy.
The purpose of this work is to study the warehouse features, its management policy adopted by the company and the flow passing through it, in order to suggest a methodology to solve the highlighted criticalities. As a matter of fact, not only a rationalization and optimization of the warehouse management policies can increase the efficiency of the single company but also of the whole supply chain.

Keywords: salted codfish supply chain, warehouse management, optimization, logistics

1. INTRODUCTION
The dried and salted codfish supply chain consists in different steps that permit to deliver it all over Europe.
Salted codfish is produced using Gadus Morhua, which is caught in the North Atlantic Ocean and in the Barens Sea. Fishermen sell it to producers mainly located in Norway, Iceland, Denmark and Spain. Here the fish, already beheaded and eviscerated, is salted and dried ashore. Traditionally the fish was sun-dried on rocks or wooden frames, but today it is mainly dried indoors by electrical heating. Than, codfish is collocated in packs of 25 kg, which are loaded on pallets of 40 packs each one. Some suppliers use packs of 20 kg and\or pallet made up of 30 packs. Packs may contain a whole codfish or a portion of it, with or without bones. Hence goods are sold to foreign countries importers. They can purchase a single truck of 18 tons or they can stipulate contracts that provide for a number of trucks delivered to deadlines. Vessels transfer goods from Iceland to Rotterdam where they are forwarded to Italy and to the other European destinations by refrigerated trucks. The transport from the place of production to the final destination takes about 10 days. The goods coming from Norway and Denmark are, however, loaded on trucks directly in the places of production and shipped to its final destinations.

The Gadus Morhua is utilized also to produce a different kind of goods, the stockfish. It is unsalted codfish, hung on wooden racks and dried. Anyway, it has more or less the same supply chain of salted codfish but stockfish is produced only in Norway due to its particular weather conditions.

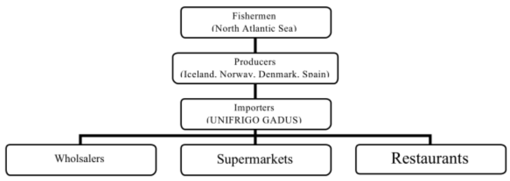


Figure 1: The salted codfish supply chain

The salted codfish and stockfish supply chain is a critical issue for several reasons.
First of all, since it is not an industrial product, it is hard to state properly the quality of each lot and to find an agreement among suppliers and customers about it. Moreover, even though the delivery time does not represent a matter, as dried and salted codfish is a long life product, it must be transported in fridge trucks or containers. Anyway, a relevant problem is the impossibility of forecasting neither the market demand nor the suppliers offer as they depend on different factors such as weather conditions and wildlife preservation regulamentations. However, the main problem is the highly seasonable sales trend, which affects salt cod. This issue involves every link of the supply chain, causing several difficulties in getting into proportions properly the work force and warehouses.
Actually, the aim of this work was to study the features of a warehouse managed by Unifrigo Gadus Spa, an Italian firm operating in the field of salt cod importation, in order to suggest a correct way to solve the pointed out criticalities.

2. WAREHOUSE ANALYSIS

Unifrigo Gadus Spa is a firm operating in the field of salted codfish and stockfish supply since the beginning of the last century. It represents a key link in the supply chain for these products in the Italian market. This market currently is worth around 200 million euro of annual turnover. It is a marginal sector and the players at the national level are very few, a dozen in all. However the possibilities of the entry of new competitors are very remote due to some barriers to entry such as the paucity of suppliers and the close personal ties that bind them to the importers. The business of Unifrigo Gadus consists in the importation and distribution of salt cod and stockfish on the Italian territory through a network of food wholesalers, supermarkets, markets, large retailers, etc. Unifrigo Gadus Spa trades 84 different articles in all that differ for quality, size and brand. The imported merchandise is stored, for the markets of the north Italy, into a refrigerated warehouse owned by the company in Novi Ligure (Alessandria). Conversely, goods for customers located in the south and in the centre of Italy, are stored in a cold store situated in a large industrial complex in Campania.

2.1. The warehouse in Campania

The analyzed warehouse consists in 4 cells that Unifrigo Gadus S.P.A. currently rents and manages. Even if it were necessary, the company cannot get more space, as it is not available. Furthermore, Unifrigo Gadus Spa is not interested in building and owning another store. The following numbers marks the cells: 16,17,18 and 38.
Next to the cells there are the company sales offices and a goods load\unload area.

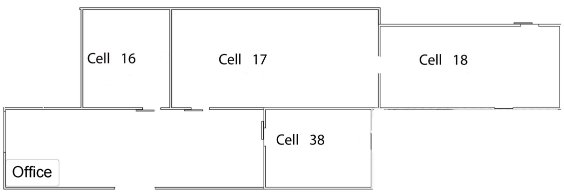


Figure 2: Unifrigo Gadus warehouse layout

Due to the salt cod seasonal sales trend, the most part of goods movement is condensed in a very short lapse of time. Actually, in 2008, the 69% of goods loads and the 80% of unloads, took place from September to December as displayed in the following pie charts.

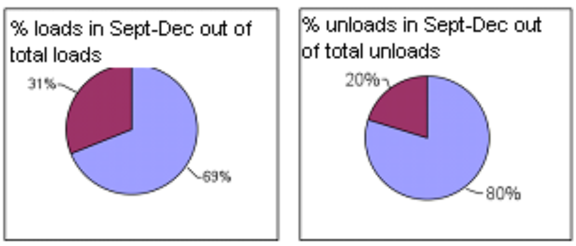


Figure 3: % Loads and unloads In September-December out of total loads and unloads

2.1.1. Cell 16 features

The cell number 16 is 6,9 meters long and 7,7 meters wide and is kept at a temperature of -2 Celsius degrees. The theoretical capacity of this room is 37 500 kg. It is used to store stockfish and it is not equipped with shelves, as suppliers do not place the stockfish on pallets. Moreover, it is not possible to store here salted and dried codfish since this is characterized by a different humidity percentage.

Figure 3: Packs of stockfish in cell 16

Even though the stockfish is mostly handled in the period September-December, with the 66% of goods unloads and 52% of loads, it has a less seasonal sales trend than the salt cod.

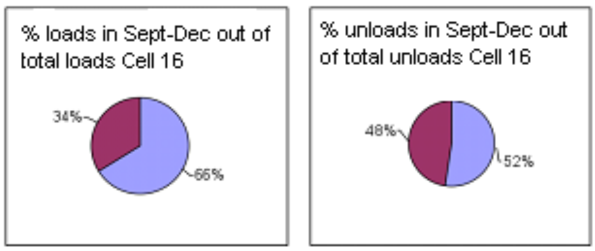


Figure 2:% Loads and unloads In September-December out of total loads and unloads of product in cell 16

In the year 2008, the stock peak was registered during the 41st week of the year and was an amount of 16 806 kg of stockfish representing the 44% of the theoretical capacity. The average stock quantity of cell 16 is 8 994 kg, the 53% of the maximum stock and just the 23% of the theoretical capacity.

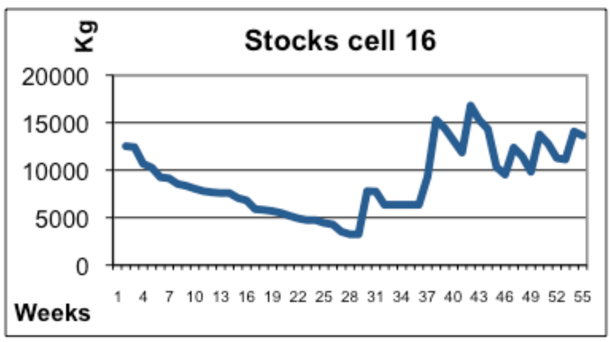


Figure 6: Stocks trend of cell 16

Hence, the cell 16 does not represent, at the moment, a problem for Unifrigo Gadus Spa as it is sized properly for the required task. Anyway, it is not possible utilize the remaining space for others duties due to the stockfish conservation peculiarities.

2.1.2. Cell 38 features

The cell 38 is 8 meters long and 5,8 meters wide. It is used to store dried products such as dried salted codfish and Gaspe that are both more dried than the common salt cod. The cell 38 is equipped with shelves only on the right wall. Here there are 12 slots for euro-pallets per each vertical row. There are 10 vertical rows for a theoretical capacity of 90 000 kg of goods.

Figure 7: internal view of cell 38

In the year 2008 the stock peak was registered during the 46th week with an amount of merchandise of 76 600 kg. This data represent the 17,5 % less than the theoretical maximum capacity. The average quantity of goods stored was 49 930 kg which is the 65% of the theoretical capacity.

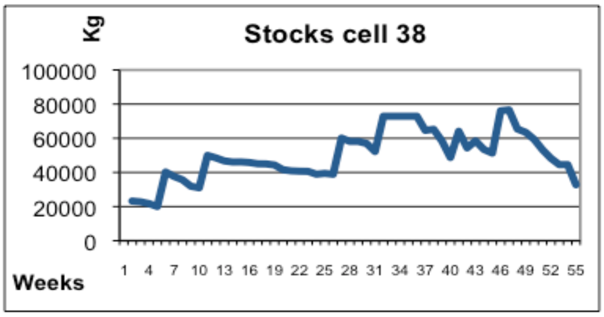


Figure 8: Stocks trend cell 38

The stock graph is characterized by an irregular trend, but it is easily explainable by the fact that in a so small cell even the arrival of just one truck of goods (20 000 kg) leads to a big shift in the stock quantity. Considering these data, the cell 38 does not matter the company and currently it does not require a specific management policy.

2.1.3. Cells 17 and 18 features

Cells 17 and 18 are connected through a door, so they can be considered as a single room. It measures 200 square meters and it is kept at a temperature between -2 and +2 Celsius degrees. In this area are stored the salt cod and some other products known as Ling and Brosme that are different fishes but prepared exactly as the salted codfish is. Due to the high percentage of salt and humidity that characterizes these articles, it is not possible store here neither the dried codfish nor the stockfish. Cells 17 and 18 are equipped with shelves on both sides that allow a central transit only to one forklift. The layout is *drive-in* as the shelves are close to the walls and goods can be picked just from one side.

Figure 9: Shelves and drive-in layout in cells 17 and 18

In this area, there are 441 slots for pallets for a total amount of 363 000 kg of merchandise. In the year 2008, the stock peak was registered during the 46th week. It was 374 363 kg, the 3,1% more than the maximum theoretical capacity. In addition it is important to underline that a number of slots are occupied by partially empty pallets. Indeed, several articles stored in the cells 17 and 18 are characterized by the sale of single boxes of goods in spite of the entire pallets. Actually, the sales of entire pallets are only the 11,44% of the total goods unloads. The average stock during the year 2008 was 194 838, the 53,2% of the theoretical capacity. The minimum stock, 111 696 kg and was registered during the 54th week of the year. The considerable difference between the maximum and the minimum stock quantity is explainable by the fact that salted codfish is always available and it is not necessary a particular purchase policy.

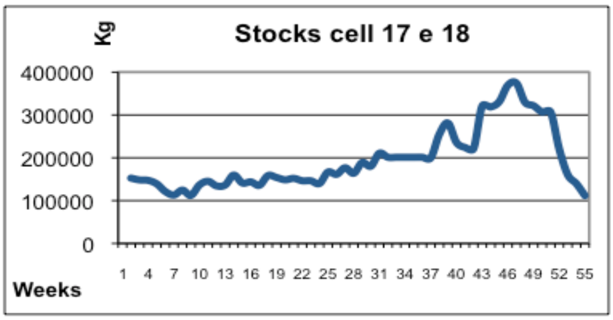


Figure 10: Stocks trend in cells 17 and 18

However, all the products stored in cells 17 and 18 are characterized by a highly seasonable sales trend. Actually, in the period September-December of the year 2008 were registered 357 loads of goods out of 497 in all, and 4 266 unloads and sales out of 5 133 in all. These data represent respectively the 72% and the 83% of the entire year movements.

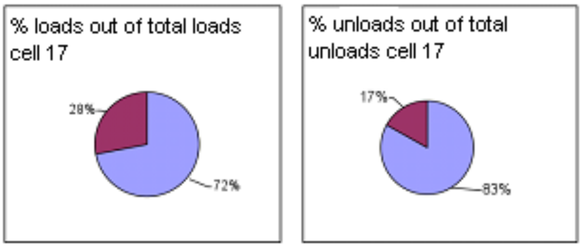


Figure 11: % Loads and unloads In September-December out of total loads and unloads

2.2. The current state of the warehouse

Currently three workers are employed at the Unifrigo Gadus store. There is one storekeeper, who is the responsible of the warehouse organization, and two skilled workmen. There are two different kind of operations made when it is necessary to deliver merchandise, depending on if it is required a full pallet of codfish or just part of it. In the former instance, the storekeeper, who drives the forklift, forks a pallet and puts it on the vehicle used to deliver the goods. The other two employers are totally useless in this case. In the latter instance, the forklift driver takes a pallet and puts it on the floor where the other two workmen can collect the requested packs. The warehouse is overstaffed in March-July. Hence, in this period were registered just the 18% of the goods loads and the 9% of goods download. On the contrary, the store is heavily short-staffed during the last three months of the year. Actually, the company has to pay overtime and even hire short-term workers. However, this is not a valid and effective solution, since due to the current warehouse organization, the staff has to know the different articles features. This implies a necessary training time for workers.

At the moment, is not followed a specific criterion to arrange the goods. The store man allocates these each time as he regards convenient. Usually he tends to put in close slots products commercially homogeneous. However, this means that very similar goods, but with different brands are not arranged one next to the other.

Furthermore, the store man does not make any difference among the levels of the shelves even if the pallets positioned at the ground floor are clearly easier to take. Therefore, all the goods in the store are always moved with the forklift truck and never with the transpallets. Moreover, some vertical rows are occupied by pallets and packs already sold by the company but not delivered yet. Nevertheless, from September, even this rough method is dropped. Actually, the incoming pallets are just put in the first available slot, supposing that there is one. Otherwise these are simply piled up out of the shelves as well.

2.3. The current state analysis

Cells number 17 and 18 represent a nodal point for Unifrigo Gadus business. Indeed are stored there as many as 62 different items out of 84 usually sold by the company. However, as the data clearly show, they are undersized to accomplish the requirements. Analyzing the data about the goods unloads in the year 2008, it come out that just the 9,26% of sales involved a full pallet. It makes clear that the company material handling policy based on the pallet movements with a forklift is useless and too slow for the most part of warehouse operations. Moreover, human resources are not optimally capitalized as each operation or movement depends on the storekeeper. Since he works with complete autonomy in storing the goods and choosing which deliver to each customer, the warehouse management is very hard when he is absent. Furthermore there is not a clear strategy carried out in order to pursue good results of traceability. Working only with the forklift and never with the transpallets it takes a long time to prepare the merchandise to be delivered. Furthermore, two of three employers are constantly underused. Since there is not an assigned warehousing plan, the different goods are not always stored in the same place. The workforce is so required to know the merchandise and to recognize it in order to collect the right article when requested. This implies a substantial difficulty in changing the workforce and employ workers for a short-term. All the refrigerated cells are set up with shelves attached to the wall. This makes not possible a *First In-First out* strategy. So the company is obliged to adopt a *Last In-First out* strategy, which is surely not indicated for food with expiration date.

Summarizing, the problems highlighted are:

1. Inadequate size of the cell number 17
2. Stocking strategy adapted only for pallets movements
3. Tight dependence on the store man
4. Workers must know the goods and recognize the different products
5. Human resources are not properly utilized
6. Too much time needed to prepare the merchandise to be delivered
7. LIFO strategy obligatorily adopted
8. Difficulties in pursuing good results of traceability

3. SOLUTIONS

At the moment, it is not possible to solve the problems related to the insufficient size of the cell 17 and 18. Even if this implies a number of troubles, the company do not intend leave the building where are located the cells that it has now in use. Furthermore Unifrigo Gadus does not want to build an own warehouse due to the high costs and the long time requested as already highlighted. However, as cells 17 and 18 are oversized for a remarkably long term during the year, the company could split them by closing the internal door and sublet one of them from March to August.

3.1. Picking zone

A possible solution to the points 2,3,4,5 and 6 is the arrangement of zone picking system. This would sensibly facilitate the preparation of the merchandise to be delivered. In particular, the advice is to assign to each ground-floor-slot a different product that could, indeed, be collected using two transpallets instead of the single forklift. If it be so, the two workmen currently bound to the forklift driver due to the their impossibility in reaching products stored in the high shelves, could contrary work autonomously as they could take with their transpallet any kind of merchandise. Moreover, applying a *dedicated storage* strategy, workers are not obliged to know and recognize the different products and would not waste time. As the company already owns an electric transpallet, it should just buy another one capable of moving 1,5 tons since the heaviest pallet weighs 1,3 tons. Furthermore the software presently used by the company is already capable of calculating the best picking track and of printing it on a paper. In this way, everybody at the store should be able to pick quickly the product to dispatch. A test has been conducted in order to quantify the time that could be saved with this solution. The test consisted in measuring the time needed in collecting 10 different lots of goods from 5 different pallets, so 2 lots for each distinct pallet, all positioned at the ground floor. The result showed that the time required doing the job with the forklift is 27% higher than the time required to take the goods with the transpallet. This would mean a conspicuous reduction of the time used for material handling which is clearly not enough as, in the year 2008, were paid 388 hours of overtime.

At the ground floor of the cells 17 and 18 there are 43 slots available for pallets. Since the different articles here stored are 62, it seems that not every product could be allocated in the picking zone. However, some articles are characterized by only full pallet handling so are not suitable for the picking zone, while others could be put in the same slot being commercially homogeneous. Hence, the articles to be assigned to the ground floor slot are in sooth 41. It is now necessary a criterion to assign the different slots to the articles as the ones near the door are clearly more accessible. Drowning up a list where the products (article id) are ranked by the number of pickings registered during the year 2008, it is possible to allocate the most handled articles to the most accessible slots.

article id	pos.picking	# movements	# pallet movements	# picking
BCI17 e BCI 17\2	1	536	79	457
BCI28 e BCI 28\2	2	481	82	399
FCG07 e FCN07	4	283	36	247
BCI12 e BCI12\2	3	270	23	247
FBA04	5	277	43	234
BCI41 e BCI 41\2	6	264	32	232
FLA10	7	244	19	225
FCG10 e FCN10	8	240	16	224
FLA07	9	206	10	196
FCG04 e FCN04	10	178	30	148
FBA02	11	165	26	139
SLI20	12	138	12	126
BCN16	13	134	12	122
FBA07	14	130	26	104
BCN13	15	115	13	102
SLI40	16	120	21	99
FLA10/20	17	106	8	98
BCG17	NO	96	4	92
BCN07	18	95	7	88
BCN21	19	87	3	84
BCG40	NO	92	14	78
BCG27	NO	77	6	71
FLA04	20	75	5	70
BFM27/20 e 27/25	21	66	1	65
WCP	23	75	14	61
FLA15/20	22	63	2	61
BCN10	24	56	2	54
BFM40/20 e 40/25	25	49	1	48
BCG12	NO	50	4	46
BFM17 e 17/25	26	44	0	44
BFM12 e 12/25	27	43	0	43
FLA15	28	35	0	35
FLA20/20	30	32	3	29
FLA07/20	29	31	2	29
SBI17	31	40	12	28
SBI12	32	26	3	23
FBA01	33	18	1	17
BFM28/20 e 28/25	34	16	0	16
SLF40/20	35	15	0	15
FLA00	37	11	0	11
BFM41/20 e 41/25	36	15	4	11
BFM13 e 13/25	38	9	0	9
BFM18 e 18/25	39	7	0	7
BFM00/20 e 00/25	40	5	0	5
BFM09	41	3	0	3
FCG02	NO	11	11	0

Table 1: Articles stored in cells 17 and 18 ordered by number of pickings in the year 2008

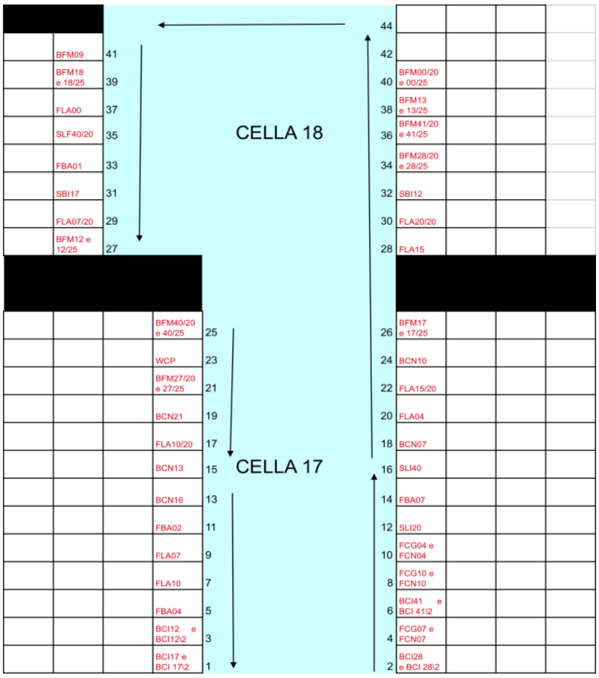


Table 2: The suggested layout of the picking zone

Once the picking area has been arranged, the attention should be focused on the goods disposition in the shelving upper floor. It is obviously impossible organize all the floors with a dedicated storage strategy, as the space would not be enough and due to the different quantity of the several stored products. Moreover, a consistent part of the goods stored in the warehouse is not available for sale because has already been purchased by customers that have not collected it yet. Anyway, analyzing the data referred to the movement of entire pallets of codfish, it comes out that there are products more involved in this kind of handling than others. It is strongly suggested to place these articles in the upper floor, as they must always be moved with the forklift. Unfortunately this solution would led to a *Last-in First-out* strategy, making the solution non entirely feasible, unless the warehouse would be redesigned applying a drive through layout.

3.2. Bar codes

An efficient solution to problem number 8, the difficulty in pursuing good results of traceability, is labeling with bar codes all the goods passing through the store. It is suggested the adoption of EAN-128 as standard bar code for Unifrigo Gadus because of the amount of data that it can provide. Actually, on each label can be printed information such as article code, lot and expiring date. This would make the company aware, in every moment, of which goods are in the warehouse and which were already sold and shipped and to whom. The company already owns two labeling machines and hence should just buy a barcode reader. Moreover, the best benefit of the implementation of a bar code labeling system is, as already highlighted; the possibility of pursuing excellent results in product traceability. Actually, a traceable product, gives o the customer a guarantee of quality and certainty about the goods origin. Additionally, traceability could be a powerful marketing tool as it can enhance the company brand image. Hence, in an uneasiness moment for the food industry, this is surely an important competitive edge. Consequently, the company could ask a premium price on the market and furthermore, acquire new customers attracted by the high quality of the whole supply chain.

4. CONCLUSION

Unifrigo Gadus Spa is by all means an efficient and cost-effective company. As a matter of fact, it has been on the market for over 100 years.

So, at the beginning of this work there were not guarantee about finding mistakes in any of its management strategies. Due to the features of the field in which the analyzed company is embedded, considering and evaluating just one-year data is a bit limiting. However the evidence and the degree of the highlighted criticalities makes them to be perforce taken into consideration. In order to came up with valid and applicable solutions, was analyzed each product flow, and simplifications were minimized. Hence it is to be hoped that Unifrigo Gadus Spa values this work and put in practice the suggested solutions. Actually, nowadays, the competitive edge cannot be based just on the product quality or on the price, especially in those markets such as the food one where brands are not always a factor and there are not exclusive representations. The optimization of goods flows, not only leads to money save and to a complete workforce capitalization, but also enhance the corporate image. This can make the difference for companies such as Unifrigo Gadus Spa as its customers frequently visit it in order to evaluate the company's logistic quality and organization.

5. REFERENCES

Colleen Cunningham, Il-Yeol Peter P. Chen, *"Data warehouse design to support customer relationship management analyses",* Proceedings of the 7th ACM international workshop on Data warehousing and OLAP, pp. 14-22, 2004.

Jain, Dipak and Singh, Siddhartha, *"Customer Lifetime Value Research In Marketing: A Review and Future Direction",* Journal of Interactive Marketing 16 (2), 34—46, 2002.

Manzini R., Gamberi M., Persona A., Regattieri A., *"Design of a class based storage picker to product order picking system",* International Journal of Advanced Manufacturing Technology, 811-821, 2007.

Carol F.,Marchet G., Perego A., *"Optimal layout in low level picker-to-part systems"*, International Journal Prod Res, 32-43, 2000.

Buonassisi V., Torre S. *"Stoccafisso&Baccalà"* Idea Libri, 1988

Bowersox D.J., Closs D.J., Helferich O.K. *"LOGISTICA – strategia e integrazione in azienda"* tecnichenuove, 1989

Ballou R. H. *"Business logistic managment (IV ed.) – planning, organizing and controlling the supply chain",* Prentice Hall, 1999

Christopher M. *"Logistics and Supply Chain Management (II ed.) – strategies for reducing costs and improving services"* Pitman Publishing, 1998

M. Gallo, L. Guerra, G. Naviglio, *"Multi-Echolon Inventory Performance Evaluation. The Case of a Communications Company".* Business Performance Measurement and Management,Springer, Gennaio 2010.

Grisi R.M., Murino T., Zoppoli P., *"Risk in Supply Networks: The Case of Aeronautical Firms",* Business Performance Measurement and Management,Springer, 2010

APPLICATION OF ARTIFICIAL NEURAL NETWORK FOR DEMAND FORECASTING IN SUPPLY CHAIN OF THAI FROZEN CHICKEN PRODUCTS EXPORT INDUSTRY

Pongsak Holimchayachotikul[a] , Teresa Murino[b], Pachinee Payongyam[c], Apichat Sopadang[d] , Matteo Savino[e], Romano Elpidio[f]

[a]College of Arts, Media and Technology Chiang Mai University, Chiang Mai, 50200, THAILAND

[b] ,[f]Department of Materials Engineering and Operations Management
University of Naples "Federico II" P.le Tecchio – 80125 Napoli ITALY

[c],[d]Department of Industrial Engineering Faculty of Engineering
Chiang Mai University, Chiang Mai 50200, THAILAND

[e]Department of Engineering, University of Sannio
Piazza Roma, 21 Benevento 82100, ITALY

[a]holimchayachotikul@hotmail.com, [b]teresa.murino@unina.it, [c]karagenan@hotmail.com,
[d] apichat@chiangmai.ac.th, [e] matteo.savino@unisannio.it , [f]elromano@unina.it.

ABSTRACT

Owing to the U.S Hamburger crisis effect since the middle of 2007, frozen food products export industry sector, especially cooked chicken products export to Japan of Thai industry, endeavor has been spent in the supply chain management (SCM) of internal efficiency, merely aiming at competitiveness survival in terms of better quality and cost reduction. To reach the customer satisfaction, the company must work towards a right time and volume of his demand delivery. Therefore, forecasting technique is the crucial element of SCM operation. The more reducing inventory and capacity planning cost increase their company competitiveness; the more understanding how their company use the right forecasting based on information sharing in their SCM context. Currently, most of the companies, in this sector, do not have a right knowledge to implement the suitable forecasting system to sustain their business; furthermore, they only use top management judgment and some of the economical data for production. On the ground of the complex, stochastic, dynamic nature and multi-criteria of the logistics operations along the food products exporting to Japan of the Thai industry supply chain, the existing time series forecasting approaches cannot provide the information to operate demand from upstream to downstream effectively. The aim of the paper is to develop an innovative and simplified forecasting system and then implement for this industry based on data mining including time series factors and causal factors. This research methodology was designed with the case study company managers and engineers. Artificial neural network (ANN) theory was used to develop time series forecasting model for case study product. The type of ANN implemented was Multilayer Perceptron with the Quick-propagation training algorithm by using time series factor and causal factor such as Thai- Japan, EU-Thai and USA-Thai exchange rate, customer demand forecast and the other economic factors, from the case study company as input. The accuracy of the neural network model was compared with traditional customer demand forecast. The experimental results suggested that the ANN was capable of high accuracy modeling and resulted in much smaller error in comparison with the results from the present forecasting method of the company case study.

Keywords: supply chain collaboration, artificial neural network, frozen food

1. INTRODUCTION

Supply chain management strategies are mostly focused on improvement of customer support service levels as well as the operational cost reduction in order to sustain their profit margins. It is extensively admitted many various forecasting techniques by global firms that is one of the outstanding nub competencies for an organization to reach the right quality and time to deploy their goods in the markets. Therefore, the forecasting system performance in supply chain has attracted firm and researcher s' attention. The more complicated in supply chain system according to various demand patterns, the more forecasting methods are developed and augmented to handle with it. No matter what the dramatic change in quantity from each unit in supply chain, an inaccurate forecast in one place of the supply chain can affect the whole supply chain due to the bullwhip effect, which also affects the manufacturing plans and any plans to conform to customer demands in terms of time and quantity - a significantly difficult problem in business.

This research is appointed to apply the novel back-propagation artificial neural networks, namely Quickprop in the demand forecasting of the supply chain to be able to realize the true demand of customers even more accurately by the special input preparation. The forecasting techniques used in supply chain management are categorized into three groups, which are 1) Traditional techniques such as moving average, exponential smoothing and ARIMA such as Co and Boonsarawondse (2007) have forecasted the rice export of Thailand using artificial neural networks that imports time series, smoothing exponential time series and ARIMA. The imported data was dated from January 1996 to December 2004 and January 2005 to December 2005. The results of the trial were that artificial neural networks were rated best with ARIMA in second.
2) Computational intelligence techniques such as artificial neural network and support vector regression. For instance, Leung (1995) has introduced an approach to applying artificial neural networks to various aspects of the supply chain management for instance, forecasting, optimum parameter achievement, model and simulation creation, and decision support. Chiu and Lin (2004) has also applied multilayer perceptron to forecast collaborative supply Chain planning of an alliance of small firms.

3) Hybrid methods such as applying traditional techniques such as ARIMA with artificial neural networks or support vector regression, or applying fuzzy system techniques with ARIMA which presents us with techniques more complex but of higher accuracy. Most of application in this field has also use the traditional input type to form forecasting model; hence, this research use the combination of input factors from time series and economical factors from the industry of interest while traditional techniques can only use time series data. For incident, Vahidinasab (2008) introduced a price forecasting system for electronic appliance repair and maintenance in the Pennsylvania-New Jersey-Maryland using artificial neural networks trained

This paper is organized as follows. In section 2, the Quickprop algorithm was briefly described. In section 3, the problem statement of the frozen chicken products exports to Japan of Thai industry sector. In section 4, the methodology of the proposed approach was shown. Results and discussion of the proposed framework were shown in section 5. This section has the proposed model performance comparison with the present forecasting method of company case study. Finally, conclusions were provided in section 6.

2. BACKGROUND
ARTIFICIAL NEURAL NETWORK

Multilayer perceptron (MLP) was wildly used in many researches. It comprises of processing elements called neuron located in layers. Some or all of the outputs in each layer are connected to one or more inputs in the next layer. The input layer is the first layer, where the MLP receives input parameters. The output layer is the final layer, where the outputs are provided to the user. The hidden layers are located between input and output layer. The task of the individual neuron is to take inputs from the outside, or from other neurons connected to it, and sum these inputs according to their weight or the strength of the connection of each input. A transfer function is then adopted to produce the output. Back propagation (BP) is the most extensively adopted learning algorithm C.A.O. Nascimento *et.al* (2000). The output layer provides a response depending on training history of the network. The trained network should be able to correctly predict outputs for unseen input conditions. The Quickprop can be described as follows: Quickprop uses the concept of second order error derivative information instead of only the usual first order gradients algorithm S. Kuman (2005). This is based on two assumptions. First, the error function ε is a parabolic function of any weight w_{ij}, and second the change in the slope of the error curve is independent of other concurrent weight changes. To compute the weight, the previous value of the gradient $\partial\varepsilon/\partial w_{ij}^{[s-1]}$ and the previous weight change $w_{ij}^{[s-1]}$ are required. Then

$$w_{ij}^{[s]} = \frac{\dfrac{\partial\varepsilon}{\partial w_{ij}^{[s]}}}{\dfrac{\partial\varepsilon}{\partial w_{ij}^{[s-1]}} - \dfrac{\partial\varepsilon}{\partial w_{ij}^{[s]}}} w_{ij}^{[s-1]} = \alpha_{ij}^{[s]} w_{ij}^{[s-1]} \tag{1}$$

3. PROBLEM STATEMENT AND CASE STUDY

The stated problem has taken place the case study factory which is a frozen chicken products export to Japan of Thai industry sector. From this case study supply chain diagram in Figure 1, the research area was focused on the planning division of case study company, who forecasts and plans the finished frozen chicken product, exported following Japanese customer demand.

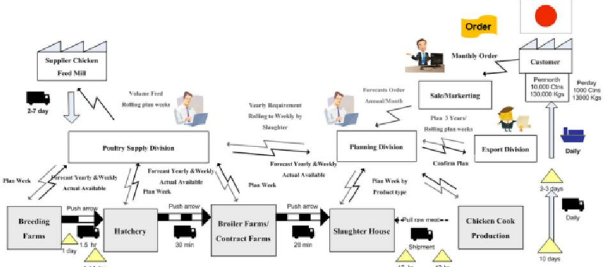


Figure 1: Supply chain of the Thai frozen chicken export to Japan

The customer demands are highly uncertain, causing current forecasting methods not being accurate enough and can lead to various problems in production plans such as over purchasing clutch food and planning clutch production, which results in high costs on reserved goods. Moreover, the material in this company case study is not able to storage much more time because it is the fresh chicken meat. Other effects are excess overtime for employees and increased costs in bringing chick up. Purchasing insufficient materials can also result in production holds, leading to loss in sales opportunities. This is why demand forecasting is very important in management of the supply chain. Leading companies have agreed that customer demand can be managed only to a certain degree. Demand fluctuation is an important reason that causes conflicts in demand and supply chain which in ideal conditions; everyone desires to know the demand and the value chain to be constant.

4. METHODOLOGY

From documents and related researches, we can define the processing methodology. A schematic diagram of the proposed conceptual framework is shown in Figure. 2. This comprises of the combination of feature selection, ANN applied to build the innovative and simplified forecasting system implementation for supply chain of frozen chicken products export to Japan of Thai industry based on data mining including time series factors and causal factors such as gold price, oil price, dollar-bath and yen-bath exchange rate. According to the normal planning production of this case study company, the proposed framework is developed to provide the potential forecasting value of production plan when they do not receive the final confirmation of demand within the period.

The phases are as follows :

4.1. Exploring and selection of data

Current demand in case study company of cooked chicken products export to Japan of Thai industry supply chain Primary data analysis, following the concept of demand forecasting in SCM based on collaborative planning forecasting and replenishment (CPFR), of the case study factory are conducted by means of basic demand and supply data of the supply chain to measure the efficiency of customer conformance and production and resource management to define the direction of solving the problems.

4.2. Data Preparation and Sufficiency

Data cleaning process was performed to eliminate noise data. Next, the cleaned data was rearranged following input and output format for each method. Data sufficiency was employed to indicate the suitable quantity of data for data mining learning process. Moreover, monte carlo simulation will generate the data in case of insufficiency of data

4.3. Learning data preparation

The data from 4.2 can used for forecast modeling by randomly dividing the data sets into three groups for training and test set were 80 and 20 percentage of all data, respectively.

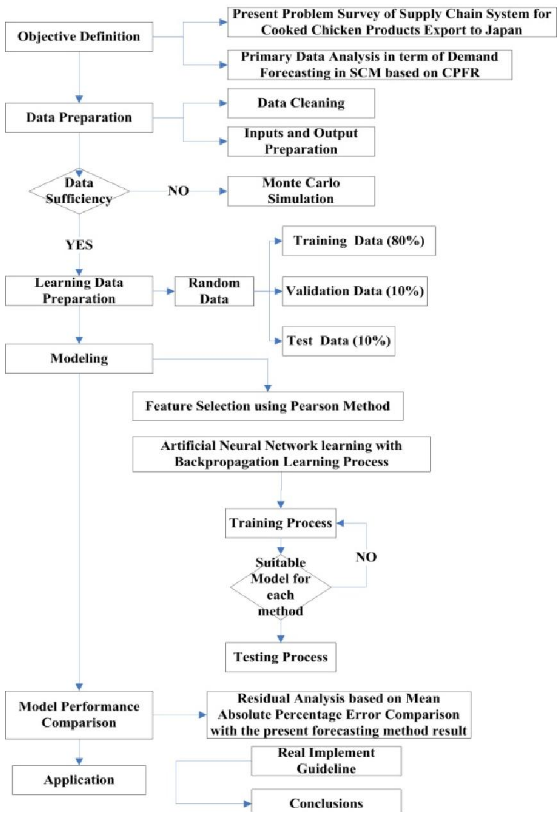


Figure 2: Schematic diagram of the proposed

4.4. Artificial Neural Network Learning Process

4.4.1. Input Feature Selection process

Pearson's chi-square was used for indicating significant input factors related with the next week customer demand at the 95 percentage of confident interval.

4.4.2. Develop the Suitable Structure of Artificial Neural Network Model

Artificial neural network learning with Quickprop was constructed based on the appropriated component from grid search. The data from 4.3 can be used for forecast modeling development. In addition, MAPE of test set was used as the threshold for indicating the appropriated model based on over fitting checking with residual analysis for each data mining technique. If the MAPE of test set was less than or equal five percentage, it can imply that the structure of this method will be the suitable structure.

4.4.3. Model Performance Analysis and Comparison

MAPE of artificial neural network employed for comparison with the traditional forecasting (case study company's present forecasting) to find the best technique for demand forecasting of case study company.

5. RESULT AND DISCUSSION

5.1. Input Feature Selection process

The result of Pearson's chi-square was used indicate the significant degree of each input factor ,related with the next week customer demand at the 95 percentage of confident interval. 22 of the interested factors are chosen as the inputs of this feature selection process. Last but not least, the result Pearson's feature selection was shown in the Figure 3. It is certainly true that the next plan load is the most significant factor with 0.999 of importance value. In the research, the factors ,which have the important value greater than 0.75, were used as the input factor for the neural network model as follows the next plan load, Thai-Japan exchange rate, fish scrap, broken-milled rice, gold price, 4 moving average and 3 moving average. We also found that the other exchange rates and the fuel price are not effect to the customer demand.

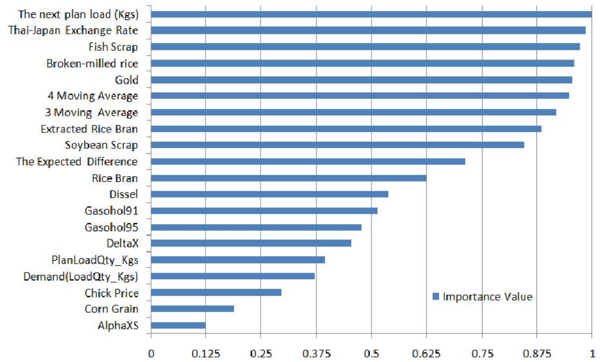


Figure 3: The importance value of each factor

5.2. Artificial Neural Network learning process

In this study, all computational experiments are performed on Intel Centrino Core 2 Duo, 2.4 GHz CPU and 4 GB of memory. A total of 80 actual results obtained from actual customer demand collection. The period of data collection is 2 year and 7 month. It is enough to perform the forecasting model because its period can capture the changing and movement of the customer demand in this supply chain. After data cleaning (remove the abnormal values) process, these data were divided into two sets. The first 80% of data (approximately 64 samples) were used for training, while the rest 20% (approximately 16 samples) were used in the testing process. Accuracy of the network was measured by mean square error. Exhaustive search was used to identify network parameters to achieve the best setting with minimum error. The search was conducted with 10,000 iterations and two retrain in each combination. Testing error fitness criterion was used. The smaller the error on the test set the better the accuracy of the network. Space search of two hidden layers started from 1 to 50 hidden nodes in each layer with search step one by one. The best topology obtained from the search was 7-20-20-1 network, as depicted in Figure. 4. The Quickprop algorithm was used in training process. The network was trained with sigmoid transfer function for hidden and output layers. The coefficient term of 1.75 was used for fast convergence. Consequently, the number of training iterations was 500,000 epochs and the initial values of weights and biases are random.

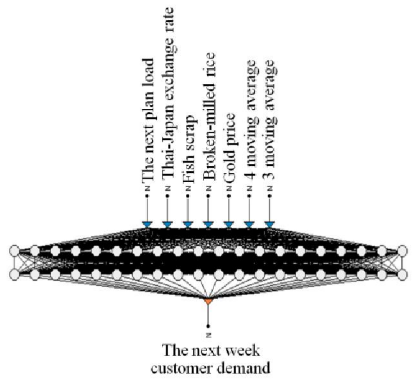


Figure 4: The Quickprop network topology

5.3. Model Performance Comparison

The results from the traditional method and neural network based on time series and economical data. The test set data are shown in Figure 5. The performance of each model was compared by using MAPE of the overall data set, training data set and testing data set.

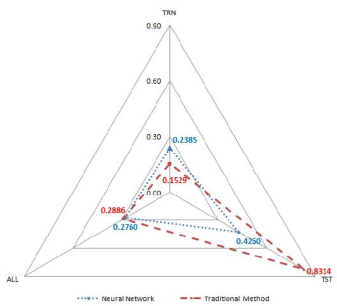


Figure 5: The MAPE comparison of desired output and the output from approaches.

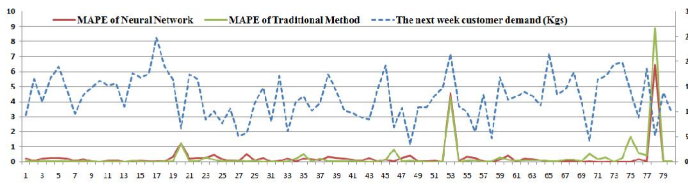


Figure. 6 The MAPE comparison of desired output and the output from approaches.

Figure. 6 shows the MAPE comparison of the desired output of the next week customer demand compared with the results obtained from two approaches. The training data were cases 1-64 and the testing data were cases 65-80. This chart has also provided some of the real next week customer demand from January 2007 – July 2009. According to the overall data set error, it was found that neural network is lower error than the traditional method. It is clearly seen that neural network provides a good results and suitable to deal with the real problem. As a result, it was used for the forecasting demand model for this case study supply chain.

6. CONCLUSIONS

This paper has described the application of neural network, trained with the time series factor, the causal and the other economic factors, to construct the innovative and simplified forecasting model for the Thai frozen chicken product export to Japan supply chain. After performing test set forecasting (16 weeks), it can be efficiently employed to reduce the waste production of frozen chicken approximately from 16,500 kgs to 3,800 kgs. As a result, the direct cost of company cuts has been cut down around €5,800 of this period, from the enchanting forecasting system of this supply chain planning system based on the information sharing between customer and company. Further research in each step of this research will develop the complicated forecasting system based on qualitative factor with some data to see the real effect should be done. Moreover, we might conduct the other data mining tools such as support vector regression, recurrent neural network and ANFIS to compare their performance with this work.

ACKNOWLEDGEMENT

The financial is supported by three main organization as follows Department of materials engineering and operations management of University of Naples "Federico II", Erasmus Mundus, External Cooperative Window Project, The Logistics Research Center, The Thailand Research Fund (TRF Master Research) and College of Arts, Media and Technology Chiang Mai University, THAILAND.

REFERENCES

C.A.O. Nascimento, R. Giudici, R. Guardani, 2000. Neural network based approach for optimization of industrial chemical processes, *Computers and Chemical Engineering*, 24 (9-10), 2303-2314.

CHIU, M. & LIN, G., 2004. Collaborative supply chain planning using the artificial neural network approach. *Journal of Manufacturing Technology Management*, 15, 787-796.

CO, H. C. & BOOSARAWONGSE, R., 2007 Forecasting Thailand's rice export: Statistical techniques vs. artificial neural networks. *Computers and Industrial Engineering*, 53, 610-627.

LEUNG, H. C.,1995 Neural networks in supply chain management. *IEEE International Engineering Management Conference* , 347-352.

VAHIDINASAB, V., JADID, S. & KAZEMI, A. ,2008 Day-ahead price forecasting in restructured power systems using artificial neural networks. *Electric Power Systems Research*, 78, 1332-1342.

S. Kuman,2005. Neural networks a classroom approach, *International Ed. Mc Graw Hill*, 198-199

AUTHORS BIOGRAPHY

Pongsak Holimchayachotikul is a Eramus Mundus Doctoral student at Department of Engineering, University of Sannio, Italy. He also do research at Department of Materials Engineering and Operations Management University of Naples "Federico II" , Italy. He received M.Eng in Industrial Engineering and B.Eng in Computer Engineering at Chiang Mai University, Thailand in 2008 and 2006 respectively. His research interests include supply chain and logistics management, data mining, optimization, decision making for management and applied operations research.

Teresa Murino is researcher in Department of Materials Engineering and Operations Management University of Naples "Federico II". She teaches "Industrial Logistics" at the University for students in Logistics & Production Engineering (3rd year) and "Manufacturing System Management" for students in Mechanical Engineering (4th year) degree courses. The research interests include Advanced Models and Applications of Logistics & Manufacturing, simulation with system dynamics and optimization problems , data analysis

Pachinee Payongyam is a Researcher in Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Thailand. She is going to study in Master Program of Industrial Engineering at Chiang Mai University. She has received the scholarship from Her research interests include supply chain management, simulation and lean manufacturing

Apichat Sopadang is an Assistant professor in Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Thailand. He received a Doctoral of philosophy degree from Clemsom University, USA in 2001. His research interests include lean manufacturing, supply chain and logistics management.

Matteo Mario Savino is Professor of Industrial Operations and Industrial Management at the University of Sannio. He got a PhD in Industrial plants in 1999 at the University Federico II of Naples, Department of Design and Industrial Engineering. His research interests are mainly related to Supply Chain and ERP management, Quality aspects related to industrial production and scheduling of production systems. He has managed several National and EU Funded research and educational projects. From 2008 he is Delegate of the Rector for Quality Assurance and is the President of the University Quality Centre.

Romano Elpidio is a Doctoral student at Department of Materials Engineering and Operations Management University of Naples "Federico II" The research interests include Advanced Models and Applications of Logistics & Manufacturing, simulation with system dynamics and optimization problems , data analysis

PARAMETRIC ESTIMATION OF SPARE PARTS IN CUSTOMER SUPPORT ACTIVITY

D. Chiocca[(a)], T. Murino[(b)], G. Naviglio[(c)]

[(a, b, c)] D.I.M.P, University of Naples, Italy

[(a)]Daniela.chiocca80@alice.it, [(b)] murino@unina.it, [(c)] Giuseppe.naviglio@unina.it

ABSTRACT

The SCM is an integrated approach, process-oriented, purchase, production and delivery of products and customer services. The scope of SCM include subcontractors, suppliers, internal operations, business customers, customers, distribution and end users. The SCM covers the flow management of materials, information and capital. The goal that wants to achieve is the *Customer Satisfaction.* In this point of view, we have analyzed the issues related to estimate of parts during the offered-phase. Then we went to the definition of an algorithm that allows the estimation of parts in short time.

The Customer Support is the key element, present throughout the cycle life of the aircraft for customer loyalty and ensure a business long term. The current commercial process with the client always passes through an early stage, called RFQ (Request for Quotation), fro which is sufficient an *"estimate of costs"*, and a more advanced stage, called RFP (request for Proposal) for which instead is necessary a *"detailed assessment"*. To date, in both cases working with a very accurate expensive estimation.

INTRODUCTION

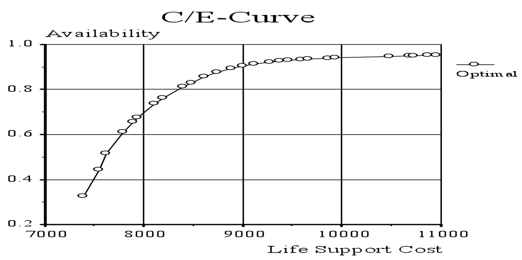
The demands that always occur in the logistics market, as the drive towards a more value for money performance have always been and always will be pressing. The overall objective is to maintain or enhance current service levels without increasing the cost of logistics in the face of increasing demands and needs of recipients increasingly pretentious.

In a market constantly and rapidly evolving needs of the customer satisfaction is the minimum essential in order to be competitive. Loyalty effectively allows for a real investment return (ROI), in particular as regards the medium to long term, but it is especially important because the costs of acquiring new customers are almost always higher than those incurred for the maintenance of old. Customer Relationship Management (CRM) was founded with the aim to help companies in customer loyalty, with the aim to create new opportunities for intervening where customers anticipate and meet needs. CRM allows the management of customer relationships in order to always have this situation, anticipate future needs and maintain alive in the final customer's attention for the company. A strategy of customer loyalty always sees in POST-SALE his central issue. The supply of spare parts to the customer is a crucial step in the delicate process of customer loyalty as well as a link in the chain of offered services by the very delicate logistics. At first the company had to pay that cost to produce a good or service that was only on its material production. Today the spectrum of performance of a company goes beyond the proper production of new products. A key factor in the high availability of products and their use is the optimal supply of spare parts. The parts, at first glance, are considered a mere cost factor. Seen from another perspective, however, must be considered that an efficient management of spare parts helps to ensure high machine availability and avoid the high costs due to the arrests of the devices. A correct spare parts logistics plays a decisive role in the interest of high economy. The handling and storage of spare parts for each company is a cost factor that raises a question: is it necessary to keep large stocks of spare parts? The correct answer depends on many factors: geographical location of the company, links to global systems of transport, delivery, standards on imports. Many companies offer their customers the possibility of solutions for financial management of spare parts and optimized according to individual needs. The primary interest is to configure a flow distribution in the most functional and comfortable as possible for the customer. n this regard it is important that spare parts can be ordered through the faster channel or be provided directly to the customer during the INITIAL Provisioning. This means that there is almost no need to keep their own stock of spare parts and the supplier company is concerned to deliver spare parts to customers in a short time set. It’s necessary to draw up a document whose purpose is to define the process of quantification of support materials and required spare parts to maintain the operational efficiency of the product in its life cycle in operation. The process of Material Support has a target of meeting the performance requirements of the product during operation cycle, and to that end provides the information and documentation relevant to the definition, classification, formation, organization and management of support materials and stock levels, predict the risk of non-compliance, lack of (low stock) or a capital lock (over stock). The Material Support, then, identifies and classifies the good and marketable material support, depending on the characteristics and technical configuration of the product and the level of provided maintenance by the analysis of tolerability and defines and proposes the quantity of materials necessary to support maintaining the product in operation depending on the level of request operational availability. In order to ensure continued availability of the required operating the product in operation, the Initial Planning of support materials and spare parts must be constantly updated in the report: to changes in configuration and product reliability in service; At the time of maintenance, handling, recycling and supply of materials relevant financial year; Under the scenario operational variables, maintenance policies and sources of supply.

During the lifecycle of the product, the Material Support detects and analyzes the pattern of consumption of materials and non-repairable defective repairable. It 'a need to formulate guidelines for the loan under the broader business process materials management, which must be set by software during the entire lifecycle of products in service. The software can solve logistical problems related spare parts and identify optimized decisions at the lowest possible cost for: Arrange alternative logistics support; Define values of tolerability for all systems and equipment; Establish policies for repair and localization of repair; Establish policies for spare parts and equipment constraints (initial supply);

Compare competitive proposals to support systems and chains; Assess the impact of preventive maintenance on the operational availability (costs / resources / staff).

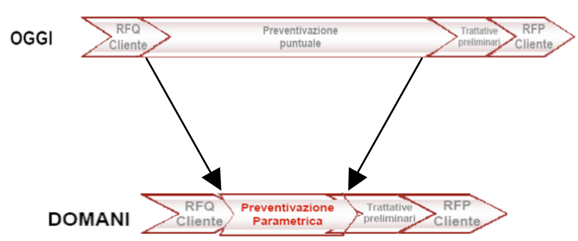
The software we use provides output data and full opportunity to assess the cost of spare parts to support function of many measures of effectiveness (MOE: measures of effectiveness), giving curves and tables showing the range and optimal allocations of spare parts. The result of an exercise in quantification is expressed by curves showing the MOE on the basis of support costs (Cost Life Support).



In figure (curve cost-effective) to each identified point on the curve corresponds to a range of materials, depending on the investment put in place; great the investment, great the number of parts purchased and improved the MOE. The C / E curves display the values of efficiency calculated from the model of the set of stocks in the investment function and to identify critical points in the case (eg point of flattening of a curve that represents the value of the investment above which do not result in more significant increases in MOE in question). The result from the preparation of model elaboration of the mathematical model must then be analyzed in order to optimize the MOE through appropriate targeted interventions, such as: Allocate minimum quantities; Running multiple simulations with separation of items critical / non-critical items and repairable / non-repairable; Identify the "COST DRIVERS (high defect and high cost) and check carefully the relevant parameters and results; Availability Balance values between the bases in the presence of significant imbalances.

At the end of the process activities, Material Support issues the Recommendation Document quantification and Support Materials that illustrates the calculation method and results, different for each type of exercise required.

The shopping process with the client always passes through an early stage that the RFQ (Request for Quotation) for which the estimate is of type ROM (Rough Order of Magnitude) and for which sufficient "estimates of costs” and a more advanced stage that RFP (Request for Proposal) where the assessment is of type IP (Initial Provisioning) and which is needed is a "detailed assessment.”ROM is an assessment of first approximation and can be obtained in the evaluation phase of a product by the customer who wants to know the quantity of parts required (and the corresponding costs) to support it during operation (costs are estimates).The evaluation IP is the common situation of initial acquisition and distribution of spare parts by the customer. The result is a quantification of the materials. Today we work with a very accurate estimation expensive. Considering that not all business negotiations are successful, early in the RFQ can be applied a method of approximate calculation that allows us a significant reduction in response time and cost.



SCOPE

Our attention has been devoted to aviation, where the method of calculation used to determine the cost of service parts is very precise but extremely costly in terms of workload and performance time (accurate estimate). Because of all bids for only 18% is successful, the remaining 82% we intend to find an algorithm whose response times are much narrower (10 days to 1). If we assume a base of 35 evaluations per year of which only 5 are RFP and the remaining 30 have RFQ, we see the savings in economic terms the use of a method of calculation by this simple calculation makes it a good idea of the current situation and that ideally reach:

-TODAY - (35 EVALUATION x 10 days) = 350 days around 200keuro

-TOMORROW - (5 EVALUATION x 10 days) + (30 EVALUATION x 1 g) = 80 days about 50 keuro

The mathematical algorithm that will replace the regular calculation tool will be implemented through a simple application such as Excel.

At the beginning, we will try to reduce as many variables freezing a logistical scenario, secondly, the launch will proceed with a discrete number of simulations, in relation to the number of real variables in the process. The last step will be to find the envelope of all simulations in order to obtain an algorithm that allows us to obtain a result parameter. For simplicity of calculation it was decided to divide the parameters of the scenario logistic constants and variables:

✓CONSTANT PARAMETERS: sites, maintenance policy, maintenance times, lead times, scheduled maintenance and overhauls, transit times, politics, storage, life support, reliability data, cost of parts, the average duration of missions;

✓VARIABLE PARAMETERS: fleet size, factor use of the fleet, fleet availability.

It will perform a series of simulations that allow to quantify the cost of parts supplied in a given scenario logistics for a set period of time (three years). In particular, the simulations will be made on time assuming a fleet of 2, 3, 5 or 7 aircraft should fly 300/500/700 hours annually ensuring fleet availability (availability of the fleet) 70%, 80% or of 90%.

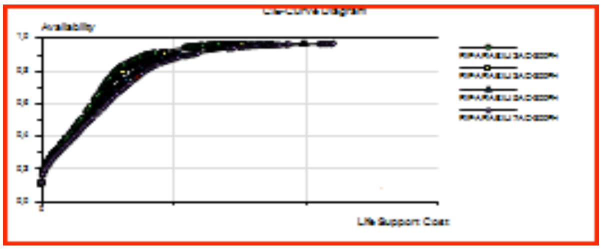
SCENARIO

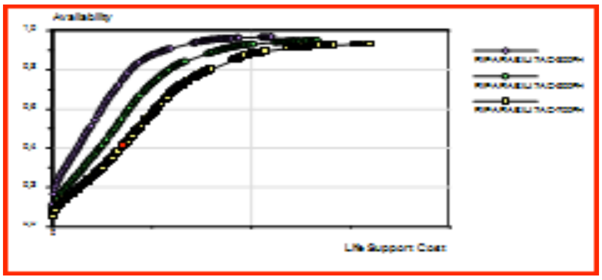
All parts, or more generally, all systems are generally classified into non-repairable and repairable. Non-repairable systems are those that are not repaired when they fail, this does not necessarily mean that they cannot be repaired, rather than no economic sense to do it and that the repair would cost about the same as purchasing a new unit. In turn, contain a category of non-repairable systems such consumers: they are all effects of non-repairable low value. Repairable systems are those that are repaired when they fail, ie when no longer operating at 100%. A system is not operational when a component or subsystem is damaged, it is replaced or repaired, a serviceable system is generally a system with a high economic value to which the cost of replacement / repair of a component is certainly more convenient ' purchase of a new system. The tool we use requires us, by reason of similarity of characteristics of data input, a subdivision of parts for repair, NO REPAIRS AND CONSUMABLES for the quantification of the parties. We anticipate that the total number of simulations is 108.

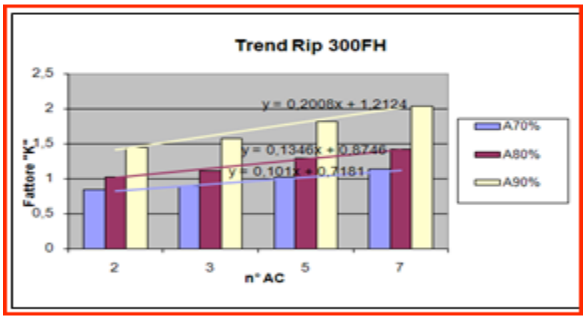
SIMULATION

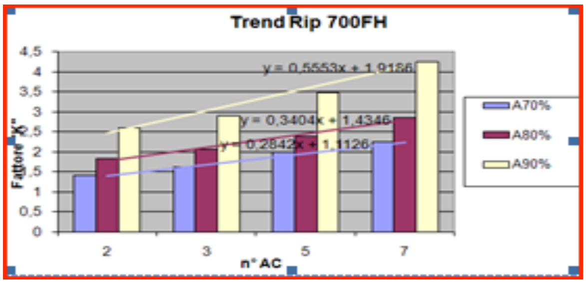
Here the curves C / E (cost effectiveness) of output produced by the software whereas a fleet of seven aircraft flying 300, 500 and 700 FHS to highlight what is the trend of increasing costs of flight hours per year (to repair, not repairable and consumable).

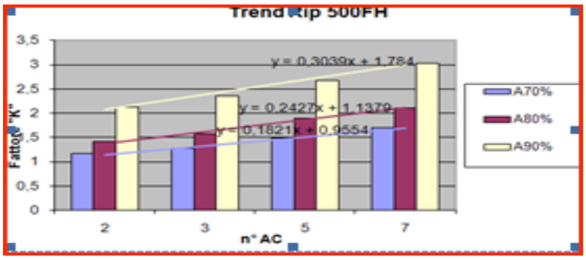
Classe	N° AC	FH	FH*3years*N°AC	A 70%	A 80%	A 90%
R	2	300	1800	0,836547	1,026453	1,443519
R	3	300	2700	0,89365	1,1099	1,567094
R	5	300	4500	1,021917	1,294655	1,817093
R	7	300	6300	1,130463	1,413664	2,029369
R	2	500	3000	1,1703	1,407923	2,118847
R	3	500	4500	1,276772	1,569516	2,357678
R	5	500	7500	1,488799	1,891193	2,671201
R	7	500	10500	1,706634	2,109535	3,027328
R	2	700	4200	1,419961	1,824909	2,589634
R	3	700	6300	1,634076	2,068114	2,905415
R	5	700	10500	1,989319	2,400609	3,48476
R	7	700	14700	2,248797	2,848693	4,247474











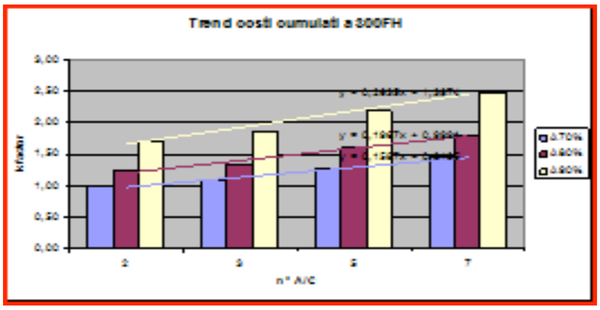
We have done the same simulations for the Not Repairable and for Consumable.

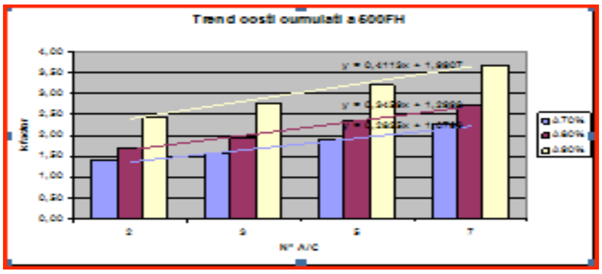
The goal is to make an envelope of all simulations, while reducing the number of variables and thus the number of charts on which to operate. Now we eliminate in this respect the distinction between repairable materials, consumables and non-repairable, thus obtaining a table of cumulative cost in which each item of cost is the sum of the costs of all 3 types of materials.

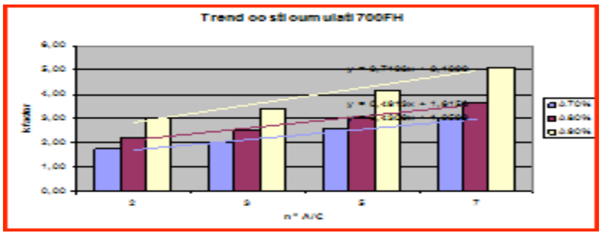
N° AC	FH	FHx3years	A 70%	A 80%	A 90%
2	300	1800	1,00	1,23	1,70
3	300	2700	1,09	1,34	1,86
5	300	4500	1,28	1,60	2,19
7	300	6300	1,46	1,80	2,47
2	500	3000	1,41	1,69	2,45
3	500	4500	1,58	1,92	2,75
5	500	7500	1,91	2,35	3,19
7	500	10500	2,25	2,70	3,68
2	700	4200	1,74	2,19	3,00
3	700	6300	2,04	2,52	3,40
5	700	10500	2,56	3,02	4,16
7	700	14700	3,01	3,86	5,11

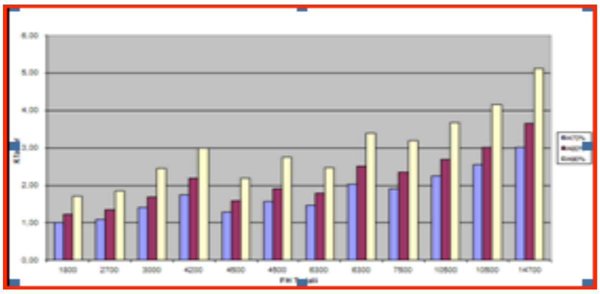
This makes it possible to build only three histograms Plot the total costs according to the FH.

Sorting the data by increasing the total Fh we incorporate two variables into one, namely the number of aircraft and Fh, allowing the construction of a single histogram showing the evolution of the cumulative total costs to changes in total and FH and request Availability.





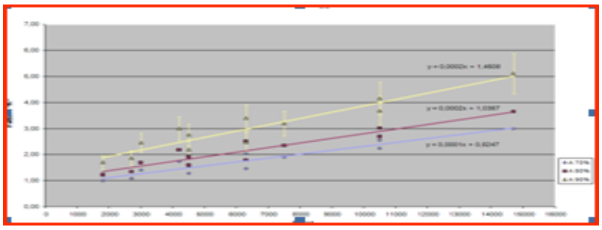




Now we define the mathematical law which best interpolates all data points found with an error not exceeding 10-15% and therefore an explicit algorithm that allows us to calculate the outside and within the range we considered, the cost support of parts for a fleet with certain benefits.

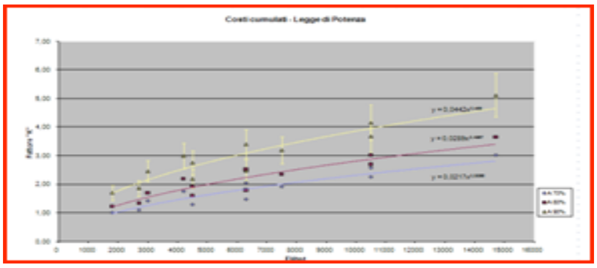
THE ALGORITHM

To define the algorithm were all plotted as a function of cumulative costs FH tot getting three curves, each of the level of required availability. The first approach was to diagram the evolution of points and a linear law interpolate them, drawing attention to the deviation of real points of the curve and checking that the error did not exceed 15%.



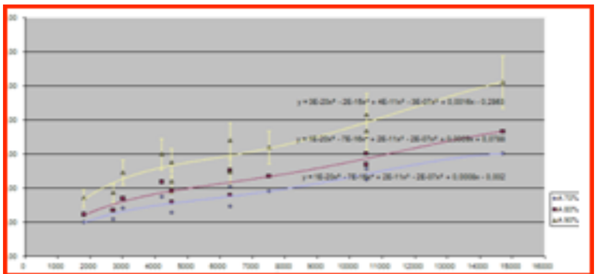
A	Legge Lineare	Algoritmo	X=FHtot	Costo
A70%	y = 0,0001x + 0,8247	= 0,0001 *(G3) + 0,8247		
A80%	y = 0,0002x + 1,0367	= 0,0002 *(G4) + 1,0367		
A90%	y = 0,0002x + 1,4508	= 0,0002 *(G5) + 1,4508		

The cost may be acceptable to admit an error not greater than 15% which, when offered, is admissible in relation to the amount of time saved for the calculation. The graphs show that the real points which deviate from the curve are those relating to Availability of 90%. The interpolation of points based power law shows the following situations:



A	Legge di Potenza	Algoritmo	X=FHtot	Costo
A70%	y = 0,0217* x ^(0,5066)	= 0,0217* (G3) ^(0,5066)		
A80%	y = 0,0289* x ^(0,4967)	= 0,0289* (G4) ^(0,4967)		
A90%	y = 0,0442* x ^(0,485)	= 0,0442* (G5) ^(0,485)		

Again the errors were graphically highlighted by the curve corresponding to 90% Availability (being that of presenting the largest deviations). Here are also interpolations of points logarithmic law, exponential law, law of 5th degree polynomial. From this analysis, we note that the algorithms are more relevant than those that respond to a linear law, 5th degree polynomial and power.



A	Legge Polinomiale di 5°grado	Algoritmo	X=FHtot	Costo
A70%	[illegible]	[illegible]		
A80%	[illegible]	[illegible]		
A90%	[illegible]	[illegible]		

At this point a number of FHtot entering and remaining within the range considered, we examine the response of each (the best is one that provides output values closer to known those).

We try to include as the value of FHtot a number equal to 2700 which is given by producers support 3 years, 3 v3livoli FH 300 per year. From the simulations it is evident that the real values for an Availability of 70, 80 and 90% are circled in Figure:

N°AC	FH	FH*3*N°AC	70%	80%	90%
2	300	1800	1,00	1,23	1,70
3	300	2700	1,09	1,34	1,86
2	500	3000	1,41	1,69	2,45
2	700	4200	1,74	2,19	3,00
5	300	4500	1,28	1,60	2,19
3	500	4500	1,58	1,92	2,75
7	300	6300	1,46	1,80	2,47
3	700	6300	2,04	2,52	3,40
5	500	7500	1,91	2,35	3,19
7	500	10500	2,25	2,70	3,68
5	700	10500	2,56	3,02	4,16
7	700	14700	3,01	3,66	5,11

The algorithms respond as follows:

A	Legge di Potenza	X=FHtot	Costo	Valore Reale	Errore
A70%	y = 0,0217* x ^(0,5066)	2700	1,19	1,09	circa 9%
A80%	y = 0,0289* x ^(0,4967)	2700	1,46	1,34	circa 9%
A90%	y = 0,0442* x ^(0,485)	2700	2,04	1,86	circa 9%

A	Legge Lineare	X=FHtot	Costo	Valore Reale	Errore
A70%	y = 0,0001x + 0,8247	2700	1,09	1,09	circa 1%
A80%	y = 0,0002x + 1,0367	2700	1,58	1,34	circa 14%
A90%	y = 0,0002x + 1,4508	2700	1,99	1,86	circa 7%

A	Legge Polinomiale di 5°grado	X=FHtot	Costo	V. Reale	Errore
A70%	y = 1E-20x5 - 7E-16x4 + 2E-11x3 - 2E-07x2 + 0,0008x - 0,002	2700	1,06	1,09	circa 3%
A80%	y = 1E-20x5 - 7E-16x4 + 2E-11x3 - 2E-07x2 + 0,0009x + 0,0788	2700	1,41	1,34	circa 5%
A90%	y = 3E-20x5 - 2E-15x4 + 4E-11x3 - 3E-07x2 + 0,0016x - 0,2863	2700	2,53	1,86	circa 36%

The law and the linear power supply values that fall within the range of safety assumed initially. Conducting further tests with different values of FH, has identified the suitability of the algorithm power law (because it always shows an error of less than 15%), fully respecting the requirements and can be considered acceptable in an estimation ROM phase.

CONCLUSION

We can conclude by saying that in a RFQ when it is not certain that the commercial negotiations to succeed, you can avoid the method of estimating accurate, very precise but extremely costly in terms of time spent and therefore cost the company. By using this tool Excel can get quick feedback on the estimate of the cost of spare parts with good accuracy (around 15%). The margin is quite acceptable in relation to the amount of saved time and the ability to almost instantly give an order of representative magnitude of the associated cost with the allocation of spare parts for logistical support in terms of assigned operational scenario.

SIMULATION MODELLING OF A MARINE TURBOGENERATOR

Josko Dvornik [(a)], **Enco Tireli** [(b)], **Josip Orovic**[(b)]

[(a)] University of Split
Faculty of Maritime Studies
Zrinsko-Frankopanska 38
21000 Split
+385 21 380 762

[(b)] University of Rijeka
Faculty of Maritime Studies
Studentska ulica 2
51000 Rijeka
+385 51 338 411

[(a)] josko@pfst.hr, [(b]tirelli@pfri.hr), [(b)]jorovic@pfri.hr

ABSTRACT
Marine steam turbine at the load of synchronous generator is a complex non-linear system, which needs to be systematically investigated as a unit consisting of a number of subsystems and elements, which are linked by cause-effect feedback loops. In this paper the authors will present the efficient application of scientific methods for the research of complex dynamic systems called qualitative and quantitative simulation methodology of System dynamics. This will allow continuous computer simulation of various models and significantly contribute to acquisition of new information about the non-linear character of performance dynamics of turbo generator systems in the process of designing, failure diagnosis, optimization and education. The results presented in the paper have been derived from the scientific research project "Shipboard energy systems, alternative fuel oils and reduction of pollutants emission" supported by the Ministry of Science, Education and Sports of the Republic of Croatia.

Keywords: steam turbine, simulation and heuristic optimisation, failure diagnosis

1. INTRODUCTION

The model of marine steam turbine machinery which drives electric synchronous generator, shown in Figure 1 (Isakov 1984), has two essential situations of energy accumulation: in the steam volume (steam area, steam volume of the turbine) and in the turbine rotor. The main condenser is observed as a special governing object.

Each of the stated parts can be described by its mode equation, that is, by the differential equation which describes the performance dynamics.

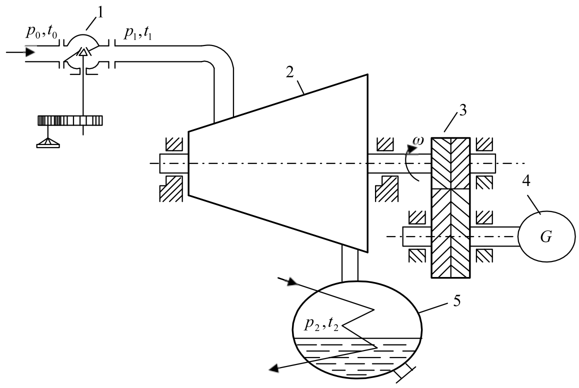


Figure 1: Steam condensation machinery of the marine turbine generator (1- governing valve, 2- turbine, 3- reduction gear, 4- generator, 5- condenser)

2. SIMULATION MODELLING OF MARINE STEAM TURBINE

The system dynamic mathematical model of the marine steam turbine can be defined by means of differential equations (Isakov 1984).

Equation of the turbine steam volume:

$$\frac{d\Psi_1}{dt} = \frac{\mu}{R_\mu} + \frac{\Psi_0}{R_{\Psi 0}} - \frac{\Psi_1}{R_{\Psi 1}} \tag{1}$$

Equation of the turbine rotor dynamics:

$$\frac{d\varphi}{dt} = \frac{\Psi_1}{T_{\Psi 1}} - \frac{\Psi_2}{T_{\Psi 2}} - \frac{\varphi}{T_\varphi} \tag{2}$$

Where the following symbols stand for:

ψ_1 - relative increment of the steam pressure in the steam volume, φ - relative increment of the turbine rotor angular velocity, $T_{\psi 1}$ - time constant of the turbine rotor, T_φ - time constant of the turbine rotor, R_μ - time constant of the steam volume, $R_{\psi 1}$ - time constant of the steam volume, ψ_0 - relative increment of the steam pressure before the manoeuvring valve, $R_{\psi 0}$ - time constant of the turbine rotor, μ - relative change of the position of the manoeuvring valve, ψ_2 - relative increment of the steam pressure in the main condenser, $T_{\psi 2}$ - time constant of the boiler.

2.1. System dynamic mental-verbal model of marine steam turbine

On the basis of a mathematical model, or the explicit form of the mode equation of the marine steam turbine (1), it is possible to determine the mental-verbal model of the marine steam turbine.

If the relative increment of the steam pressure in the turbine steam volume ψ_1 increases the speed of the relative increment of the steam pressure in the turbine steam volume ψ_1 will decrease, which gives a negative cause-effect link.

If the relative increment of the steam pressure before the manoeuvring valve ψ_0 increases the speed of the relative increment of the steam pressure in the turbine steam volume will increase, which gives a positive cause-effect link.

If the relative change of the position of the manoeuvring valve μ increases the speed of the relative increment of the steam pressure in the turbine steam volume will increase, which gives a positive cause-effect link.

If the time constant of the steam volume R_{μ} increases the speed of the relative increment of the steam pressure in the turbine steam volume will decrease, which gives a negative cause-effect link.

If the time constant of the turbine rotor $R_{\mu 0}$ increases the speed of the relative increment of the steam pressure in the turbine steam volume will decrease, which gives a negative cause-effect link.

If the time constant of the steam volume $R_{\mu 1}$ increases the speed of the relative increment of the steam pressure in the turbine steam volume will increase, which gives a positive cause-effect link.

On the basis of a mathematical model, or the explicit form of the mode equation of the marine steam turbine (2), it is possible to determine the mental-verbal model of the marine steam turbine.

If the relative increment of the steam pressure in the steam volume ψ_1 increases the speed of the relative increment of the turbine rotor angular velocity will increase, which gives a positive cause-effect link.

If the relative increment of the turbine rotor angular velocity φ increases the speed of the relative increment of the turbine rotor angular velocity will decrease, which gives a negative cause-effect link.

If the relative increment of the steam pressure in the main condenser ψ_2 increases the speed of the relative increment of the turbine rotor angular velocity will decrease, which gives a negative cause-effect link.

If the time constant of the turbine rotor $T_{\psi 1}$ increases the speed of the relative increment of the turbine rotor angular velocity will decrease, which gives a negative cause-effect link.

If the time constant of the turbine rotor T_{φ} increases the speed of the relative increment of the turbine rotor angular velocity will increase, which gives a positive cause-effect link.

If the time constant of the turbine rotor $T_{\psi 1}$ increases the speed of the relative increment of the turbine rotor angular velocity will decrease, which gives a negative cause-effect link.

If the time constant of the turbine rotor $T_{\psi 2}$ increases the speed of the relative increment of the turbine rotor angular velocity will increase, which gives a positive cause-effect link.

2.2. System dynamic structural model of the marine steam turbine

On the basis of the stated mental-verbal models it is possible to produce structural diagrams of the marine steam turbine, as shown in Figures 2, 3 and 4.

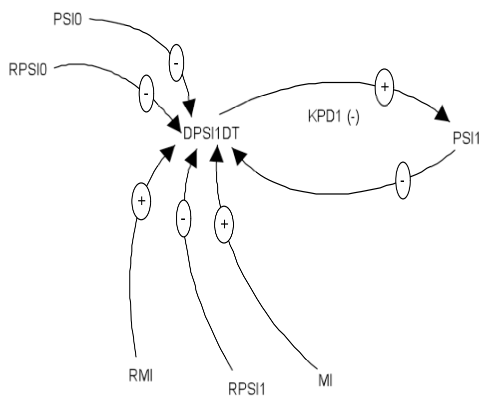


Figure 2: Structural model of the steam turbine – steam volume

In the observed system there is the feedback loop (KPD1).

KPD1(-):PSI1=>(-)DPSI1DT=>(+)DPSI1DT=>(+)PSI1; which has self-regulating dynamic character (-), because the sum of negative signs is an odd number.

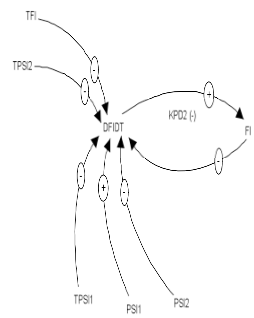


Figure 3: Structural model of the marine steam turbine – rotor dynamics

In the observed system there is the feedback loop (KPD2).

KPD2(-):FI=>(-)DFIDT=>(+)DFIDT=>(+)FI; which has self-regulating dynamic character (-), because the sum of negative signs is an odd number.

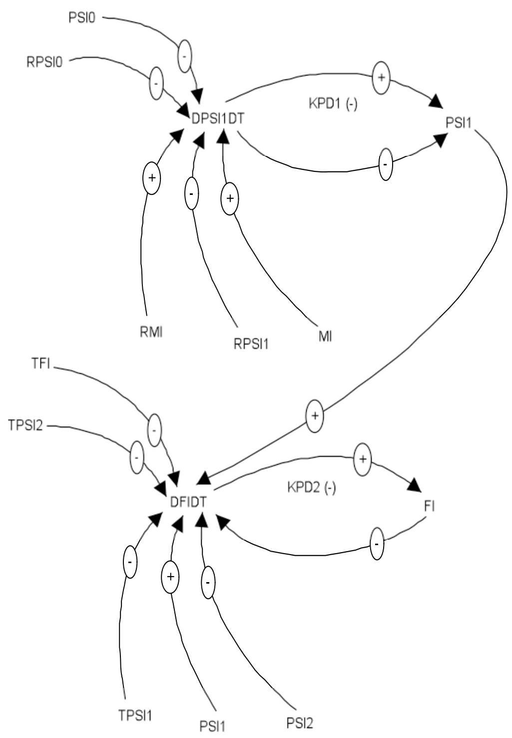


Figure 4: Global and structural model of the marine steam turbine

2.3. System dynamic flowcharts of the marine steam turbine

Flowcharts shown in Figures 5, 6 and 7 are based on the produced mental-verbal and structural models.

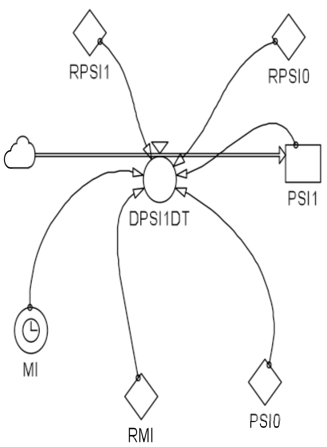


Figure 5: Marine steam turbine flowchart – steam volume

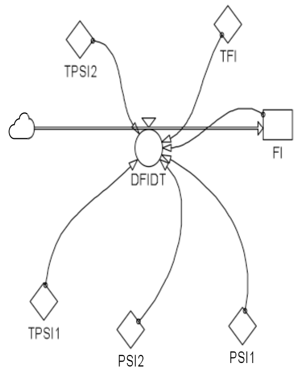


Figure 6: Marine steam turbine flowchart – rotor dynamics

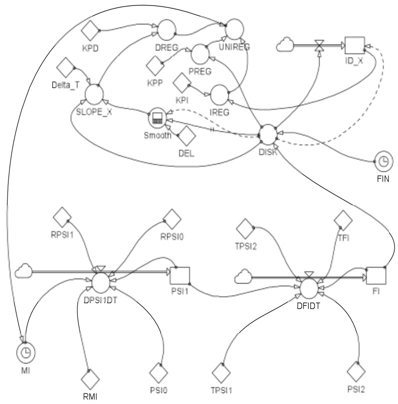


Figure 7: Global flowchart of the marine steam turbine with built-in PID governor

MACRO DYNAMO functions built in the simulation model of the marine steam turbine: CLIP, STEP and UNIREG.

3. QUANTITATIVE SIMULATION MODEL OF THE MARINE STEAM TURBINE

Simulation model of the marine steam turbine in the simulation language:

```
MACRO SLOPE(X, DEL)
*
A SLOPE.K=(X.K-SMOOTH(X.K,DEL))/DT
*
MEND
* ...............................
* UNIREG-PID REGULATOR:
*
MACRO UNIREG(X, KPP, KPI, KPD)
*
INTRN IBD, PREG, IREG, DREG
*
```

```
A PREG.K=KPP*X.K
*
L IBD.K=IBD.J+DT*X.J
*
N IBD=X
*
A IREG.K=KPI*IBD.K
*
A DREG.K=KPD*SLOPE (X.K, DT)
*
A UNIREG.K=PREG.K+IREG.K+DREG.K
*
MEND
*
R DPSI1DT.KL=(MI.K/RMI.K)+(PSIO.K/RPSIO.K)-(PSI1.K/RPSI1.K)
*
L PSI1.K=PSI1.J+DT*DPSI1DT.JK
*
N PSI1=0
*
A MI.K=CLIP(STEP(.05,10)+STEP(.95,50)+PIDFI.K,0,DELAY1(RE.K,2),1E-16)
*
A RMI.K=5
*
A PSIO.K=0
*
A RPSIO.K=5
*
A RPSI1.K=5
*
SAVE DPSI1DT, PSI1, MI, RMI, PSIO, RPSIO, RPSI1
*
R DFIDT.KL=(PSI1.K/TPSI1.K)-(PSI2.K/TPSI2.K)-(FI.K/TFI.K)
*
L FI.K=FI.J+DT*DFIDT.JK
*
N FI=0
*
A TPSI1.K=5
*
A PSI2.K=0
*
A TPSI2.K=5
*
A TFI.K=.1+MEL.K
*
* UNIREG-PID REGULATOR INSTALLING:
*
A DISK.K=FIN.K-FI.K
*
A FIN.K=STEP (.05, 10) +STEP (.95, 50)
*
A PIDFI.K=CLIP (UNIREG (DISK.K, KPP, KPI, KPD), 0, TIME.K, 10)
*
C KPP=100
*
C KPI=0.1
*
C KPD=100
SAVE DISK, PIDFI, FIN
*
SAVE TPSI1, PSI2, TPSI2, FI, TFI
```

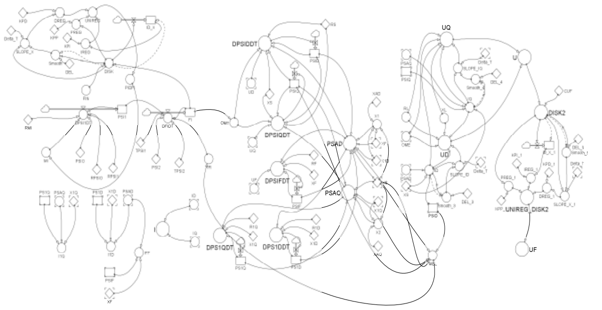


Figure 8: Global flowchart of the marine steam turbine generator system with built-in PID governors in POWERSIM simulation language

4. INVESTIGATING PERFORMANCE DYNAMICS OF THE MARINE STEAM TURBINE

After system dynamics qualitative and quantitative simulation models were produced, all possible operating modes of the system will be simulated in a laboratory, using one of the simulation packages, most frequently DYNAMO (Richardson and Aleksander 1981) or POWERSIM (Byrknes).

After the engineer, designer or a student has conducted a sufficient number of experiments, or scenarios, and an insight has been obtained about the performance dynamics of the system using the method of heuristic optimisation.

For the example, the scenario of starting the marine steam turbine and connecting the synchronous generator on switchboard in TIME = 100 has been simulated. Figure 9 shows changes in relative increment of the angular speed of the rotor FI and relative increment of the steam pressure in the steam volume PSI1 and Figure 10 shows voltage and current changes.

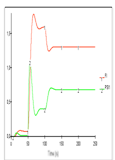


Figure 9: Relative increment of the angular speed of the rotor FI and relative increment of the steam pressure in the steam volume PSI1

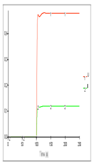


Figure 10: Voltage and electric current of marine turbogenerator

The model can be used to simulate deviation of operating parameters such as main condenser pressure inlet steam pressure, opening and closing of manoeuvring valve and etc. It may also be used in heuristic optimisation of the PID governor coefficient.

Change of these parameters will have an important influence on the performance (frequency and voltage) of turbo generator when working in load operating condition. All these results of simulation are very valuable in process of failure diagnosis, optimization of steam turbine thermodynamic process and educational purposes for future marine engineers.

5. CONCLUSION

System dynamics is a scientific method which allows simulation of the most complex systems. The method used in the presented example demonstrates a high quality of simulations of complex dynamic systems, and provides an opportunity to all interested students or engineers to apply the same method for modelling, optimising and simulating any scenario of the existing elements.

Furthermore, the users of this method of simulating continuous models in digital computers have an opportunity to acquire new information in dynamic system performance. The method is also important because it does not only refer to computer modelling, but also clearly determines mental, structural and mathematical modelling of the elements of the system.

This brief presentation gives to an expert all the necessary data and the opportunity to collect information about the system in fast and scientific method of investigation of a complex system.

This means: “Do not simulate the performance dynamics of complex systems using the method of the "black box", because education and designing practice of complex systems confirmed that it is much better to simulate using the research approach of the “white box”, i.e. System dynamics methodology."

REFERENCES

Byrknes, A. H. *Run-Time User’s Guide and Reference Manual*, Powersim 2.5, Powersim Corporation, Powersim AS, 12007 Sunrise Valley Drive, Reston Virginia 22091 USA.

Forrester, Jay W. (1973/1971). *Principles of Systems*, MIT Press, Cambridge Massachusetts, USA

Hind, A. (1968). *Automation in merchant marines*, London

Isakov, L.I.; Kutljin, L.I. (1984) *Kompleksnaja avtomatizacija sudovljlh dizeljnih i gazoturbinmljih ustanovok*, Leningrad, Sudostreonnie

Munitic, A. (1989). *Computer Simulation with Help of System Dynamics*, Croatia, BIS Split, p. 297

Munitic, A.; Kuzmanic, I.; Krcum, M. (1998). System Dynamic Simulation Modelling of the Marine Synchronous Generator, *Modelling and Simulation, IASTED*, Pittsburgh, 372-375

Munitic, A.; Milic L. and Milikovic M. (1997). System Dynamics Computer Simulation Model of the Marine Diesel-Drive Generation Set, *IMACS World Congress on Scientific Computation, Modelling and Applied Mathematics*, vol.5, Verlag, Berlin

Nalepin R. A.; Demeenko O.P. (1975). *Avtomatizacija sudovljih energetskih ustanovok*, Leningrad, Sudostroennie

Richardson, George P. and Aleksander L. (1981). *Introduction to System Dynamics Modelling with Dynamo*, MIT Press, Cambridge, Massachusetts, USA

Suprun, G.F. (1972). *Sintezsistem elektroenergetiki sudov*, Leningrad, Sudostroenie

AUTHORS BIOGRAPHY

Josko Dvornik was born in Split in 1978. He completed undergraduate studies at Faculty of Maritime Studies in Split in 2001 and was awarded the BSc degree – graduated engineer in Maritime transport, marine engineer. In 2001 he employed at the Maritime Faculty in Split as Junior Researcher at the scientific project No 01717007, 2004 graduated from post graduate studies at the Faculty of Electrical Engineering, Mechanical Engineering and Shipbuilding as a Master of Science in Technical Sciences, filed of Mechanical Engineering. In 2001 he won the doctor’s degree at Faculty of Maritime Studies in Rijeka – doctor of Technical Science, field of Traffic and Transport Technology, branch of Marine and River transport. He published over 50 scientific papers about the field of System Dynamics Computer Simulation Modelling, of which over 20 paper relate to the ship steam and gas turbines, ship engines and complex ship propulsion systems.

Enco Tireli was born in Rijeka in 1947. He completed undergraduate studies at Faculty of Engineering in Rijeka in 1970 and was awarded the BSc degree – marine engineer. He was awarded the master's degree at Faculty of Engineering in Ljubljana, Slovenia, in 1975 – MSc in technical sciences, the field of energetic. In 1978 he won the doctor's degree at Faculty of

Engineering in Ljubljana, Slovenia – PhD in technical sciences. In 1970 he worked as a planner at Rade Končar factory in Rijeka. From 1970 to 1973 he was the Development and production manager at the factory of thermal installations TTU in Labin. From 1974 to 1991 he was the Plant manager of the thermo-electric power plant TE Plomin 1, as well as the Construction manager of the TE Plomin 2. Since 1992 he has been Vice-dean for business relations at Faculty of Maritime Studies in Rijeka. Since 2004 he has been Full professor in charge of courses in Failure diagnosis, Marine thermal turbines, Exploitation of marine steam boilers, Exploitation of marine thermal turbines, Fuels, lubricants and water, Optimisation of the ship's propulsion, and Thermal science.

Josip Orovic was born in Zadar in 1979 where he graduated at the Nautical School – Engineering Department in 1997. In 2002 he got his BSc degree and in 2006 his MSc degree at the University of Rijeka, Faculty of Maritime Studies in Rijeka. Currently, he is lecturing as a member of the Marine Engineering and Ship Power Systems Department at the University of Rijeka, Faculty of Maritime Studies. His expertise is mainly in areas dealing with marine boilers, marine steam turbines, engine room simulators, failure diagnosis and thermodynamics. He sailed several years as certified engine officer on crude oil tankers and LNG carriers.

COMBINED INFORMATION AND COMMUNICATION TECHNOLOGIES FOR LOCATION AND STATUS TRANSPRANCY ON RO-RO TERMINAL

Bernd Scholz-Reiter[(a)], Mehmet-Emin Özsahin[(b)], Anne Schweizer[(c)], Marc-André Isenberg[(d)]

[(a), (b), (c), (d)] BIBA – Bremer Institut für Produktion und Logistik GmbH, University of Bremen

[(a)]bsr@biba.uni-bremen.de, [(b)]oez@biba.uni-bremen.de, [(c)]vir@biba.uni-bremen.de [(d)]ise@biba.uni-bremen.de

ABSTRACT
Against the background of a steadily growing High & Heavy traffic at international seaport terminals and the use of ever wider encountered areas, the transparency of location and status of loadings and load carriers is particularly important for efficient warehouse management on seaport terminals. But the previously practiced manual space management of cargos abuts on its limits. Depending on the size of a seaport terminal it leads to time-consuming searches for order bound roll-trailers. Further, manual unscheduled relocations of loaded or free roll-trailer result to considerable information problems concerning the exact storing positions of roll-trailer. Automated support in the collection of movements and status changes of load carriers through IT-systems is currently not realized. Thereby, the transparency regarding the location and status of cargos and load carriers is essential for efficient inventory management at seaport terminals.

To handle these information problems, the BIBA – Bremer Institut für Produktion und Logistik GmbH and a German seaport-owner are designing and modelling in a research project a system that enables automated detection of location and status of load carriers on seaport terminals. The system combines innovative information and communication technologies for identification, communication and localization tasks.

This paper shows how the Radio Frequency Identification technology and Global Positioning System can be integrated in the terminal processes of the roll-trailer operation cycle. It shows what potential this solution would increase in the operational processes for location and status transparency on Roll on/Roll off (Ro-Ro) terminals.

Keywords: load carrier management, Ro-Ro terminals, information and communication technologies

1. INTRODUCTION

The important role of sea harbours for unobstructed cargo handling via German seaports can be described with increased rates from 224 million tons in 1999 to 334.6 million tons in 2008. The sea traffic prognosis passed by the German federal government in May 2007 forecasts a continuing growth of cargo shipping from German sea harbours to reach 759 million tons in 2025. (BMVBS 2007) Although there were caused of the world economic crisis a considerable reduction of the amount of the handling of goods with approximately 21.3 percent in 2009 (DESTATIS 2009a; DESTATIS 2009 b) the seaport-owners expects further increasing cargo rates.

Besides the container traffic the Ro-Ro traffic in particular is regarded as a main driver of this development with high potential for growth. The mentioned prognosis forecasts, that Ro-Ro traffic of the German Baltic range sea harbours will grow over-proportionally with average growth rates of 4.8% and thusly increase by more than a factor of three from 27 million tons in 2004 to 71.7 million tons in 2025 (ZDS 2007). In order to successfully manage the challenges related to this growth, next to increasing harbour capacities by expanding harbour infrastructure and connection to the hinterland, better use of existing capacities is required. In this context, process improvements using intelligent storing position management systems and automatic freight or load carrier identification systems have been proposed (Oppel 2008).

A substantial part of the goods in Ro-Ro traffic are transported with specialised load carriers, which are called roll-trailers. Roll-trailers are defined by the German industrial norm DIN 30781 as carrying means for combining loadings to a loading unit and fulfilling transport, aggregation and handling functions as well as protective functions for these goods (Arnold 2002).

The transport function for bridging spatial differences requires an optimised size for efficient usage of transport spaces, e.g. fitting into ship hull spaces. Additionally, roll-trailers fulfil a storage function for bridging timely differences and, in some cases, a handling function for assembly, picking and finishing processes (Heimbrock 2001).

This contribution focuses on the operational planning and control depends on a permanently up-to-date overview of roll-trailer inventory sizes as well as state and position of the roll-trailers. In this context, innovative technologies like identification based on radio frequency and satellite based positioning offer high potentials for improved roll-trailer processes and management (Fleisch 2005).

2. OBJECTS OF INVESTIGATION

Roll-trailers that are used particularly in Ro-Ro traffic will be transported with their prime movers (tug-masters). They are used to transport high and heavy loadings whose size is too big or too heavy for the transportation with containers, but that is not depending on the lifting capacities of special heavy-height vessels. There are two different types of cargos on the high and heavy segment: self- and non-self-propelled cargos. Self-propelled cargo units like trucks, tractors or construction vehicles can be loaded on their own axes. But non-self-propelled units like locomotives, generators or wind turbines have to be loaded on a roll-trailer which can be moved with a tug-master inside the Ro-Ro vessel. The advantage of this technical solution results from the low conception of the trailer-chassis and the flexible connection through a z-shaped, hydraulically movable boom to the tug-master. It allows the transportation of voluminous loads in shipping spaces with low ceiling heights and to facilitate the handling of loads at sharp angles.

Roll-trailers are mainly a property of the shipping companies and rest at the seaport terminal until the shipping companies assign them to specific orders. Each roll-trailer has markers with standard alpha-numeric codes. To handle rearrangements of loadings in the seaport terminal or move loadings without defined shipping company roll-trailers, the seaport operators use their own roll-trailers called service roll-trailers. These roll-trailers always remain on the seaport terminal. They just bridge the relocation distance between the ship and the terminal, until a forklift unloads the loadings.

2.1. Roll-trailer operations cycle

The project relevant section of the roll-trailer cycle can be differentiated to the import and export processes. The import processes begins with the arrival of the vessel, which are loaded on shipping company roll-trailers, in which import means the import to Germany. After the vessels unloading and the cargo´s registration, the loaded roll-trailers come into stock. Following the delivery of the loadings, the empty roll-trailer comes back into the stock. To reduce the area by occupied empty roll-trailer, forklifts stratify empty load carriers to so called ‘stacks’. These stacks can reach a high up to four roll-trailers.

The export process includes the roll-trailer activities to load the goods to the ship for their transportation from Germany to abroad. During the delivery the customer, a shipping company for example, brings the cargo to the terminal. If the shipping company has already allocated a specific roll-trailer to this order, a seaport operator employee searches for the roll-trailer, loads it and puts it into stock. If there is no direct allocation of a roll-trailer to a loading, the good is stored temporarily on a service roll-trailer. After the arrival of the Ro-Ro vessel the settling activity starts, where the employees remove the loadings from the stock. If the good is loaded on a roll-trailer of a shipping company, the roll-trailer is set onto the vessel directly. If the good is temporarily stored on a service roll-trailer, the good itself is set onto the vessel and the service roll-trailer leaves the ship. Figure 1 depicts the relevant activities of the import and export processes.

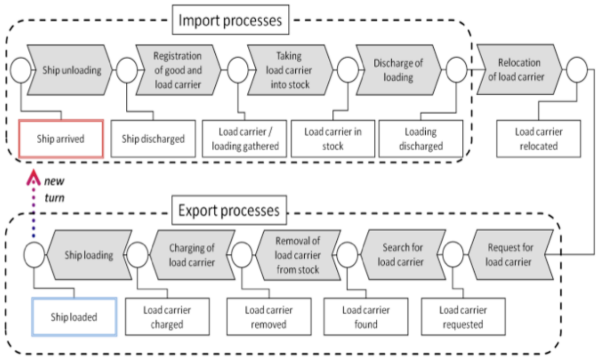


Figure 1: Current roll-trailer operations cycle (based on Scholz-Reiter et al. 2008)

3. CRITICAL POINTS

A detailed examination of the relevant roll-trailer processes has identified several critical points within the terminal operations. These critical points decrease the efficiency in a significant manner. Following points can be divided:

Lack of knowledge about the position and status of a roll-trailer

The storage of loaded and empty roll-trailers is documented in lists of identification codes and storing positions. Due to the strong increase of the cargo volume over the last years and more extensive land use, the assignment situations became more complex and this manual type of documentation has reached its limit. The storage capacity of the terminal is almost utilised, so that stored or parked roll-trailers increasingly constrict the terminal operations. Within such a situation, the paper based documentation causes information gaps. Relocations of roll-trailers, reorganisation of storage areas under time pressure and temporary use of roll-trailers are undocumented, so that accurate information about storing positions and status to roll-trailer are lost. To detect such position and status errors, the seaport operator performs manual stocktaking of the roll-trailers in regular intervals. The rental of roll-trailers to other seaport areas causes additional undocumented roll-trailer movements. The transfers are made over land and sometimes they are carelessly documented.

Due to the allocation of an order to a specific roll-trailer by the shipping company, the undocumented roll-trailer position and status cause a significantly higher effort and costs for searching and handling of roll-trailers. The search time takes in exceptional cases up to two hours. Besides the inefficient use of working time there is increased fuel consumption, due to the use of tug-masters for search operations.

Unknown owners of empty roll-trailers

Although roll-trailers have identification codes, it is possible that the seaport operator cannot assign a roll-trailer to a responsible shipping company. That follows from the fact that roll-trailers are not only used by their owners, they can also be rent or leased – this also occurs during the storage stage of the terminal. Because empty roll-trailers have often not been allocated to orders or vessel departures, the responsible shipping companies cannot be identified. The lack of information about roll-trailers owners complicates concrete measures against an overload of the terminal with roll-trailers. Queries of shipping companies show, that even they do not have a complete overview about the distribution of their roll-trailer inventory. Occasionally this circumstance leads to a roll-trailer allocation, which is not realisable, because the roll-trailer has left the terminal over land for use in another seaport (as a truckload) or for repair. It is assumed, that the incomplete information as well as the lack of control and availability of roll-trailer increased the number of roll-trailers within the roll-trailer cycle.

Process delays due to the paper based information flows

The majority of the procedural information flows on the RoRo terminal occur in the form of paper documents. This delays especially those processes, which are waiting on a document as a basis for a decision or the process continuation. The main reason for this delay is the physical distance, which has to cover between the decision maker and the operator. This problem gets worse with the increasing traffic density, which is caused by the increase of the handling goods. A common characteristic of the critical points is a general lack of timely, complete and accurate information.

3. TECHNOLOGIES

To handle the identified critical points in the roll-trailer operations cycle, an adoption of innovative information and communication technologies for identification, communication and localisation tasks can be used. In this context, localisation systems as well as automated identification technologies are of particular importance.

In this chapter, the technologies, which offer a wide range of opportunities for tracking and tracing positions and status of roll-trailers in the seaport terminal, are described.

3.1. Satellite positioning system

To realize the location objective of the project, a technology is needed which can afford the most exact positioning data of the tug-masters as possible.

Via satellite positioning systems such as Global Positioning System (GPS) or the upcoming European Galileo system any object can be localised with an accuracy of several meters. This means that the exact position of an object can be determined in an appropriate frame of reference, e.g. in a geodetic graticule. However, GPS for example has some limitations. There must be a relatively clear "line of sight" between the GPS antenna and four or more satellites. Objects, such as buildings, overpasses, and other obstructions, that shield the antenna from a satellite can potentially weaken a satellite's signal such that it becomes too difficult to ensure reliable positioning. These difficulties are particularly prevalent in urban areas. The GPS signal may bounce off nearby objects causing another problem called multipath interference. Also single GPS receiver from any manufacturer can achieve accuracies of approximately only 10 meters. However, 10 meters are too inaccurate for utilization in an area of application like a seaport terminal. (Mansfeld 1998)

To achieve the accuracies needed for quality Geoinformation Systems (GIS) records from one to two meters up to a few centimetres in the seaport terminal requires differential correction of the data. The majority of data collected using GPS for GIS is differentially corrected to improve accuracy. The underlying premise of differential GPS (DGPS) is that any two receivers that are relatively close together will experience similar atmospheric errors. DGPS requires that a GPS receiver be set up on a precisely known location. This GPS receiver is the base or reference station. The base station receiver calculates its position based on satellite signals and compares this location to the known location. The difference is applied to the GPS data recorded by the second GPS receiver, which is known as the roving receiver. The corrected information can be applied to data from the roving receiver in real time in the field using radio signals or through post processing after data capture using special processing software. (Chivers 2003)

3.2. Identification system

To identify of each roll-trailer in the high & heavy area it is necessary to use a reliable and robust identification technology. To avoid identification failure based on manual and human mistakes it is equally important to make use of automated identification systems. The main purpose of automated identification systems is the fast and reliable identification of several objects. In addition to identification technologies such as barcode and OCR (Optical Character Recognition), especially the Radio Frequency Identification (RFID) technology gains in significance.

A RFID system consists of at least one storage medium (RFID transponder) fixed to the corresponding object and a reading/writing device (RFID reader), which communicates with each other via radio signals. Figure 2 illustrates the functional principle of an RFID system.

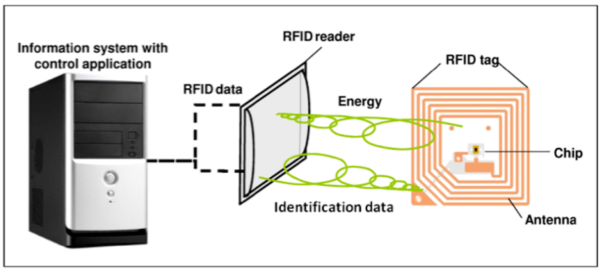


Figure 2: Function principle of a RFID system

The RFID reader generates an electromagnetic frequency field that provides power and data to the RFID transponder. These data stored onto the transponder is transmitted to the reading device as a response to a request impulse. Both the transponder as well as the reading device has an integrated transmitting and receiving antenna. Thus is it possible to write and read a RFID transponder with the same device. The RFID transponder, which contains a unique identification number, uses its antenna to take energy from the frequency field of the RFID reader. This energy is used from the RFID transponder to send the stored identification data to the RFID reader via its antenna. The RFID reader transfers the identification data to a computer unit. RFID transponders which use the signal energy from the RFID reader to transfer their data are called passive transponders. In contrast to passive transponders, active transponders have their own source of energy in form of a battery, so they are independent of the frequency field of a RFID reader. However, compared with passive RFID transponders active ones are more expensive and need much more maintenance. (Shepard 2005)

Additionally to their energy supply, RFID tags can also be differed concerning to their transmission frequency. This high frequency (HF) and ultra high frequency (UHF) transponder have enforced. During HF transponder with a frequency field of 3-30 MHz and a range up to 10 cm are mainly used for access control, UHF transponder with a field frequency of 850-950 MHz and a range of up to six meter as passive and up to 100 meters as active ones can be used for object identifications where a wide range identification is necessary.

The main advantage of RFID technologies as against optical identification technologies is that RFID readers do not need a direct view to RFID transponders for data exchange. Rather, the data exchange is independent from RFID transponder positions in the reading area of the RFID reader. Thereby, it is possible to read multiple RFID tags at once. The so called "bunch processing" has positive emergences by the identification of stacks in the high & heavy area. Furthermore, their exist many design solutions of RFID transponder which do not lose their reliable functionality on metallic surfaces, for example on a roll-trailer, and which are robust against mechanical stress and wet weather conditions.

3.3. Communication system

If the position and status data of roll-trailers are generated and used by spatially distributed and asynchronous operating employees, for collecting and providing up-to-date data, the project solution requires a centralised server (i.e. a data base). For the communication between mobile data terminals and a centralised server, the project uses a Wireless Local Area Network (WLAN), which already exists on nearly all Ro-Ro terminals.

WLAN is a well accepted technology for data transmission. It includes encryption and authentication mechanisms and operates on different frequencies, data transfer rates and ranges – depending on the used standard. WLAN can be operated in two modes: the infrastructure mode and the ad-hoc mode. While the ad-hoc mode is designed to enable spontaneous connections of coequal end devices, the infrastructure mode are less dynamically and more stationary: there are fixed installed base stations (access points). They provide access to the basic network (centralised server) and coordinate the devices within their work area (Netgear 2009). So, even if the WLAN on the Ro-Ro terminal operates in the infrastructure mode, it is possible to work real-time on the centralised server. But there is a special challenge for the WLAN: the so called handoff. A handoff is necessary when a device leaves the cell of a base station and enters the cell of another base station. The movement is detected by regularly measuring the received transmitting power of the surrounding base stations. If the received transmitting power of another base station exceeds those of the current one, it is assumed that the device moves into this direction, so that a connection change is advisable. To ensure an uninterrupted data stream, the connection change has to occur simultaneously on the centralised server as well as on the end device (Zhang et al. 2007).

3.3. Technical Implementation

The technical implementation of the designed system for tracking and tracing roll-trailers on seaport terminals is based on the described technologies RFID for identification, GPS, especially DGPS technology, for positioning and WLAN for communication as illustrated in figure 3.

The focus of the technical implementation is directed to stationary and mobile detection of position and status information of roll-trailer on seaport terminals. For this purpose, roll-trailers are fitted with passive UHF transponder. Tug-masters are equipped with combined data terminals, which contain an UHF reader to identify the related roll-trailers, a positioning component for locating the current position as well as a communication component for transmitting transport orders, positioning and status data. The position of the roll-trailer determined by DGPS, or Galileo in the near future is assigned to the roll-trailer identified by its RFID tag.

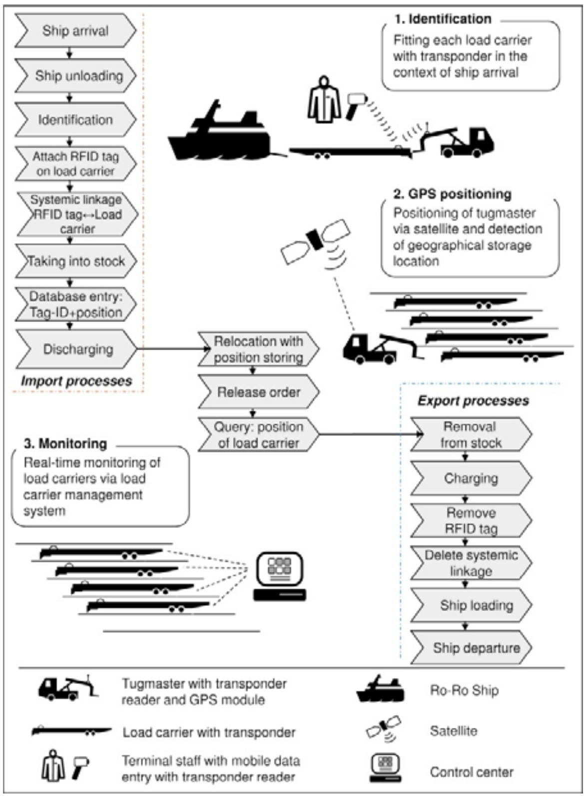


Figure 3: Technical implementation of the composed IC-Technologies (based on Scholz-Reiter et al. 2008)

A detection of the specific position of the roll-trailer can be achieved while moving the roll-trailer with a tug-master from one location to another. An appropriate combination of the described technical components allows a continuous monitoring of position and status of the roll-trailers (loading status, current allocation of roll-trailer to tug-master, movement status etc.) on the huge terminal area. As a result, the main stock keeping processes of roll-trailers such as taking into stock, removing from stock and relocation can be tracked. For each process step (ship loading / unloading, taking into stock / removal from stock / relocation of roll-trailers, unloading of roll-trailers etc.) a timestamp as well a location stamp is documented. The identification number of the roll-trailers and loadings as well as the voyage numbers are documented in the corresponding software system and are assigned to the related ships and shipping companies in their function as invoice recipient for storage charge. At neuralgic points of the seaport terminal area (ship ramps, storage gates etc.) additional stationary reader devices are implemented, which complete the monitoring of roll-trailer movements by identifying passing roll-trailers fitted with passive transponders.

By means of the IT-based roll-trailer management system described above, the process chain in the field High & Heavy (ship unloading, taking into stock, relocation of roll-trailer, removal from stock to ship loading) can be permanently observed and therefore significantly improved. Further sub processes are primary data collection and receiving inspection in the context of the ship arrival process. On the seaport terminal, the RFID system represents a temporary closed loop solution with main focus on the time periods, during which the roll-trailers are staying on the terminal area. Transponders, which are tagged to the roll-trailers in the context of the ship unloading process, are read by stationary or mobile RFID reader devices at the ship ramp. When a roll-trailer leaves the seaport terminal area, the transponder is read again by the RFID reader at the ship ramp and after that removed from the roll-trailer. Another field of application of the described system is the inventory of roll-trailers, which can be significantly, accelerated using a mobile data entry device (MDE) with integrated RFID reader and GPS component. (Scholz-Reiter et al. 2008)

4. TECHNICAL AND ECONOMICAL EXAMINATION

In a first one year technical examination, 20 RFID transponders from two different producers were tagged on the front side of different roll-trailers in an early project stage. The intention was to get some knowledge about the reliability of the transponders under the influence of metallic environment, wet weather conditions and mechanical stress. During the examination, the roll-trailers were normally used, a part of them even travelled to another seaport harbour abroad. The results of the survival test for the RFID transponder were surprisingly good. Even though the rough handling on the high & heavy section and the associated use without carefulness, the RFID transponders were not damaged even after one year of use. Quite the contrary, even during the winter with cold, snowy and rainy weather, reliable reading ranges up to 4 meters could be measured. Even the metallic surface of the roll-trailer, which mostly can be a problem for the reliability of RFID transponder, had only, if any, an insignificantly influence on the reading distance. First tests of WLAN connectivity and DGPS accuracy were convincingly. Detailed tests will be conducted over several months in the next stage of the project.

Furthermore a first economic estimation, which based on the current and target process models was calculated. Therefore the process cost accounting method was compiled with the use of total costs of ownership. A comparison of estimated cost reductions through the use of the composed technologies and the estimated investigation costs for software and hardware came to the mentioned amortisation of 1.5 years. A full comprehensive economic analysis about the cost effectiveness of the technical implementation will be made after implementing a prototypical system and generating real data.

5. CONCLUSION AND OUTLOOK

This paper presents an implementation concept of IC-technologies that captures position and status of roll trailers in Ro-Ro traffic on sea harbour terminals. The described analysis points out weaknesses in the roll trailer operations cycle and show how to handle these weaknesses by implementing of IC-Technologies. The paper also shows that an early economical examination comes to the result that an amortisation of the implementation concept can be generated in 1.5 years. The integration of the concept into the seaport warehouse management system includes the development of software for roll-trailer management and the selection of appropriate hardware components. Thus, further steps of work will be the implementation of software and hardware components according to the model.

A prototypical system based on the shown model and system concept will be implemented on a German Ro-Ro terminal and an extended testing will be carried out. With the expectation that sea harbours will be increasingly frequented in the future the implementation of IC-technologies into Ro-Ro traffic in sea harbours cannot be disregarded.

6. ACKNOWLEDGMENTS

This research was supported by the Federal Ministry of Economics and Technology (BMWI) as part of the program “ISETEC II - Innovative Seaport Technologies”.

7. REFERENCES

Arnold, D.; H. Isermann, A. Kuhn, H. Tempelmeier (Hrsg.), 2002. *Handbuch Logistik*. Springer Verlag Berlin.

BMVBS, 2007; Seeverkehrsprognose 2025. http://www.bmvbs.de/-,1477/knoten.htm [Accessed 16 February 2010]

CHIVERS, M., 2010: Differantial GPS Explained, http://www.esri.com/news/arcuser/0103/differentiad1of2.html [Accessed: 12 July 2010]

DESTATIS, 2009a; Beförderungsmenge nach Hauptverkehrsrelationen. http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Statistiken/Zeitreihen/LangeReihen/Verkehr/Content100/lrvkr004a,templateId=renderPrint.psml [Accessed: 16 February 2010]

DESTATIS, 2009b; Güterverkehr 2009: Starker Rückgang des Transportaufkommens um 11,2%. http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Presse/pm/2010/01/PD10__030__46,templateId=renderPrint.psml [Accessed: 16 February 2010]

Fleisch, E., F. Mattern (Hrsg.), 2005. *Das Internet der Dinge*. Springer Verlag Berlin.

Heimbrock, H., 2001. *Palettenlose Lager- und Transportsysteme als Alternative zu konventionellen Ladungsträgern.* Deutscher Fachverlag, Frankfurt am Main.

Mansfeld, W.; 1998; Satellitenortung und Navigation: Grundlagen, Wirkungsweise und Anwendung; Vieweg + Teubner – GWV Fachverlage GmbH; Wiesbaden

Netgear, 2009. Basiswissen - Wireless LAN Grundlagen.

Oppel, J.-A., 2008. *Der Seehafen als Engpass.* März 2007. Online source. Available from: http://www.dmkn-beta.de/downloads/51/De/FILE451/DerHafenalsEngpass.pdf/ [Accessed: 31 March 2008].

Scholz-Reiter, B.; Böse, F.; Teucke, M.; Virnich, A.; 2008; Load Carrier Management on Ro-Ro Terminals. Proceedings of the 11th International Workshop on Harbor, Maritime & Multimodal Logistics Modelling & Simulation. Campora San Giovanni, Italy, September, pp. 274-279.

Shepard, S.; 2005; RFID - Radio Frequency Identification, The McGraw-Hill Companies, New York.

Zhang, Y.; Yongquiang, L.; Xia, Y.; Huang, Q. (2007): LeapFrog: Fast, Timely WiFi Handoff. Proceedings of the IEEE Global Communications Conference 2007 (GOBCOM 2007), Washington, USA, November, pp. 5170-5174.

ZDS, 2007; Zentralverband der deutschen Seehafenbetriebe: Jahresbericht 2006/2007. September 2007. Online source. Available from: http://www.zds-seehaefen.de/pdf/jahresberichte/2007.pdf [Accessed: 31 March 2008].

8. AUTHORS BIOGRAPHY

Prof. Dr.-Ing. BERND SCHOLZ-REITER is Managing Director of BIBA - Bremer Institut für Produktion und Logistik GmbH and professor at the University of Bremen, Ger-many. His research includes production planning and control and logistics.

Dipl.-Wirt.-Ing. MEHMET-EMIN ÖZSAHIN works as a research scientist at BIBA – Bremer Institut für Produktion und Logistik GmbH at the University of Bremen, Germany. His research emphasis are modelling of production and logistics systems, production planning and control as well as the application of innovative information and communication technologies to logistic processes.

Dipl.-Inf. ANNE SCHWEIZER works as a research scientist at the BIBA – Bremer Institut für Produktion und Logistik GmbH at the University of Bremen, Germany. Her research emphasis is placed on the modeling of production and logistics systems as well as the application of innovative information and communication technologies to logistic processes.

Dipl.-Wirtsch.-Inf. MARC-ANDRÉ ISENBERG works as a research scientist at BIBA – Bremer Institut für Produktion und Logistik GmbH at the University of Bremen, Germany. His research emphasis are planning and control of production, transport and logistics systems as well as the application of innovative information and communication technologies to logistic processes.

SUPPLY CHAIN SIMULATION METHODS ANALYSIS: AN APPLICATION TO THE BEER GAME

Daniel Guimarans[(a)], Julija Petuhova[(b)], Yuri Merkuryev[(c)], Juan José Ramos[(d)]

[(a), (d)] Telecommunication and System Engineering Dept., Universitat Autònoma de Barcelona, Spain
[(b), (c)] Department of Modelling and Simulation, Riga Technical University, Latvia

[(a)]daniel.guimarans@uab.cat, [(b)]julija@itl.rtu.lv, [(c)]merkur@itl.rtu.lv, [(d)]juanjose.ramos@uab.cat

ABSTRACT
The Beer Game has a typical supply chain structure that permits exploring a variety of supply management concepts. Many modelling methods have been used for supply chain analysis and so they can be applied to the Beer Game specific case study. Among them, discrete-event systems simulation has deserved special attention due to its suitability for modelling dynamic systems with a high degree of detailed elaboration and stochastic factors. For this reason, several discrete-event simulation oriented models have been elaborated to tackle the Beer Game and, by extension, multi-echelon supply chains. In the present paper, four of these models are described. Some of their applicability characteristics are also outlined, so a further discussion of their suitability according to simulation purposes can be done. Conclusions extracted from this analysis are presented in this work, aiming to help on choosing the most suitable model according to end user's preferences and purposes.

Keywords: supply chain simulation, Beer Game, Coloured Petri Nets, constraint programming, models analysis, uncertain environment.

1. INTRODUCTION

The Beer Game has a typical supply chain structure when it is represented as a serially connected inventory management systems chain. The Beer Game application enables to explore a variety of simple and advanced supply management concepts, taking into consideration environment uncertainty.

There are a variety of methods which address modelling and analyzing the supply chain. Within them, simulation has become an important tool for analysis and improvement of an entire supply chain operation. Different modelling methods that can be used for supply chain analysis may be classified as follows:

1. Analytical modelling: algebraic methods, automatic control theory, Petri-Nets, queuing theory, Markov chains, etc.
2. Algorithmic modelling:
   (a) Continuous Systems Simulation: differential equations, difference equations, etc.
   (b) Discrete-Event Systems Simulation: event or process oriented simulation, etc.

Analytical models have their place at a tactical level in the design of supply chains. Analytical techniques are able to solve batch sizing and job sequencing problems, yet fail to throw much light on the dynamic behaviour of the supply chain as a whole (Riddals, Bennett and Tipi 2000). Analytical techniques are useful in providing solutions to local tactical problems. Nevertheless, the impact of these solutions on the global behaviour of the whole supply chain can only be assessed using dynamic simulation. In addition, the computational burden associated to such techniques is to be considered an important drawback.

Ishii, Takahashi and Muramatsu (1988) developed a deterministic model for determining the base stock levels and lead times associated with the lowest cost solution for a supply chain. The stock levels and lead times are determined in such a way as to prevent stockout and to minimize the amount of obsolete inventory at each stock point. In this model, they need to decide upon two linearly varying demand rates in order to carry out the computation.

Williams (1981) presents seven heuristic algorithms for scheduling production and distribution operations in an assembly supply chain. The objective of each heuristic is to determine a minimum-cost production and/or product distribution schedule that satisfies the final product demand. However, they fail to illuminate the dynamics of the system.

Cohen and Lee (1989) present a deterministic, mixed integer, non-linear mathematical programming cost-based model. They use an economic order quantity technique to maximize the total after-tax profit for the manufacturing facilities and distribution centres, but dynamics are not included.

Modelling supply chains using continuous system simulation holds great appeal for control theorists. This is because many of the influential characteristics of the problem can be succinctly expressed in a differential equation form (Riddals, Bennett and Tipi 2000). Continuous systems simulation has the advantage of being a conduit into the frequency domain, which offers a framework particularly suited for the study of systems in which oscillations are a salient attribute, e.g. analysis of factors having impact on a seasonal, or other demand fluctuations, amplification as they are passed along the chain. Since differential equation produce "smooth" outputs, they are not suited to modelling of all supply chains. The system must be considered at an aggregated level, in which individual entities in the system (products) are not considered. Rather, they are aggregated into levels and flow rates. Consequently, these methods are not suited for production processes in which each individual entity has an impact on the fundamental state of the system. For the same reasons, continuous systems simulation cannot solve lot sizing and job sequencing problems.

Forrester (1961) developed what he called Industrial Dynamics, which he later extended and renamed System Dynamics. He developed a nonlinear model of a supply chain using first-order differential equations. He analysed the demand fluctuation amplification as it proceed down the multi-echelon supply chain, using continuous time models. However, no sensitivity and cost-based analysis have been carried out on these models, which are solely concerned with the dynamics. Many discrete-event simulation packages available today provide a more advanced simulation capability. Armbuster, Marthaler and Ringhofer (2002) modelled high volume production flows using nonlinear hyperbolic partial differential equations, with Little's law explicitly built into the formulation. By using the developed models, they are able to analyse multiple products, dispatch polices and control actions.

The emergence of discrete-event systems simulation (DES) was engendered by the deficiencies of differential equation approaches to the solution of even simple man-made problems (Riddals, Bennett and Tipi 2000). Consider, as an example, governing the behaviour of a series of queues at a supermarket. The modelling of phenomena such as queue swapping (when customers jump to shorter queues) or variable service speed (faster when there are more customers) would make impossible the application of differential equations, as well as any other theoretical approach. However, such phenomena can easily be incorporated into a DES model.

DES has the following two characteristics: (1) it represents individual events, e.g., the arrival of an individual customer order; (2) it incorporates uncertainties, e.g., customer orders arrive at random points in time, machines break down at random points of time, etc. (Kleijnen 2005). Most systems dynamics models are non-stochastic, but their behaviour often becomes incomprehensible due to nonlinear feedback loops. Most econometric models are also based on the deterministic, nonlinear differential equations. DES provides more accurate simulation capabilities against above described techniques and so it has been considered an important method in supply chain modelling. Banks, Buckley and Jain (2002) described a lot of DES based studies, like commercial packages developed by IBM for supply chain management simulation for both operational and strategic planning levels. For more details on DES one could refer to the many textbooks, e.g., Law and Kelton (2000), Banks, Carson and Nelson (2004), Ho and Cao (1991), etc.

Different described methods of mathematical modelling are suitable for different problems solving and all have their place in the design and management of supply chains. However, the analysis of advantages and disadvantages of the proposed methods specifies DES as the more appropriate method for modelling dynamic systems with a high degree of detailed elaboration and stochastic factors, such as supply chains. For this reason, only models included in the DES category have been considered in this paper.

The remainder of this paper is structured as follows: next section presents a rough description of the Beer Game and introduces the studied models. Section 3 presents a discussion about models suitability according to end user purposes. Finally, some conclusions are outlined in the last section.

2. THE BEER GAME

The Beer Game is a role-playing simulation developed at Massachusetts Institute of Technology in the 1960's to clarify supply chains' behaviour (Jarmain 1963). The Beer Game model considers a simplified beer supply chain, consisting of a single retailer, a single wholesaler which supplies the retailer, a single distributor which supplies the wholesaler, and a single factory with unlimited raw materials which makes (brews) the beer and supplies the distributor (Figure 1).

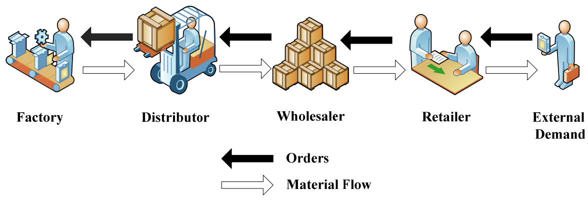


Figure 1: Beer Game's Supply Chain Structure

Each component has unlimited storage capacity and the manufacturer has also unlimited raw materials. There are a fixed supply lead time and order delay time between each participant.

Every week, each component in the supply chain tries to meet the demand of the downstream participant. Any orders which cannot be fulfilled are recorded as backorders. These unmet orders are to be satisfied as soon as possible, since no orders can be ignored. At each period, each member orders some amount from its upstream supplier. It takes one week for this order to arrive at the supplier. Once the order arrives, the supplier attempts to fill it with its available inventory and it takes an additional delay time, commonly set to two weeks, before goods arrive to the customer who placed the order. Usually, each supply chain component has no knowledge of the external demand or the orders and inventory of the other members. Nevertheless, in some cases, all components may share information in order to optimise supply chain's behaviour (Simchi-Levi, Kaminsky, and Simch-Levi 2003).

At each period, each component owns the inventory at that facility and goods in transit to the downstream participant. Each location is charged $1 per item that it owns as inventory holding cost. In addition, any backordered item is charged $2 per week. The external demand is uncertain and the goal of the retailer, wholesaler, distributor, and factory, is to minimise total cost, either individually, or for the whole system.

2.1. Computerised Beer Game

The Computerised Beer Game is a Windows based program written in C++, developed by Kaminsky and Simchi-Levi (1998), providing an interactive tool for teaching some supply chain behaviour characteristics.

The Computerised Beer Game follows the original rules of the Beer Game, with few exceptions aimed to enhance teaching possibilities. The end user can only take one role, usually the distributor, while the computer manages all remaining components according to the chosen policies (Figure 2). These characteristic allows the player focusing on single managerial decisions rather than understanding the whole chain behaviour, for which few information is known. Furthermore, demand in the Computerised Beer Game may be chosen to be either completely deterministic, as in the original game description, or random, following a statistical distribution.

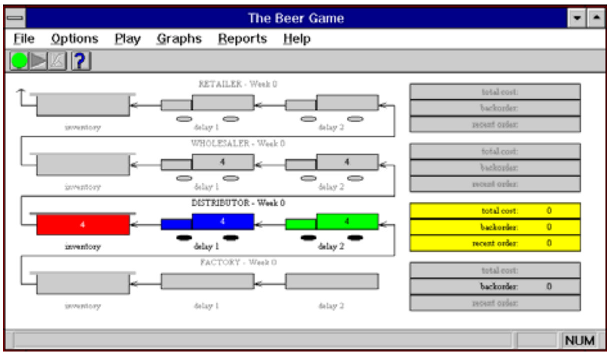


Figure 2: User Interface of the Computerised Beer Game

However, main changes with respect to the original beer game are the options to play with global information, centralized information and/or shortened lead time. When playing the global information scenario, all information is always known, including customer demand and inventories. In the centralized information version, the player can only take the role of the manufacturer. Because the system is centralized, only this component can place orders, while goods are moved downstream as quickly as possible. As in the previous option, all information is always available. This option permits to compare centralized and decentralized policies if costs are correctly adjusted, since no backorders are allowed in the decentralized scenario. Finally, the short lead time version allows reducing the delivery delay from two weeks to one.

The Computerised Beer Game is mainly aimed to education and training on supply chain management. Although results obtained are equivalent to other models and the interactive role may be switched off, so all participants are controlled by the computer, its graphical interface significantly slows down its performance. Therefore, it might not be a good option if the simulation is aimed to analytical purposes, for which other models may provide the same results faster.

2.2. Coloured Petri Nets Model

Coloured Petri Nets (CPN) formalism has proven to be a successful tool for modelling the characteristics for any type of discrete event oriented system. CPN shows several advantages such as the conciseness of embodying the static structure and the dynamics, the availability of the mathematical analysis techniques as well as its graphical nature (Jensen 1997).

The Beer Game has been modelled using timed Hierarchical Coloured Petri Nets (Jensen 1997) following the general scheme presented in Panic, Vujosevic and Makajic-Nikolic (2006). The top level of the model is the whole supply chain represented in the Beer Game, including a customer and the four described agents: retailer, wholesaler, distributor and manufacturer (Figure 5).

The customer is presented by a place, whose initial marking specifies its demand in time. Retailer, wholesaler and distributor are modeled by a *Supplier* sub-model (Figure 3). Finally, the manufacturer is represented by a *Manufacturer* sub-model (Figure 4). Furthermore, this hierarchical model allows including additional suppliers between the customer and the manufacturer, each of them modelled by an instance of the *Supplier* sub-model. This is possible due to in the Beer Game it is assumed all participants make decisions according to the same rules. Thus, all agents included in the supply chain are equal from a modelling perspective.

Although the CPN model may be extended by adding additional parameters, only orders, backorders and deliveries have been considered. These variables are enough to trace system's behaviour in order to show and analyze the bullwhip effect.

An instance of the sub-model *Supplier* has been used to represent the retailer, wholesaler and distributor. According to the order received in place `Demand (downstream)`, the current inventory at place `Stock` and backordered items in place `Backorders`, a supplier makes its own order. This process is modelled through the instantaneous transition `Place order` and the function `order(b,k,n)`, where different policies may be used. These policies may be implemented in a deterministic way or kept open to allow interaction with end users, according to simulation goals. Transition `Fulfil demand` is used to model requested amount's delivery. If the inventory stores enough goods, the complete demand, including last received order and backordered items, is satisfied and the remaining (function `rest(n,b)`) is kept in the stock. Otherwise, all available goods are delivered and the difference is backordered (`rest(b,n)`). The duration of transition `Fulfil demand` is @+2, since the Beer Game rules establish that deliveries last 2 weeks. The associated guard function ensures this transition is only fired when an order exists, or there are backorders to satisfy, and there are goods in stock.

The *Manufacturer* sub-model is similar to the *Supplier* one. In fact, the manufacturer acts as other suppliers, but deciding what amount to produce in the following period instead of placing an order to its upstream agent. Again, this decision is made according to the current demand, backorders and inventory. The associated transition is `Manufacture`, which has associated a duration of 2 weeks (@+2) as MIT Beer Game rules state.

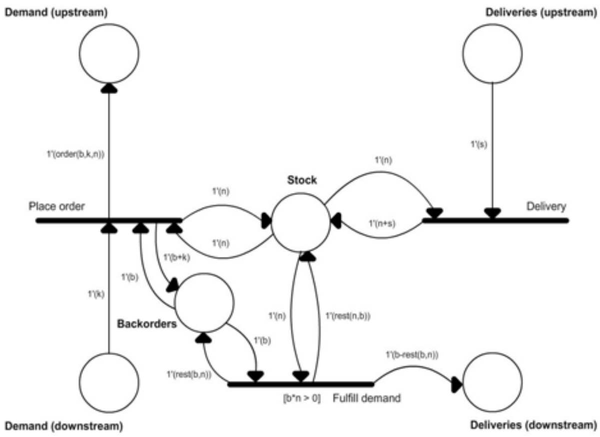


Figure 3: Sub-Model Supplier

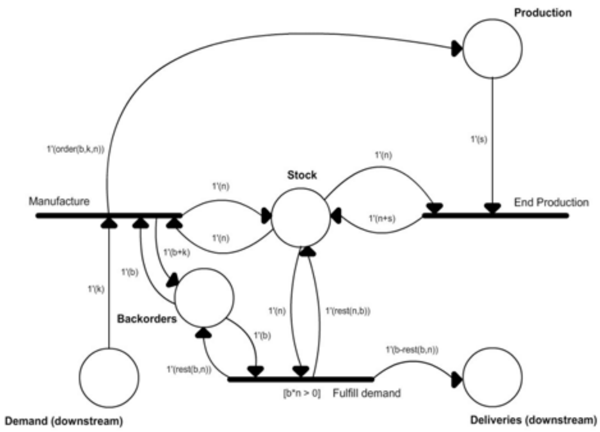


Figure 4: Sub-Model Manufacturer

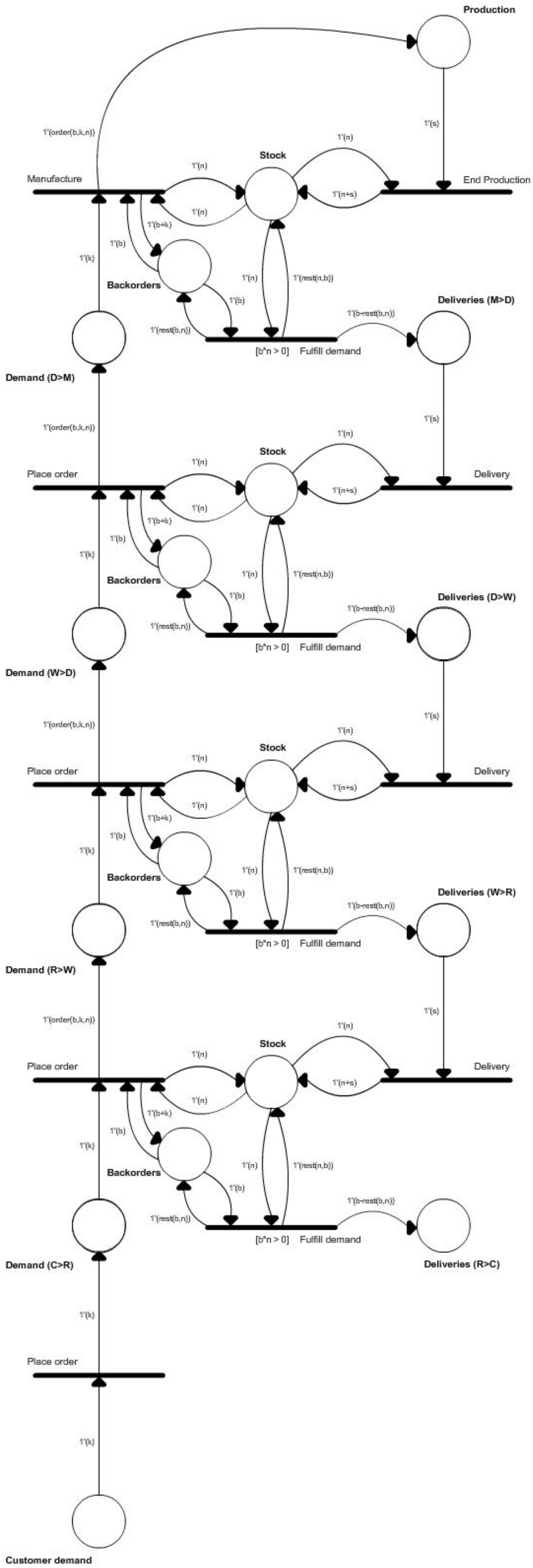


Figure 5: Complete Beer Game CPN Model

This model may be implemented in several platforms supporting CPN simulation, such as CPN Tools (2010), or using any programming language (Guasch, Piera, Casanovas and Figueras 2002). According to implementation details, the model is likely to be used with different purposes. As an example, all policies may be implemented so all participants behave in a deterministic way. On the other hand, function `order` may be left in blank for one, some, or all participants, allowing end users interaction. Thus, an interactive CPN model is implemented, especially suitable for educational and training purposes, comparable to the original Beer Game. Taking into account extra variables may be included in the model, this CPN model is more likely to be extended according to training preferences and dynamics to be studied.

2.3. Constraint Programming Model

Constraint Programming (CP) is a powerful paradigm for representing and solving a wide range of combinatorial problems. Problems are expressed in terms of three entities: variables, their corresponding domains and constraints relating them. The problems can then be solved using complete techniques such as depth-first search for satisfaction and branch and bound for optimization, or even tailored search methods for specific problems. Rossi et al. (2006) presents a complete overview of CP modelling techniques, algorithms, tools and applications.

The CP model may be seen as a specific implementation of the CPN model described in the previous section. Constraints among variables are defined as a set of rules, relating each component's variables with its upstream/downstream participant and their values at each period.

Four sets of variables have been defined, one for each component *i=[1..4]* (1: retailer, 2: wholesaler, 3: distributor, 4: manufacturer) and the final customer being *i=0*. Periods are denoted by the variable $t=[1..t_{max}]$, where t_{max} is usually set to 50 weeks. Thus, for component *i* at period *t*, variables defined are: $\mathtt{INV}_{it}$ is the current inventory, $\mathtt{DEL1}_{it}$ and $\mathtt{DEL2}_{it}$ are the goods in transit, $\mathtt{BO}_{it}$ is the number of backordered items, $\mathtt{DEM}_{it}$ is the demand to be satisfied, $\mathtt{ORD}_{it}$ is the order placed by the component, $\mathtt{SHIP}_{it}$ is the amount shipped by the component in the current period and $\mathtt{COST}_{it}$ is the associated cost to this turn. Variables are related according to the following rules:

$$\mathtt{DEM}_{1t}=\mathtt{ORD}_{0\ t} \tag{1}$$
$$\mathtt{DEM}_{it}=\mathtt{ORD}_{i-1\ t-1} \tag{2}$$

$$\mathtt{INV}_{i\ t-1} + \mathtt{DEL1}_{i\ t-1} \bullet \mathtt{DEM}_{it} + \mathtt{BO}_{i\ t-1} \rightarrow \tag{3}$$
$$\begin{aligned}&\mathtt{INV}_{it}=\mathtt{INV}_{i\ t-1}+\mathtt{DEL1}_{i\ t-1}-\mathtt{SHIP}_{it}\\&\mathtt{SHIP}_{it}=\mathtt{DEM}_{it}+\mathtt{BO}_{i\ t-1}\\&\mathtt{BO}_{it}=0\end{aligned}$$

$$\mathtt{INV}_{i\ t-1} + \mathtt{DEL1}_{i\ t-1} < \mathtt{DEM}_{it} + \mathtt{BO}_{i\ t-1} \rightarrow \tag{4}$$
$$\begin{aligned}&\mathtt{INV}_{it}=0\\&\mathtt{SHIP}_{it}=\mathtt{INV}_{i\ t-1}+\mathtt{DEL1}_{i\ t-1}\\&\mathtt{BO}_{it}=\mathtt{BO}_{i\ t-1}+\mathtt{DEM}_{it}-\mathtt{SHIP}_{it}\end{aligned}$$

$$\mathtt{DEL1}_{it}=\mathtt{DEL2}_{i\ t-1} \tag{5}$$
$$\mathtt{DEL2}_{it}=\mathtt{SHIP}_{i+1\ t} \tag{6}$$

$$\mathtt{COST}_{it}=1*(\mathtt{INV}_{it}+\mathtt{DEL1}_{it}+\mathtt{DEL2}_{it})+2*\mathtt{BO}_{it} \tag{7}$$

The total cost for component *i* for the whole simulation period is then calculated trivially:

$$TCOST_i = \sum_{t=1}^{t_{max}} COST_{it} \tag{8}$$

The value of $\mathtt{ORD}_{it}$ in (2) is determined according to the chosen policy. Several policies may be implemented, usually depending on inventory and demand parameters.

Rule (3) is only applied to update parameters when there is enough stock to fulfil the current demand. On the other hand, rule (4) is used whenever the component *i* is not able to meet demand requirements. Constraints (5) and (6) update transportation variables at each period.

Departing from a given initial state and a list of customer's demand along periods, CP propagation rules determine immediately all remaining variables. Therefore, the model is able to provide instantaneously results corresponding to a complete simulation. Moreover, since propagation rules are not unidirectional, the model may provide a mechanism to infer other participants' policies, inventory bounds and even final customer's demand. With this goal, initial information concerning the evolution of own variables should be provided, instead of final customer's demand. So, the model may reconstruct demand patterns from other participants, even for the final customer, and provide a good mechanism for analysis and a first step to get a reliable forecasting tool.

The CP model, implemented using the CP platform ECLiPSe (Apt and Wallace 2007), is instantaneous for common simulation periods. Since propagation is very fast, the model is especially suitable for analysis purposes. Furthermore, it is likely to be parallelized, so different scenarios may be defined and run simultaneously to get different data. Nevertheless, the model provides a low level of interaction, so it might not be a good option for decision making training.

2.4. Arena

Simulation techniques are used when analytical solving is impossible. Most of all analytical approaches do not succeed analysing complex, dynamic systems like supply chains. For this reason, the Beer Game has been modelled using DES software Arena by Rockwell Automation (2010). Arena software is effective when analysing complex, medium to large-scale projects, involving highly sensitive changes related to supply chain, manufacturing, processes, logistics, distribution, warehousing and service systems. Arena proposes an event-oriented modelling approach and consists of "libraries" of modelling objects that make it significantly easier and faster to develop models. Arena exploits two Windows technologies that are designed to enhance the integration of desktop applications. The first, ActiveX Automation allows applications to control each other and themselves via a programming interface. The second technology addresses the programming interface issues to a Visual Basic programming environment. These two technologies work together to allow Arena integrating with other programs that support ActiveX Automation, e.g., Excel, AutoCAD, or Visio.

The Beer Game supply chain and its inventory control systems have been implemented combining Arena software and Visual Basic for Applications (VBA). The model logic is represented comprehensibly in the Arena flowchart-style environment, while the more complex calculation algorithms are programmed in VBA. The traditional four-stage Beer Game structure has been modelled in combination with two information sharing strategies (centralised and decentralised) and two inventory control policies (s-S and Stock-To-Demand).

In accordance with specific features of the Beer Game, the proper event processing schedule implementation in Arena environment is shown in Figure 6. If several events are scheduled to occur at a certain supply chain stage at the same simulation time, there is a fixed order in which the events should be processed:

1. order or backorder arrival from upstream stage (stock replenishment);
2. fulfilling of backorders (only if an order has arrived);
3. new demand fulfilling.

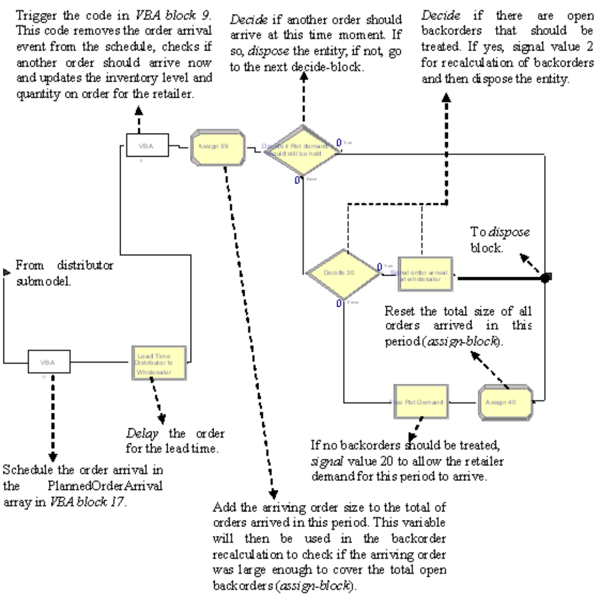


Figure 6: Submodel of Order Shipment to Wholesaler

As Arena's simulation engine do not always process the events in this order (Kelton and Sadowski 2002), a procedure has been developed to guarantee that events are processed in the mentioned sequence. `Wait` and `Signal` blocks form implementation's basis of this procedure in Arena.

Various experiments may be performed with the created model and achieved results may be analysed by the Output Analyzer. This is a component of Arena that provides an easy-to-use interface, simplifying data analysis and allowing viewing and analysing simulation data quickly and easily.

The Arena model is suitable for research purposes, since it incorporates both dynamic and stochastic nature of the supply chain operations and the simulation execution speed without animation is quite fast. The analysis of system's behaviour under specified conditions may be easily performed and allows foreseeing thousands of situations which could result from supply chain operations. Each of the supply chain stages is modelled as a separate module and it is possible to change both supply chain structure (e.g., add or remove a stage) and supply chain management concepts (e.g., centralized or decentralized information sharing strategy).

However the model is not suited for training and education due to low level of interaction with the end user. To modify the model parameters, end user should have previous experience on working with Arena software.

2.5. Excel

An alternative to DES specific software is developing a supply chain simulator implemented in a general-purpose high-level programming language, e.g., C++, Java or VBA. Programming languages are mainly used for simulation in order to avoid additional expenses of commercial software purchasing and maintenance.

The user interface of the Beer Game supply chain model is developed by means of Microsoft Excel spreadsheets (Figure 7), which is widely applied and easy accessible software. The programming logic is implemented using VBA (Ternovoy 2004).

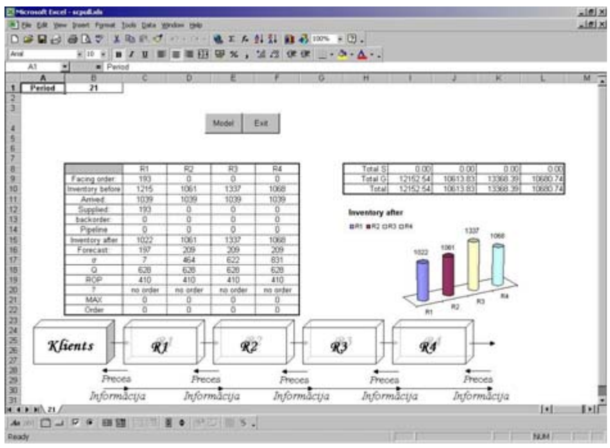


Figure 7: Supply Cain Model User Interface

Supply chain's control variables' values, as well as initial data, are defined by the user using a MS Excel interface, and then the simulator is run for the specified number of periods by means of a VBA procedure (Figure 8).

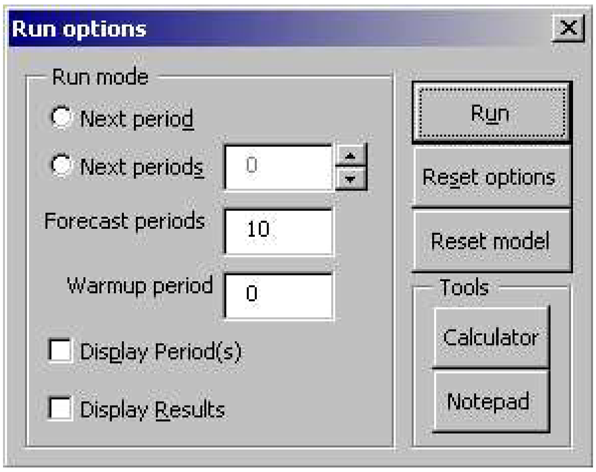


Figure 8: Simulation Parameters

The simulation procedure `Next_n` runs the model in accordance with defined user settings. First, constants and variables are defined and information is read from the data files. Then, the simulation of the processes scheduled is performed and repeated four times for all supply chain's stages, i.e. once for each component. Events management is performed in accordance with the Beer Game structure. Eventually, simulation results appear in separate spreadsheets showing different types of charts, histograms and tables.

The functional possibilities of the Excel simulation model are quite similar to the Arena model, but since the special simulation software is not needed and experiments are easily configured, it can be used for educational and training purposes. However, the speed of executing a simulation run in Excel is quite slow and the number of simulated periods is restricted, so research tasks are difficult by using this model.

3. MODELS SUITABILITY

Although all described models yield the same results, choosing one or another relies on simulation's goals. Each model's characteristics make it more suitable according to pursued purposes: research or training/education. However, all models may be used to simulate the Beer Game regardless of their characteristics, being only a matter of efficiency which one is best suited to a specific simulation goal.

Table 1: Models' Characteristics Summary

Model	Interactive	Scalable	Speed	Infer Policies
Comput.	X			
CPN	X	X		
CP		X	X	X
Arena		X	X	
Excel	X	X		

Table 1 summarizes characteristics for all described models in the previous section. Even though different parameters might be defined, only those relevant for purposes considered in this paper have been included, i.e. interactivity, scalability, execution speed and the capability of inferring demand patterns from a data set. Interactivity is a characteristic of Computerised, CPN and Excel models. In all of them, different parameters can be chosen or modified on runtime, or the model is likely to be modified easily to include some level of interaction with the end user. On the other hand, the CP model is completely deterministic and results are only derived from the initial data and set-up. Arena model requires some particular skills in order to permit some interaction with the end user. Models' modularity determines their capability of being scaled to represent larger systems. In this sense, Arena, Excel, CPN and CP models are clearly modular, since different components are defined separately and may be concatenated with little changes. The computerised Beer Game is proprietary software and so the system it represents cannot be modified. According to the simulation speed, CP and Arena models are clearly faster than other models. This characteristic makes them especially efficient when running a set of simulations with different parameters, as demanded for analysis purposes. Finally, only the CP model allows performing simulations with different initial data than the final customer demand and participants' policies. This characteristic provides a mechanism especially important from a forecasting perspective. As mentioned in the CP model description, it also permits reconstructing demand patterns and inferring other participants' policies and inventory bounds. Therefore, this characteristic might be an interesting tool for analysis, either for research or management.

Table 2: Models' Suitability According to Simulation Purposes

Model	Training / Education	Research	
		Analysis	Strategies develop.
Computerised	X		
CPN	X	X	
CP		X	X
Arena		X	
Excel	X		

All parameters related in Table 1 characterize models' performance and adaptability, and help on choosing one or another depending on simulation purposes. For example, if the simulation is training or education oriented, requested characteristics mainly include a high interactivity, in order to permit the end user making his own decisions and introducing them into the system. These decisions could be programmed in advance for all models, so not interactivity is allowed at all, but it would reduce the teaching or training experience to a single analysis after the simulation ends.

For this reason, interactive models among described ones, i.e. Computerised Beer Game, CPN and Excel, are considered to be best suited for management training or education. On the other hand, research tasks demand another kind of characteristics, especially related to execution speed. Usually, separate sets of simulations are run combining different demand patterns and policies, in order to analyse system's behaviour. With this goal in mind, it is more appropriate to choose a model which allows running a complete simulation in a low time, such as CP or Arena models. Although the execution time depends on the implementation platform and computer's characteristics, both models have demonstrated being fast enough for research tasks. Another desirable model characteristic is scalability, since it allows modifying system's dimensions with analytical purposes. In this sense, both CPN and CP models permit changing the number of components easily while ensuring a complete integration of all variables. Finally, the capability of the CP model to infer other components' policies, demand patterns and inventory bounds, combined with its low execution time, make it especially suitable for strategies and policies development, as well as a first step for developing forecasting tools. Table 2 presents which models best fulfil different simulation goals. Nevertheless, conclusions presented in Table 2 are to be considered more a guide than a rule, since all models may be used for all selected purposes according to end user preferences, as mentioned.

4. CONCLUSIONS

The Beer Game has a sequential supply chain structure that permits exploring many supply management concepts. In the present paper, four discrete-event simulation models representing the Beer Game have been described. Some of their characteristics have also been outlined and related to their suitability according to simulation purposes. This analysis may form a helpful basis for choosing the most suitable model according to end user's preferences and purposes.

The Computerised Beer Game is mainly aimed to education and supply chain management training. It allows a high level of interaction with the end user, although the interactive role may also be switched off aiming to increase the simulation speed. However, its graphical interface significantly slows down model's performance, so it might not be the best option if the simulation has analysis purposes.

CPN provide a mechanism to specify a conceptual model, likely to be implemented either on CPN simulation platforms or by using high-level programming languages. Thus, it possesses a set of characteristics that permit using it for educational and training purposes, as well as for analysis and research tasks.

The CP model may be considered as an implementation of the proposed CPN model. Since constraint propagation is very fast, it provides almost instantaneous results for common simulation periods. This way, thousands of different scenarios could be simulated sequentially, or even in a parallelized environment, getting results in reasonable times. On the other hand, there is a lack of interactivity with the end user that makes it difficult to be used with real-time decision making training.

The Arena model incorporates advantages from using specific simulation software, such as the capability of including both dynamic and stochastic nature of supply chains operations. Since it is able to provide results in a quite reasonable time, this model is suitable to be used for research purposes. However, using Arena on developing and modifying supply chain models requires particular skills on working with simulation software environment.

Using Excel for developing a simulation model becomes an alternative to using Arena. Both models possibilities are similar, having the advantage that no special simulation software is needed. Thus, Excel model may also be used for educational and training purposes. However, its simulation speed is quite low compared to Arena, so research tasks are limited when using this model.

Described models' main purposes are clearly determined by parameters analysed in section 3, among others. As an example, for training simulations is highly desirable to run a model which allows interacting with the end user. Thus, he can check almost instantly consequences derived from his decisions. On the contrary, research tasks often require a high execution speed, so different scenarios may be simulated and analysed in low times. Scalability is another desirable characteristic, even though it is not critical due to Beer Game models simplicity. It should be remarked a characteristic that only the CP model possesses: inverse deduction and reconstruction of policies and inventory bounds. CP paradigm allows this characteristic, since constraints are not unidirectional, unlike rules included in other models.

Finally, it should be remarked that all four presented models are simulation oriented. Simulation models are the so-called input-output models, i.e., they yield the output of the system for a given input. Therefore, simulation models are "run" rather than "solved" (Hurrion 1986). For this reason, no one of presented models may be used for optimization purposes without significant changes. In any case, system may be studied and optimised, but depending entirely on the end user. Among models described in the present paper, only the CP model is suitable to be easily modified to include an objective function in order to be optimised. However, supply chains nature would induce to explore a huge search space, characteristic of NP problems. Tackling this kind of problem would require using complex algorithms, i.e. heuristics and metaheuristics, combined with simulation and other operational research techniques.

REFERENCES

Apt, K., and Wallace, M.G., 2007. *Constraint Programming using ECLiPSe*. Cambridge: Cambridge University Press.

Armbuster, D., Marthaler, D., and Ringhofer, C., 2002. Efficient simulations of supply chains. *Proceedings of the 2002 Winter Simulation Conference*, 1345-1348. December 8-11, San Diego (USA).

Banks, J., Buckley, S., and Jain, S., 2002. Panel session: opportunities for simulation in supply chain management. *Proceedings of the 2002 Winter Simulation Conference*, 1652-1658. December 8-11, San Diego (USA).

Banks, J., Carson, J.S., and Nelson, B.L., 2004. *Discrete-Event System Simulation*. New Jersey: Prentice Hall.

Bessiere, C., 2006. Constraint propagation. In: Rossi, F., van Beek, P. and Walsh, T., eds. *Handbook of Constraint Programming*. Amsterdam: Elsevier, 29-83.

Cohen, M.A., and Lee, H.L., 1989. Resource deployment analysis of global manufacturing and distribution networks. *Journal of Manufacturing and Operations Management*, 2: 81-104.

CPN Tools, 2010. *CPN Tools, Computer Tool for Coloured Petri Nets*. Available from: wiki.daimi.au.dk/cpntools.

Forrester, J.W., 1961. *Industrial Dynamics*. New York: MIT Press and Wiley.

Guasch, A., Piera, M.A., Casanovas, J. and Figueras, J. (eds.), 2002. Simulación de Sistemes Orientados a Eventos Discretos. In: *Modelado y Simulación. Aplicación a Procesos Logísticos de Fabricación y Servicios*. Barcelona: Edicions UPC.

Ho, Y.C., and Cao, X.R., 1991. *Perturbation Analysis of Discrete Event Dynamic*. Boston: Kluwer Academic Publisher.

Hurrion, R.D., 1986. *Simulation: Applications in manufacturing - International trends in manufacturing technology*. Bedford: Springer-Verlag.

Ishii, K., Takahashi, K., and Muramatsu, R., 1988. Integrated production, inventory and distribution systems. *International Journal of Production Research*, 26(3): 473-482.

Jarmain, W.E., 1963. *Problems in Industrial Dynamics*. Cambridge: MIT Press.

Jensen, K., 1997. *Coloured Petri Nets. Basic Concepts, Analysis Methods and Practical Use*. Volumes 1, 2, 3. Berlin: Springer-Verlag.

Kaminsky, P., and Simchi-Levi, D., 1998. A new computerized beer game: a tool for teaching the value of integrated supply chain management. In: Hau Lee and Shu Ming Ng, eds. *Global Supply Chain and Technology Management*. Miami: The Production and Operations Management Society, 216-225.

Kelton, W.D., and Sadowski, R.P., 2002. *Simulation with Arena*. New York: McGraw-Hill.

Kleijnen, J.P.C., 2005. Supply chain simulation tools and techniques: a survey. *International Journal of Simulation & Process Modelling*, 1(1-2): 82-89.

Law, A.M., and Kelton, W.D., 2000. *Simulation modeling and analysis*. International Series in Industrial Engineering and Management Science. Singapore: McGraw-Hill.

Panic, B., Vujosevic, M., and Makajic-Nikolic, D., 2006. A Supply Chain Simulation Model Based on Hierarchical Coloured Petri Nets. *Proceedings of the International Scientific Days – Competitiveness in the EU – Challenge for the V4 Countries*, 1431-1436. May 17-18, Nitra (Slovakia).

Riddalls, C.E., Bennett, S., and Tipi, N.S., 2000. Modelling the dynamic of supply chain. *International Journal of System Science*, 31(8): 969-976.

Rockwell Automation, 2010. *Arena Simulation*. Available from: www.arenasimulation.com.

Rossi, F., van Beek, P., and Walsh, T. (eds.), 2006. *Handbook of Constraint Programming*. Amsterdam: Elsevier.

Simchi-Levi, D., Kaminsky, P., and Simchi-Levi, E., 2003. *Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies*. New York: McGraw-Hill.

Ternovoy, V., 2004. *Simulation-Based Analysis of the Supply Chain Operation*. Master thesis (supervisor Petuhova, J.). Riga Technical University.

Williams, J.F., 1981. Heuristic techniques for simultaneous scheduling of production and distribution in multi-echelon structures: theory and empirical comparisons. *Management Science*, 27(3): 336-352.

ACKNOWLEDGMENTS

This work has been supported by the Agència de Gestió d'Ajuts Universitaris i de Recerca (AGAUR) of the Generalitat de Catalunya (project 2009 SGR 629).

AUTHORS BIOGRAPHY

Daniel Guimarans is a PhD Student and Assistant Teacher at the Telecommunication and Systems Engineering Department at the Universitat Autònoma de Barcelona. He is an active member of the Logisim Research Group. His research interests are constraint programming, simulation and hybridisation of different techniques to solve industrial combinatorial problems.

Julija Petuhova is Doctor of Engineering, lecturer of the Institute of Information Technology at Riga Technical University. Her research interests include simulation methodology of logistics systems, supply chain dynamics, practical applications of simulation modelling, training and education via simulation-based business games. She is a member of the Latvian Simulation Society and has a wide experience in performing research projects in the simulation area at national level.

Prof. Yuri Merkuryev is Habilitated Doctor of Engineering, Professor of the Institute of Information Technology at Riga Technical University, Head of the Department of Modelling and Simulation. His professional interests include methodologies and practical implementation of discrete-event simulation, supply chain modelling and management, and education in the areas of modelling, simulation and logistics management. He is Programme Director of the Master-level curriculum “Industrial Logistics Management” at Riga Technical University. Prof Merkuryev has a wide experience in performing research and educational projects in the simulation area, at both national and European levels, and regularly participates in organising international conferences in the simulation area. He has promoted 5 PhD theses and authors about 250 scientific publications, including 5 books and numerous journal and conference papers, as well as a text-book in Logistics Information Systems. He is also co-editor of a collection of simulation-based case studies in logistics, published in 2009 by Springer-Verlag. Prof. Merkuryev is a Board member of the European Council of the Society for Modeling and Simulation International, President of the Latvian Simulation Society, and Board member of the Latvian Transport Development and Education Association.

Juan José Ramos is an Associated Professor at the Telecommunication and Systems Engineering Department at the Universitat Autònoma de Barcelona. He is coordinator and an active member of the Logisim Research Group. His research interests are modelling, simulation and optimisation of logistics problems.

TRANSPORT-STORAGE SYSTEM OPTIMIZATION IN TERMS OF EXERGY

Pawel Zajac[(a)]

[(a)]Wrocław Univeersity of Technology

[(a)]pawel.zajac@pwr.wroc.pl

ABSTRACT

The paper presents possibilities of transport-storage system optimization which takes into account energy everywhere where it and its exchange occur. It is assumed that the transport-storage system is a logistic system component and it consist of a building, spaces (with or without racks) where cargo units are stored, equipment for transferring the cargo units and personnel operating the equipment and working physically. The optimization includes integration components: a storage technology with internal transport and information interchange.

Keywords: logistics, transport-storage system

1. INTRODUCTION

The amount of energy consumed by technical systems to perform the required functions and processes is a major consideration in every sphere of economic activity. For this reason the consumption of fuels, natural gas, electricity and heat is being monitored. Currently, filament lamps are being replaced by fluorescent lamps. Also combined thermal and electrical energy management, i.e. cogeneration, is being introduced. Now it is important not only how much waste is produced or how high the recycling level is but also how much noise a technical system generates, what the environmental (thermal and harmful emission) loading during its life is and to what extent the system will burden the environment when its life ends. Automotive companies already at the car design stage decide which of the parts can be used again in a new vehicle once the life cycle ends Lewandowska (2008), Szargut (2007), Szargut (1965).

Energy savings are sought in all places where energy and its exchange occur, including logistic systems. It is assumed that a store as a transport-storage (T-S) system and a logistic system component consists of a building, spaces (with or without racks) where cargo units are stored, equipment for transferring the cargo units and an information interchange subsystem consisting of an automatic identification system and a storage management support system Korzen (1997), Korzen (1999). Besides human labour, forklift trucks, conveyors and staplers are used to transfer cargo units.

The particular processes require energy investments depending on the automatic identification and electronic data information interchange systems. The energy investments can be conveniently determined using the physical dependencies between energy, work and power.

2. EXERGY

Up till now the efficiency of energy conversion processes has been investigated through energy analysis, i.e. exclusively on the basis of the first law of thermodynamics. The energy balance treats all the forms of energy equally, without taking into account their unequal quality (practical usefulness). But it is obvious that 1 kJ of electric energy generated by a power plant is much more useful than 1 kJ of energy carried by water used for cooling the power plant. Besides, electric energy has a much higher economic value. Hence it can be assumed that electric energy and mechanical work are characterized by the highest practical usefulness and one can obtain from them any other form of energy in an equivalent amount.

The cost of producing useful energy increases as the thermodynamic processes advance. This is due to the fact that the amount of useful exergy decreases because of unavoidable losses in the irreversible processes. Moreover, at each process step an additional cost of the necessary investments appears.

The exergy of a system is always non-negative. It is equal to zero when the system is in thermodynamic equilibrium with the environment and it increases with the degree of departure from this equilibrium. The value of the system's exergy depends on both its state and the state of the environment. The energy conversion optimization problem can be formulated as an endeavour to minimize exergy losses as expressed by the ratio of the energy supplied to an actual device to the energy supplied to the ideal device, and needed to perform the same work by the respective devices.

An exergetic analysis can be a major component of a more comprehensive multifactor analysis, such as LCA (life cycle analysis), LCEA (life cycle exergy analysis, e.g. Finnveden & Ostlund) and ELCA (exergetic life cycle analysis, Cornelissen) Lewandowska (2008), Szargut (2007).

Considering the above, it is no longer enough to take into account only cost and technical factors when selecting transport-storage system components. One can say that this would be highly insufficient.

The hitherto experience indicates that it is difficult to correct errors made at the design stage, whereby the operating costs keep increasing. According to the current views on this subject, a qualitative assessment of the operating costs of products or more broadly, technical systems at the design stage should involve: a model of system operational quality assurance, an investor promotional strategy concerning the operational values of the system being created, the group qualification of the system, stemming from the adopted pragmatics of its operation.

Operational worthiness is a technical consideration for mainly the designer optimizing the system to obtain the minimum costs of its construction and lowering its quality only to a degree which will not adversely affect its performance and will not result in the lodging of complaints by the investor. In addition, one should optimize the transport-storage logistic system from the point of view its function (the proper choice of system components), which will contribute to the satisfaction of the investor who expects solutions minimizing operating costs as wells increasing safety and reliability. The technical, economic and social (ergological, ecological, safety) considerations are reconciled in the universally adopted Quality Standards. A technical system should also be assigned to a proper technical system classification group. Transport-storage logistic systems are usually placed in the group: "a system designed in such a way that its structural components can be replaced during preventive maintenance".

Despite the above determinants, design solutions are often based on the particular producer's intuition or many-year experience in the creation of systems for the average investor. The world trends indicate that the lifetime of technical systems continuously decreases and the interest in new generations of transport-storage systems steadily grows. At the same time as a result of the technological progress new systems are mostly created not through a significant improvement (based on conclusions drawn from operational experience) of the existing solutions, but through a general change of the system concept/philosophy because of new ergonomic, ecological, energy saving, work humanization, robotization, etc., requirements Korzen (1997), Korzen (1999).

The consequences of a system's potential behaviour and its operational effects should be foreseen already at the design stage and taken into account at the implementation stage.

Application of exergy in calculation of t-s systems

The whole exergy of a system can be divided into the following components: potential exergy, kinetic exergy, physical exergy, chemical exergy, nuclear exergy and other (e.g. connected with electromagnetic interaction, surface tension, etc.). For the investigation of the processes taking place in power equipment it is usually enough to take into account physical exergy and chemical exergy and if need be, kinetic exergy and potential exergy Urlich (1999).

$$B = B_f + B_{ch} + B_p + B_k \tag{1}$$

where:

B_f - physical exergy,

B_{ch} - chemical exergy,

B_p - potential exergy,

B_k - kinetic exergy.

Physical exergy is expressed by:

$$B_f = U - U_{ot} + (S - S_{ot})T_{ot} - p_{ot}(V - V_{ot}) \tag{2}$$

where:

U - internal energy,

S - entropy,

V - the system volume in a given state,

Uot, - internal energy,

Sot - entropy,

Vot - the system volume in a state of limited thermodynamic equilibrium with the environment, i.e. for the environment pressure and temperature (pot, Tot).

for a thermodynamic fluid

$$B_f = I - I_{ot} - (S - S_{ot})T_{ot} \tag{3}$$

where:

I - the enthalpy of the thermodynamic fluid in a given state,

I_{ot} - the enthalpy of the fluid in a given state and at the pressure and temperature of the environment.

imparted with work

$$B_f = W \tag{4}$$

Imparted with heat Q drawn from a source with constant temperature Tzc>Tot

$$B_f = Q\frac{T_{zc} - T_{ot}}{T_{zc}} \tag{5}$$

(it is equal to the work given up by the Carnot engine operating between heat sources with temperatures Tzc and Tot)

Imparted with heat Q drawn from a source with constant temperature Tzc<Tot

$$B_f = Q\frac{T_{ot} - T_{zc}}{T_{zc}} \tag{6}$$

(it is equal to the minimum work which should be supplied to transport heat Q, drawn from source with temperature Tzc, to the environment, i.e. equal to the work drawn by a left-running Carnot cycle operating between heat sources with temperatures Tzc and Tot)

Chemical exergy:

$$B_{ch} = \sum_i N_i(\mu_i - \mu_{iot}) \tag{7}$$

where:

N_i - the amount of moles in the i-th substance,,

μ_i and μ_{iot} - chemical potentials of the i-th substance in respectively the system and the environment.

Chemical exergy is equal to the maximum work which can be obtained when a considered substance passes from the state of limited equilibrium with the environment to the state of full thermodynamic (thermal, mechanical and chemical) equilibrium. In cases when the substance whose chemical exergy is to be determined does not occur in the environment, when calculating exergy one takes into account a chemical reaction whose products belong to the common components of the environment.

3. ANALYTICAL MODEL OF T-S SYSTEM

A closer analysis shows that in actual processes energy is not lost (we do not have in mind the energy conservation law here), but it is converted to another form, less suitable for sustaining the processes. An example here is the process of removing a pallet from the truck's floor in the cargo handling area at the entrance to the storehouse and placing it in a rack slot on the selected level. The energy spent on transporting the pallet vertically is partially recovered when the latter is being removed from the rack, minus only the energy needed to lift the fork carriage again. In this process the pallet acts as an energy accumulator.

For the exemplary store shown schematically in fig. 1 energy Q [Wh] is calculated from this equation

$$Q = Q_d + Q_w + Q_L + Q_V + Q_{ah} + Q_{Ma} + Q_{Me} + Q_S \tag{8}$$

where:

Q_d – the heat penetrating through the walls, ceiling and floor of the cold room;

Q_w – the heat removed from the merchandise;

Q_L – the heat given up by the air unintentionally brought into the cold room;

Q_V – the heat generated by the operating air cooler fan;

Q_{ah} – if need be, the heat generated during defrosting;

Q_{Ma}– the heat emitted by the lighting, the machines and similar equipment in the store;

Q_{Me}– the heat emitted by people;

Q_S – the heat constituting a standby in case of unforeseen changes in the store's thermal load.

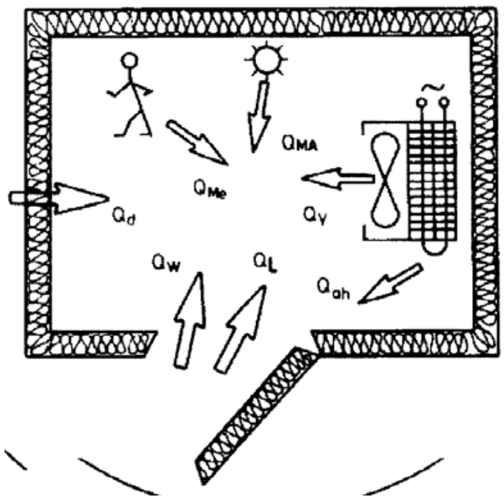


Fig. 1. Energy balance in exemplary store.

Equation (8) does not take into account, for instance, the heat which could be recovered through ventilation by proper equipment and directed to heat receivers. Moreover, the heat of condensation, generated during the operation of the refrigerating system (fig. 1) is regarded as waste heat, but it could be sufficient to heat service water in, for example, a transport-storage system consisting of a freezer and an abattoir. One can imagine the side-by-side operation of an abattoir which uses the energy remaining from the operation of a freezer (a cold store in some cases) to heat up service water for production purposes.

Taking into account the above considerations, a new approach to the optimization of transport-storage systems is needed. In the literature on the subject one can find multicriterial methods for the optimization of the drive/transfer routes Korzen (1997), Korzen (1999). Hence there is a need to introduce a new parameter to describe the energy conversions involved.

It is assumed that in a model case the cargo unit is on a semitrailer from where it is taken by a forklift truck in the cargo handling area at the entrance to the storehouse. Then it is transported to the identification point and to a power-driven roller conveyor which transfers the cargo unit to the face of the high-storage zone and to the stapler's delivery-reception area. The automatically controlled stapler places the cargo unit in the rack slot with the indicated location address. The process of release from store proceeds similarly but in reverse Lewandowska (2008), Szargut (2007).

The collection of a pallet by a forklift truck or a stapler involves covering a distance and energy expenditure on lifting or lowering the pallet (including forking). In order to simplify the model, it is assumed that the energy expended on lifting the pallet is recovered in the process of its lowering, but this applies to only electric forklift trucks.

For a forklift truck the energy needed to lift a pallet from a conveyor is expressed by formula (9). The energy needed to shift the empty fork (Es) is expressed by a similar formula (the pallet weight is subtracted from weigh m). A proper fork carriage weight should be assumed for each forklift truck.

$$E_p = m \cdot g \cdot h \tag{9}$$

where:
m - the weight of the pallet and the fork,
g - gravitational acceleration,
delta h - a height difference.

The energy needed to cover the forklift truck distance (with or without a cargo unit) is calculated from equation (10), assuming that the forklift truck resistance force must be overcome by a proper amount of kinetic energy. The type of forklift truck drive (diesel, electric) is taken into account.

$$E_K = R_L = \left(\xi + 0{,}15 \cdot \frac{V}{10}\right) \cdot G_L + 150 \cdot \chi + 3{,}5 \cdot \frac{V^2}{10} \tag{10}$$

where:
ξ – a resistance coefficient,
V – speed,
G_L – engine weight,
χ – the number of truck axles.

In the case of a stapler, the particular components of its work cycle are modelled similarly as for the forklift truck.

The energy needed to service the pallet by the forklift truck in the transport-storage system is expressed by this equation

$$E_E = E_P + E_S + E_Z + E_C + E_W \tag{11}$$

where:
E_P - the energy needed to lift a pallet with a cargo unit,
E_S - the energy expended to lift the empty fork carriage,
E_Z - the energy needed to carry the pallet with the cargo unit,
E_C - the energy needed for the passage of the truck without the cargo unit,
E_W - the energy expended on forking.

Since, as opposed to transport by forklift trucks and staplers, the pallet transported by a (roller) conveyor does not change its potential energy during the whole duration of the transport (and only a change of this energy is considered to be work), the whole electrical power of the conveyor drive converts to the energy expended to overcome the resistance to motion of the transporting device.

Ideally, in a transport-storage system there should be energy needed to perform work, e.g. to convey a pallet from one place to another in the transport-storage system. When this task is executed, a certain amount of energy arises which is simply wasted. It is assumed that this energy is exclusively thermal energy. It can be estimated using formulas (12), (13) and (14).

The heat brought in with fresh air is calculated from this equation

$$Q_P = n \cdot V \cdot \rho \cdot \Delta h \tag{12}$$

where:
n - an air change coefficient [1/day],
V - storage volume [m3],
ρ - air density [kg/m3],
Δh - a difference in air specific enthalpy [KJ/kg].

The heat generated by the lighting is expressed by this relation

$$Q_{os} = n \cdot q_{os} \tag{13}$$

where:
n - the number of lighting units,
Q_{os} - the unit power of the installed lighting depending on the illuminance and kind of lighting [W].

The heat generated by the forklift trucks, the staplers and the conveyors is expressed by this relation:

$$Q_V = n \cdot P \cdot (1 - \mu) \tag{14}$$

where:
n - the number of forklift trucks/stapler/conveyors,
P - the power applied to the device [W],
μ - the factor of the power needed to transport the cargo unit.

The heat generated by the personnel working in the store is expressed by this relation:

$$Q_L = n \cdot q_M \tag{15}$$

where:
n - the number of persons present in the store,
q_M - the flux of thermal energy generated by a single person [W].

On the basis of the energy consumption (including the consumption of electric energy, diesel fuel or gas, etc.) data for a typical transport-storage system one can calculate the amount of energy needed to obtain the desired effects, i.e. the energy expenditure per cargo unit (e.g. the europallet) in the transport-storage system.

For a transport-storage system in which pallets from the cargo handling area are collected by a forklift truck, transported to a roller conveyor, transferred to a stapler and placed by the latter in a rack slot, the system capacity is 12 europallets per hour. Exemplary results of calculations for such a system, using the model shown in fig. 2, are presented below.

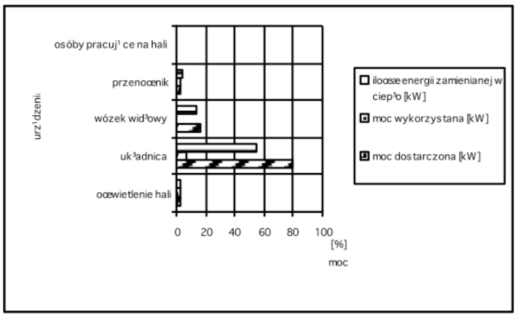


Fig. 2. Energy conversion relationships for transport-storage system. (personnel working in storeroom, conveyor, forklift truck, stapler, storeroom lighting, equipment, amount of energy converted into heat, used up power, applied power, power)

The diagram shows that a forklift truck equipped with a 4 kW engine, working in the transport-storage system, generates 3.4 kW of heat and its capacity factor is about 0.15 (the forklift truck is exceptionally badly matched). In the set of staplers this coefficient is slightly better – amounting to 0.31. In addition, the particular devices generate about 77 kW of heat. This information can be useful for the storehouse manager with regard to the selection of heating or air conditioning systems (or refrigerating units in the case of freezers). By evaluating the appropriateness of a logistic system from the energy point of view one can manage it properly, i.e. assign tasks to the particular devices.

In papers Korzen (1997) and Korzen (1999) it is suggested to take into account the following factors in an evaluation of transport-storage system appropriateness (the optimum choice of system components):

- the storage area utilization factor,
- the storage space utilization factor, etc.,
- the cost of passage of a single pallet through the store.

It is also proposed to introduce another factor – the energy consumption for the passage of a single cargo unit through the store – calculated from this formula

$$\zeta = \frac{\sum E_{delivered} - \sum Q}{\eta} \qquad (16)$$

where:

$\sum Q$ - the sum of heat yield [Wh],

η - the capacity of the transport-storage system [units.].

One can also assume a certain interval of parameter ζ. for which the optimization of the transport-storage system will not raise any reservations.

4. CONCLUSION

The benefits of an exergetic analysis are:

Unlike energy efficiencies, exergy efficiencies constitute an easy to evaluate and interpret measure of system excellence.

By calculating energy losses for the particular links of a complex system one can indentify the degree, causes and location of its imperfections. Thus an exergetic analysis is particularly useful for solving optimization problems.

Exergy is a universal measure of the practical usefulness of the different forms of energy and so it is particularly suitable for the analysis of complex systems.

An exergetic analysis (as a component of LCA) can significantly help in the assessment of the effect of a given process on the natural environment and also in the evaluation of the economic aspects (thermoeconomics, exergoeconomics). By reducing exergy losses one can reduce the operating costs of equipment, but this usually entails an increase in investment expenditures.

A major factor affecting energy consumption, but not automatically included in the presented transport-storage system model, is the way in which information directly relating to the management of the analyzed transport-storage system is transmitted. This is reflected in the number of kilometres driven by the forklift truck depending on the terminal used: a mobile radio terminal, a terminal with base station or a stationary terminal. In the latter case, information in a transport-storage system is usually printed on paper, which requires direct contact between the forklift truck operator and the storehouse manager.

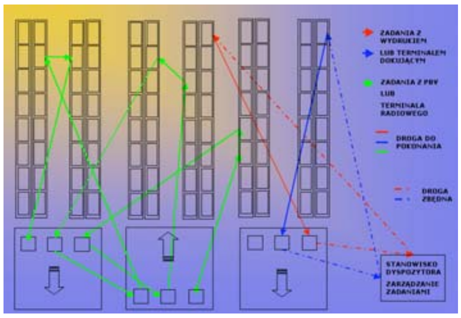


Fig. 3. Use of terminals in transport-storage systems. (tasks with printout or docking terminal, tasks with PBV or radio terminal, distance to cover, unnecessary distance, dispatcher station, management of tasks)

Storehouse operation with the use of: a (radio) terminal without a base station, a terminal with a base station, and a traditional system with a printout (a stationary scanner) is marked by respectively green, blue and red.

REFERENCES

Korzeń Zb.: Logistic systems of materials handling and storage (in Polish). vol. 1, IliM, Poznan, 1997.

Korzeń Zb.: Logistic systems of materials handling and storage (in Polish). vol. 2, IliM, Poznan, 1999.

Lewandowska M.: Exergy and sustained development (in Polish), lecture delivered at the Polish Academy of Sciences, Warsaw, 2008.

Szargut J.: Exergy, Guide: calculations and applications (in Polish), Silesian Polytechnic Publishing House, Gliwice, 2007.

Szargut J., Petela R.: Exergy (in Polish), Wydawnictwo Naukowo-Techniczne, Warsaw, 1965.

Ullrich H.-J.: Refrigerating Engineering (in Polish), IPPU MASTA, Gdansk, 1999.

STOCHASTIC ODE AND PDE MODELS OF THE CURRENT STOCK OF DIVISIBLE PRODUCTIONS

Kopytov E.A.[a], Guseynov Sh.E.[b], Puzinkevich E.[c]

[a]Transport and Telecommunication Institute
[b]Institute of Mathematical Sciences and Information Technologies, University of Liepaja; Transport and Telecommunication Institute
[c]Transport and Telecommunication Institute

[a]kopitov@tsi.lv, [b]sh.e.guseinov@inbox.lv, [c]edvin@dau.lv

ABSTRACT
In the given paper we investigate the problem of constructing continuous and unsteady mathematical models for determine the volumes of current stock of divisible productions in one or several interconnected warehouses using apparatus of mathematical physics and continuum principle. It is assumed that time of production distribution and replenishment is continuous. The constructed models are stochastic, and have different levels of complexity, adequacy and application potentials. The simple model is constructed using the theory of ODE, for construction of more complex models it is applied the theory of PDE. Besides, provided some additional conditions the finite-differenced model for determination of random volume of divisible homogeneous production is constructed, and this finite differenced mathematical model makes possible to determine one of possible trajectories of the random quantity. All constructed models can be used for on-line monitoring of the dynamics of the productions random volumes.

Keywords: inventory control model, current stock, divisible production, equations of mathematical physics

1. INTRODUCTION

One of the central problems of the inventory control theory is to find an optimal or quasi optimal solution to the task of ordering productions to be supplied, and main result of the task is the answer on two basic questions: how much to order and when to order. Of no less interest it is the task of determining the current stock of certain production (sold by the piece or indivisible production and dry or divisible production) at any given moment of a fixed time span, with any random factors taken into account. By "current stock" we denote the quantity (volume) of the production accumulated in the stock, which is used for regular distribution (i.e. replenishment). Quite a lot of different types of models of varying complexity, purpose and adequacy have been developed in the inventory control theory. Most of the existing mathematical models in this theory consider indivisible produtions (Kopytov et al 2007; Ashmanov 1980; Nikaido 1968). We can classify these models taking in account different their properties: deterministic and stochastic, linear and nonlinear, single- and multi-product, discrete and continuous models, and etc. (Nikaido 1968).

The present paper studies construction of continuous and unsteady mathematical models for calculating the volume of current stock of divisible production "from scratch" using apparatus and equations of mathematical physics. The suggested models are stochastic ones and have different levels of complexity, adequacy and application potentials. The simple models are constructed using the theory of ordinary differential equations, for construction of more complex models it is applied the theory of partial differential equations.

2. STOCHASTIC ODE MODEL FOR DETERMINING THE VOLUME OF THE CURRENT STOCK OF THE HOMOGENEOUS DIVISIBLE PRODUCTION

In the present section we construct the continuous stochastic mathematical model for determining the volume of current stock of divisible production. For this purpose, we will use the apparatus of mathematical physics and the continuum principle (Tikhonov and Samarsky 2004); as modelling language will be chosen language of ODE. Before introducing the simplifying assumptions, which are required for modeling, as well as variables, parameters and functions that describing and coupling the initial data of the simulated process with unknown quantities of the current stock dynamics, we will consider briefly the issue of stochasticity of the mathematical model under construction. Namely, to construct the stochastic (i.e. not deterministic) model, we can proceed in the following two ways:

– the current stock to be determined is not supposed to be an accidental quantity, but after the introduction of a change rate the constructed model is supplied with all random factors which visibly influence unknown rate of the current stock change. In this case the obtained relation (in the form of the above mentioned ODE) with regard to unknown volume of the current stock and rate of its change is a functional relationship among unknown volume, rate of its change, and accidental quantities (factors) influencing the current stock dynamics. In other words, in the obtained model, unknown volume, which initially did not seem to be assumed as an accidental value (stochastic value of a random function, to be more specific), due to the obtained ODE and corresponding conditions (initial conditions, conditions of co-ordination, etc.) appears dependent on the random quantities taken into account, i.e. unknown volume of the current stock is a function of the accidental quantities;

– the current stock is initially taken to be a random quantity, and this suggestion is taken into account when constructing the model.

The first of these ways is selected for the description of the mathematical model that will follow. It is worth mentioning in the way of a preliminary note that this choice will result in the construction of a stochastic model represented by the Ito-type differential equation (Ito 1987; Milstein 1995; Kuznetsov 2007; Diend 1990).

Now we can start constructing the mathematical model "from the scratch". Let us assume that the current stock volume of the considered homogeneous divisible production at the moment t equals to $x(t)$. It is required that $x(t)\in C[T_s,T_e]$; $\exists x'(t)\ \forall t\in[T_s,T_e]$ where $[T_s,T_e]$ is a segment of time during which the dynamics of the current stock change is being studied, by T_s and T_e we denote the initial and final moments of this period of time, respectively. The requirement $x(t)\in C[T_s,T_e]$ is easy to interpret economically, and it is met if we assume that the current stock $x(t)$ is being constantly distributed/replenished. The requirement $\exists x'(t)\ \forall t\in[T_s,T_e]$ is a purely mathematical one, i.e. it is necessary to ensure a mathematical correctness of the model.

If an increase of the current stock volume $x(t)$ is as

$$\Delta x(t)\overset{def}{\equiv} x(t+\Delta t)-x(t),\ \Delta t>0,\ t+\Delta t\le T_e,$$

then

$$\frac{dx(t)}{dt}\equiv\lim_{\Delta t\to 0}\frac{\Delta x(t)}{\Delta t}, \tag{1}$$

and this quantity designates the change rate of the current stock volume at a given time t.

The rate $\frac{dx(t)}{dt}$ derived from (1) is completely analogous to the rate of a material point of continuous medium moving in metric space. It is then useful to find out the factors or reasons causing the change $x(t)$ and, consequently, trigger the existence of $\frac{dx(t)}{dt}$.

With this aim in view, the following functions are introduced: $S(t,x(t))$ describing a continuous replenishment of the current stock and $C(t,x(t))$ describing a continuous distribution of the current stock. Then the difference $S(t,x(t))-C(t,x(t))$ is a measure of the change of the current stock volume, i.e.

$$\frac{dx(t)}{dt}=S(t,x(t))-C(t,x(t)). \tag{2}$$

Let us work out the functions that make up the right side of the equation (2), namely functions $S(t,x(t))$ and $C(t,x(t))$ in detail. The function of continuous replenishment $S(t,x(t))$ consists of three additive components, namely, from regulated replenishment of the stock, which is designated as $S_{reg.}(\bullet)$; from unregulated replenishment $S_{unreg.}(\bullet)$; and from random replenishment (for instance, a random stock replenishment due to an exceptionally high quality of production or because of an expected sudden deficit of particular products, etc.), which can be described mathematically as a random quantity $X_S(t)$ that designating the total volume of production that have been delivered into a particular warehouse from random and/or non-random sources by the time t , with all random circumstances taken into account. It is assumed for all types of replenishment that all orders are instantaneously executed, i.e. the shipping time for particular supplies is not considered in the present work. Let us interpret the introduced functions:

1) the function $S_{reg.}(\bullet)$ can be interpreted as "one hundred per cent" (guaranteed) constant replenishment of the current stock of divisible production, i.e. replenishment of the current stock that takes place regularly according to a contract during the segment $[T_s,T_e]$, with the volume of such replenishment being either constant (i.e. $S_{reg.}\equiv const.$) or depending on t (i.e. being a function of the argument time $S_{reg.}=S_{reg.}(t)$, or else being functionally dependent on $x(t)$ (i.e. $S_{reg.}=S_{reg.}(t,x(t))$);

2) the function $S_{unreg.}(\bullet)$ obviously depends on t and functionally on $x(t)$, and also on a certain quantity $x_0(t)$, which designates the minimal volume of stock in a particular warehouse necessary for administering unregulated stock replenishment on condition that such replenishment is guaranteed. In other words, $S_{unreg.}=S_{unreg.}(t,x(t),x_0(t))=k_0\cdot x(t)\cdot\delta(x(t),x_0(t))$, where k_0 is a proportion coefficient, and the function $\delta(x(t),x_0(t))$ is an indicator function, which has the form

$$\delta(x(t),x_0(t))=\begin{cases}1, & if\ x(t)\le x_0(t),\\ 0, & if\ x(t)>x_0(t);\end{cases} \tag{3}$$

3) the random quantity $X_S(t)$ determines the total volume of production that was delivered into the

warehouse by the time t due to random circumstances from random and/or non-random sources. Then the quantity $X_S(t+\Delta t)$ designates the sum total of all random deliveries by the time $t+dt$, where dt is an elementary interval of time (on analogy with the terminology of mathematical physics), and $0<dt\ll 1,\ t+dt\le T_e$. Consequently, it is possible to introduce a stochastic differential of a random process $X_S(t)$, namely, the quantity

$$dX_S dt \overset{def}{\equiv} X_S(t+dt)-X_S(t),$$

which determines a random addition to the current stock of divisible productions during the elementary interval of time dt.

Now the function $C(t,x(t))$ that is contained in the right-hand side of the equation (2) and describes the dynamics of the continuous distribution of the current stock of divisible productions can be looked at in more detail. The function of continuous distribution $C(t,x(t))$ consists of four additive components: regulated distribution which is denoted as $C_{reg.}(\bullet)$; unregulated distribution $C_{unreg.}(\bullet)$; possible losses $C_{\text{loss}}(\bullet)$ of divisible productions which take place during holding and distribution processes (for example, for petroleum productions it is evaporation, for grain main reasons of losses are gnawing animals and inundation); and random distributions (similar to random replenishment, there can be circumstances due to which random distribution takes place) that can be mathematically presented as a random quantity $X_C(t)$ designating the total volume of productions that was taken away from the warehouse by the time t due to random circumstances. Let us now interpret the introduced functions:

1) the function $C_{reg.}(\bullet)$ can be interpreted as "strong" (guaranteed) constant distribution of the current stock of divisible productions, i.e. the volume of the current stock that is regularly taken away from the warehouse according to contracts during the segment $[T_s,T_e]$, with the volume of such distribution being either constant (i.e. $C_{reg.}\equiv const.$) or depending on t (i.e. being a function of the argument time $C_{reg.}=C_{reg.}(t)$, or else being functionally dependent on $x(t)$ (i.e. $C_{reg.}=C_{reg.}(t,x(t))$);

2) the function $C_{unreg.}(\bullet)$ depends on the time t and functionally on $x(t)$ in general, as well as on a certain threshold function $x_1(t)$, which determines the stock volume of divisible productions allowing for its unregulated distribution, $C_{unreg.}=C_{unreg.}(t,x(t),x_1(t))$. In order to find an analytical expression of the function $C_{unreg.}(t,x(t),x_1(t))$ the following assumptions can be made:

- under $x(t)\to\infty$ must be $C_{unreg.}(t,x(t),x_1(t))\to k_1$, where the quantity k_1 is the capacity of distributing the stock volume of divisible productions from the warehouse in the sense that whatever the stock replenishment (i.e. the quantity $\max\limits_{t\in[T_s,T_e]} S(t,x(t))$, the warehouse can not possibly distribute the stock of divisible productions measured as k_1 during the entire considered time segment $[T_s,T_e]$;
- under $x(t)\to k_2\equiv const.$, where k_2 is an averaged value of the replenishment volume that allows for unregulated distribution, must be

$$C_{unreg.}(t,x(t),x_1(t))\to\begin{cases}0, & if \quad x_1(t)\ge k_2,\\ \dfrac{k_1}{2}, & if \quad x_1(t)<k_2.\end{cases}$$

The last two suppositions allow for determining unknown analytical form of the function $C_{unreg.}(t,x(t),x_1(t))$:

$$C_{unreg.}(t,x(t),x_1(t))=k_1\cdot x(t)\cdot\frac{1-\delta(x(t),x_1(t))}{x(t)+k_2},$$

where the indicator function $\delta(x(t),x_1(t))$ has the same sense/value as in determining the function $S_{unreg.}(t,x(t),x_0(t))$; it is derive by formula (3) with the corresponding substitution of $x_1(t)$ for $x_0(t)$;

3) the function $C_{loss}(\bullet)$ describes possible losses of the divisible productions current stock in storage and distribution. For instance, if we have the oil productions stock, losses will result from the evaporation and/or from the leakage through the reservoirs; if we have the agricultural productions stock (wheat, rice, meal, and the like), there will be unavoidable losses caused by pests, flood, strong winds, etc. Apparently, the value of these losses is a random one. Though, concluding the expression for the losses' function $C_{loss}(\bullet)$, we consider it reasonable to split these losses into somehow "normal/predictable" losses and into "abnormal/extraordinary" ones. Reasonability of this splitting lies in the following: any enterprise engaged in the processes of storing/distributing of the divisible vulnerable productions (for example, perishables, productions attractive for insects and rodents and the like, productions easily affected by winds and humidity and the like) should envisage in their model the parameter describing the value of the "normal/predicted" loss (for instance, in the form of a constant – the upper limit of a possible loss; in the form of a linear function – some reasonable and somehow unpredictable percent of loss of the total productions volume; etc.). But besides this accounted/envisaged value of the "normal/predictable" loss in the processes of storing-distributing of the divisible productions there

may occur some other a priori unpredictable losses which damage may greatly exceed that of the "normal/predicted" loss. Therefore, in the given paper we'll be building the loss functions $C_{loss}(\bullet)$ with the account of both normal/predictable" losses and "abnormal/extraordinary" ones. Function $C_{loss}(\bullet)$ in the general case depends on the time t as on the argument; functionally on the volume of the current stock $x(t)$; and on two more functions $x_2(t)$ и $x_3(t)$, which meaning is the following. Function $x_2(t)$ determines the most favorable scenario of the loss at each fixed moment of time $t \in [T_s, T_e]$; this function, as said above, may be chosen, for example, as a constant – the upper limit of the possible "normal/predictable" loss, or as a linear function – a predicted loss percent of the total production volume. Function $x_3(t)$ determines a less favorable scenario (average, for example) of the loss at each fixed moment of time $t \in [T_s, T_e]$.

Thus, $C_{loss} = C_{loss}(t, x(t), x_2(t), x_3(t))$. To find the analytical expression of the function $C_{loss}(t, x(t), x_2(t), x_3(t))$, we'll make the following assumptions:

- at $x(t) \to \infty$, that is at increasing the volume of the current stock, the formula $C_{loss}(t, x(t), x_2(t), x_3(t)) \to \max\limits_{t\in[T_s,T_e]} x_2(t)$ must be valid, where $\max\limits_{t\in[T_s,T_e]} x_2(t)$ is the power of the loss for the whole considered period of time $[T_s, T_e]$;
- if $x(t) \le x_2(t),\ t \in [T_s, T_e]$, the loss process must stop, i.e. $C_{loss}(t, x(t), x_2(t), x_3(t)) \equiv 0$;
- if $x(t) > x_2(t),\ t \in [T_s, T_e]$, than under the condition $x(t) \to x_3(t),\ t \in [T_s, T_e]$ the formula $C_{loss}(t, x(t), x_2(t), x_3(t)) \to \frac{1}{2} \cdot \max\limits_{t\in[T_s,T_e]} x_2(t)$ must be valid.

The three former assumptions allow us to determine the requested analytical form of the function $C_{loss}(t, x(t), x_2(t), x_3(t))$:

$$C_{loss}(t, x(t), x_2(t), x_3(t)) = \\ = \max_{t\in[T_s,T_e]} x_2(t) \cdot x(t) \cdot \frac{1 - \delta(x(t), x_2(t))}{1 + \dfrac{x_3(t) - x_2(t)}{x(t) - x_2(t)}},$$

where the indicator function $\delta(x(t), x_2(t))$ is determined by formula (3) at a corresponding change of $x_0(t)$ for $x_2(t)$;

4) the random quantity $X_C(t)$ designates the total volume of productions that has been removed from the warehouse by the time t due to random circumstances. Then $X_C(t+\Delta t)$ designates the sum total of random distribution by the time $t + dt$, where dt is an elementary interval of time, with $0 < dt \ll 1,\ t + dt \le T_e$. It follows that a stochastic differential of a random process $X_C(t)$ can be introduced, namely the quantity $dX_C dt \overset{def}{\equiv} X_C(t+dt) - X_C(t)$, which designates a random distribution of the current stock of divisible production during the elementary interval of time dt.

Thus, taking into account the above specification of functions $S(t, x(t))$ and $C(t, x(t))$ the differential the equation (2) takes on form

$$dx(t) = S_{reg.}(t, x(t))dt + k_0 \cdot x(t) \cdot \delta(x(t), x_0(t))dt + dX_S - \\ - C_{reg.}(t)dt - k_1 \cdot x(t) \cdot \frac{1 - \delta(x(t), x_1(t))}{x(t) + k_2} dt - \\ - \max_{t\in[T_s,T_e]} x_2(t) \cdot x(t) \cdot \frac{1 - \delta(x(t), x_2(t))}{1 + \dfrac{x_3(t) - x_2(t)}{x(t) - x_2(t)}} dt - dX_C. \quad (4)$$

The following initial condition (5) must be added to (4):

$$x(t)\big|_{t=T_s} = x_s. \quad (5)$$

The obtained equation (4) is the stochastic differential equation with respect to unknown random volume $x(t)$ of the current stock of divisible production; and this equation together with the initial condition (5) constitutes the Cauchy problem for determine required volume $x(t)$ of the current stock of divisible production.

It is significant that the summands dX_S and dX_C in the right-hand side of the equation (4) are not differentials in the usual sense; these summands must be understood in the sense of the Ito stochastic differential (Kuznetsov 2007). Besides, the indicator functions $\delta(x(t), x_i(t))\ \left(i = \overline{0,2}\right)$ in the right-hand side of the equation (4), derived according to formula (3), are not differentiated functions, which is caused by non-differentiability of the functions $S(t, x(t))$ and $C(t, x(t))$. Consequently, the requirement $\exists x'(t)\ \forall t \in [T_s, T_e]$, which was identified in the beginning of this section as a necessary condition for mathematical correctness of the model, will not be met. That is why in order to render a mathematical sense to the stochastic differential equation (4), it is necessary to introduce into is a corresponding amendment-condition. An easily realizable amendment might be substitution of the scalar functions $\delta(x(t), x_i(t))\ \left(i = \overline{0,2}\right)$ by the corresponding quadratic functions (which are smooth functions) on the sections $[0, x_i(t)]\ \left(i = \overline{0,2}\right)$, respectively. Such substitution is easily performed on the ground of natural and apparent requirements

$$\hat{\delta}\left(x(t), x_i(t)\right)\Big|_{x(t)=0} = 1 \quad \left(i=\overline{0,2}\right);$$

$$\hat{\delta}\left(x(t), x_i(t)\right)\Big|_{x(t)=x_i(t)} = 0 \quad \left(i=\overline{0,2}\right);$$

$$\int\limits_0^{x_i(t)} \hat{\delta}\left(x(t), x_i(t)\right) dx(t) = x_i(t) \quad \left(i=\overline{0,2}\right);$$

and in the result the following differential functions are obtained:

$$\hat{\delta}\left(x(t), x_i(t)\right) = -\frac{3}{x_i^2(t)} \cdot x^2(t) + \frac{2}{x_i(t)} \cdot x(t) + 1 \quad \text{when}$$

$$x(t) \in \left[0, x_i(t)\right] \quad \left(\forall i=\overline{0,2}\right).$$

It is obvious that other substitutions-approximations are possible (for instance, by splines, etc.), which in comparison to the described above approach, i.e. approximation of scalar functions $\delta\left(x(t), x_i(t)\right)$ $\left(i=\overline{0,2}\right)$ by the corresponding smooth functions $\hat{\delta}\left(x(t), x_i(t)\right)$ $\left(i=\overline{0,2}\right)$ provide a higher level of precision. In this sense, there is certain ambiguity in determining the functions $\hat{\delta}\left(x(t), x_i(t)\right)$ $\left(i=\overline{0,2}\right)$, and hence ambiguity of the right-hand side of the equation (4).

Thus, instead of the differential equation (4) having no mathematical sense a mathematically correctly formulated differential equation can be written down:

$$dx(t) = S_{reg.}\left(t, x(t)\right)dt + k_0 \cdot x(t) \cdot \hat{\delta}\left(x(t), x_0(t)\right)dt + dX_S -$$

$$-C_{reg.}(t)dt - k_1 \cdot x(t) \cdot \frac{1-\hat{\delta}\left(x(t), x_1(t)\right)}{x(t)+k_2}dt -$$

$$-\max_{t\in[T_s, T_e]} x_2(t) \cdot x(t) \cdot \frac{1-\hat{\delta}\left(x(t), x_2(t)\right)}{1+\dfrac{x_3(t)-x_2(t)}{x(t)-x_2(t)}}dt - dX_C.$$

It is important to note the following with regard to the obtained stochastic differential equation. It is obvious that stochastic differentials of the random processes $X_S(t)$ and $X_C(t)$ can be conjoined if a random quantity $X(t)$ designating the total volume of productions that were delivered to and distributed from, the warehouse by the time t due to random circumstances. Then we can indeed determine a stochastic differential of the random process $X(t)$ as

$$dXdt \overset{def}{\equiv} X(t+dt) - X(t),$$

and this quantity will determine the change dynamics of the random volume of the divisible productions' stock during the elementary interval of time dt, namely $dXdt > 0$ designates a random replenishment of stock during the elementary interval of time dt, and $dXdt < 0$ designates a random distribution of stock during the elementary interval of time dt. With this specification in taken into account, the last differential equation takes the following final form:

$$dx(t) = S_{reg.}\left(t, x(t)\right)dt + k_0 \cdot x(t) \cdot \hat{\delta}\left(x(t), x_0(t)\right)dt -$$

$$-C_{reg.}(t)dt - k_1 \cdot x(t) \cdot \frac{1-\hat{\delta}\left(x(t), x_1(t)\right)}{x(t)+k_2}dt -$$

$$-\max_{t\in[T_s, T_e]} x_2(t) \cdot x(t) \cdot \frac{1-\hat{\delta}\left(x(t), x_2(t)\right)}{1+\dfrac{x_3(t)-x_2(t)}{x(t)-x_2(t)}}dt + dX. \tag{6}$$

where $t \in \left[T_s, T_e\right]$; functions $S_{reg.}\left(t, x(t)\right)$, $C_{reg.}(t)$ and $x_i(t)$ $\left(i=\overline{0,3}\right)$, as well as numerical parameters k_i $\left(i=\overline{0,2}\right)$ have the described above values and are viewed as the given initial data of the problem under consideration; the functions $\hat{\delta}\left(x(t), x_i(t)\right)$ $\left(i=\overline{0,2}\right)$ are determined by the following formulas:

$$\hat{\delta}\left(x(t), x_0(t)\right) = \begin{cases} 0, \ \ if \ \ x(t) > x_0(t), \\ -\dfrac{3}{x_0^2(t)} \cdot x^2(t) + \\ +\dfrac{2}{x_0(t)} \cdot x(t) + 1, \ \ if \ \ x(t) \le x_0(t); \end{cases} \tag{7}$$

$$\hat{\delta}\left(x(t), x_1(t)\right) = \begin{cases} 0, \ \ if \ \ x(t) > x_1(t), \\ -\dfrac{3}{x_1^2(t)} \cdot x^2(t) + \\ +\dfrac{2}{x_1(t)} \cdot x(t) + 1, \ \ if \ \ x(t) \le x_1(t); \end{cases} \tag{8}$$

$$\hat{\delta}\left(x(t), x_2(t)\right) = \begin{cases} 0, \ \ if \ \ x(t) > x_2(t), \\ -\dfrac{3}{x_2^2(t)} \cdot x^2(t) + \\ +\dfrac{2}{x_2(t)} \cdot x(t) + 1, \ \ if \ \ x(t) \le x_2(t). \end{cases} \tag{9}$$

The stochastic differential equation (6) together with the initial condition (5), the initial given data $S_{reg.}\left(t, x(t)\right)$, $C_{reg.}(t)$, $x_i(t)$ $\left(i=\overline{0,3}\right)$ and k_i $\left(i=\overline{0,2}\right)$, as well as approximating smooth indicator functions (7)-(9) is the Cauchy stochastic problem. It is a stochastic mathematical model for determining the current stock volume of divisible homogeneous production. Unfortunately, the given paper did not investigate the issue of finding an analytical solution of the constructed model (5)-(9). Nevertheless, as the following section will demonstrate, if we additionally require that the random process $X(t)$ will be the Markov random process, then the constructed continuous model (5)-(9) can be easily realized numerically (Ito 1987).

Remark 1. *Stochastic equation (6) shows that irrespective of the sign of the quantity* $x_s = x(t)\big|_{t=T_s}$ *(i.e. irrespective of the initial condition (5)), unknown* *function* $x(t)$ *can assume a negative value, which, at first sight, does not make any economic sense. But a possibility of such a case was purposefully taken into account prior to constructing mathematical model (5)-(9), and this case can be understood as a debt of the warehouse with regard to the current stock of divisible production. Besides, a closer look at the left-hand side of the equation (6) (as well as the equations (2) and (4)), it becomes obvious that there can be a case when* $\frac{dx(t)}{dt}<0$, *which means a negative rate if the quantity* $\frac{dx(t)}{dt}$ *is treated as the speed of a material point of the continuous medium in metric space, which has no physical sense. But if the quantity* $\frac{dx(t)}{dt}$ *in the considered problem designates the change rate of the volume* $x(t)$ *of the current stock at the time* $t\in[T_s,T_e]$, *then the case* $\frac{dx(t)}{dt}<0$ *corresponds to the situation whereby the volume* $x(t)$ *as a function of the time argument is a decreasing function, i.e. the accumulated stock of divisible productions in the warehouse is decreasing.*

3. CONSTRUCTION OF FINITE-DIFFERENCED MODEL FOR DETERMINATION OF RANDOM VOLUME OF DIVISIBLE HOMOGENEOUS PRODUCTION

In this section we offer a finite-differenced approximation of the mathematical model (5)-(9) for determination of current stock volume of divisible homogeneous production, which was constructed in the previous section. Besides, given some assumptions, we put forward a recurrent implicit differenced scheme for numeric determination of the random volume of divisible homogeneous production at given discrete moments of time.

Let us introduce the function

$$f(t,x(t))\overset{def}{\equiv}\begin{cases}S_{reg.}(t,x(t))+k_0\cdot x(t), & if\quad x(t)>x_0(t),\\ S_{reg.}(t,x(t))+\dfrac{3\cdot k_0}{x_0^2(t)}\cdot x^3(t)- & \\ -\dfrac{2\cdot k_0}{x_0(t)}\cdot x^2(t), & if\quad x(t)\le x_0(t)\end{cases}\quad -$$

$$-\begin{cases}\dfrac{1}{2}\cdot C_{reg.}(t,x(t))+k_1\cdot\dfrac{x(t)}{x(t)+k_2}, & if\quad x(t)>x_1(t),\\ \dfrac{1}{2}\cdot C_{reg.}(t,x(t))+\dfrac{3\cdot k_1}{x_1^2(t)}\cdot\dfrac{x^3(t)}{x(t)+k_2}- & \\ -\dfrac{2\cdot k_1}{x_0(t)}\cdot\dfrac{x^2(t)}{x(t)+k_2}, & if\quad x(t)\le x_1(t)\end{cases}\quad -$$

$$-\begin{cases}\max\limits_{t\in[T_s,T_e]}x_2(t)\cdot\dfrac{x(t)}{1+\dfrac{x_3(t)-x_2(t)}{x(t)-x_2(t)}}, & \\ +\dfrac{1}{2}\cdot C_{reg.}(t,x(t)), & if\quad x(t)>x_2(t),\\ \dfrac{1}{2}\cdot C_{reg.}(t,x(t))+\dfrac{3\cdot\max\limits_{t\in[T_s,T_e]}x_2(t)}{x_2^2(t)}\cdot\dfrac{x^3(t)}{1+\dfrac{x_3(t)-x_2(t)}{x(t)-x_2(t)}}- & \\ -\dfrac{2\cdot\max\limits_{t\in[T_s,T_e]}x_2(t)}{x_2(t)}\cdot\dfrac{x^2(t)}{1+\dfrac{x_3(t)-x_2(t)}{x(t)-x_2(t)}}, & if\quad x(t)\le x_2(t).\end{cases}\qquad(10)$$

Apparently, the function $f(t,x(t))$ is a random one since in its expression (10) the function of possible losses has been accounted

$$C_{loss}(t,x(t),x_2(t),x_3(t))=$$
$$=\max_{t\in[T_s,T_e]}x_2(t)\cdot x(t)\cdot\frac{1-\delta(x(t),x_2(t))}{1+\dfrac{x_3(t)-x_2(t)}{x(t)-x_2(t)}},$$

which were entered and determined at the previous stage. Without account of these losses the function $f(t,x(t))$ is an undetermined (i.e. non-random) function (Kopytov, Guseynov, Puzinkevich and Greenglaz 2010).

After introduction the function $f(t,x(t))$ on the formula (10) the stochastic equation (6) can be rewritten in a more compact way:

$$dx(t)=f(t,x(t))dt+dX(t),\qquad(11)$$

and this equation is a particular instantiation (namely, $f_1(t,x(t))\equiv f(t,x(t))$; $f_2(t,x(t))\equiv 1$) of a more general stochastic differential equation in the Ito form

$$dx(t)=f_1(t,x(t))dt+f_2(t,x(t))dX(t),\qquad(12)$$

where the functions $f_i(t,x(t))$ $(i=1,2)$ are supposed to be non-random functions, the random process $X(t)$ the Markov random process $X(t)$, and the quantity $dX(t)$ is understood in the sense of a stochastic differential Markov random process $X(t)$.

Under the mentioned assumptions, the Ito stochastic differential equation (12) allows for the following interpretation: for the stochastic differential $dX(t)$, which is contained in the right-hand side of the equation (12), the quantity $X(t)$ can be understood as a realized random quantity which assumes the given value $\tilde{x}=X(\tilde{t})$ at the moment $\tilde{t}\in[T_s,T_e]$. Moreover, due to the assumption that $X(t)$ is the Markov process the random quantity $X(\tilde{t}+dt)=\tilde{\tilde{x}}$, where $0<dt\ll 1$, $\tilde{t}+dt\le T_e$, has a density of probability $\rho(\tilde{\tilde{x}})=\rho(\tilde{t},\tilde{x};\tilde{t}+dt,\tilde{\tilde{x}})$. Then, if randomness of $\tilde{t}$ is

taken into account, the above speculation holds for $\forall t \in [T_s, T_e]$, i.e. for random $t \in [T_s, T_e]$, the random quantity $X(t+dt) = \tilde{\tilde{x}}$ where $0 < dt \ll 1,\ t+dt \le T_e$, is determined by the density of probabilities $\rho(\tilde{\tilde{x}}) = \rho(t, \tilde{x}; t+dt, \tilde{\tilde{x}})$ only if the random quantity $X(t)$ assumed the concrete value $\tilde{x}$ at the moment $t \in [T_s, T_e]$, i.e. if $X(t) = \tilde{x}$. This interpretation of the Ito stochastic differential equation (12) allows for rewriting the equation (12) in the finite-difference approximation, namely

$$x(t+\Delta t) - x(t) = f_1(t, x(t)) \cdot \Delta t +$$
$$+ f_2(t, x(t)) \cdot (X(t+\Delta t) - X(t)) =$$
$$= f_1(t, x(t)) \cdot \Delta t + f_2(t, x(t)) \cdot (X(t+\Delta t) - \tilde{x}).$$

If we accept

$$x(t) = f_2(t, x(t)) \cdot X(t) = f_2(t, x(t)) \cdot \tilde{x},$$

then we obtain a recurrent correlation

$$x(t+\Delta t) = f_1(t, x(t)) \cdot \Delta t + f_2(t, x(t)) \cdot X(t+\Delta t),$$

which can be used for a discrete definition of the value of unknown function $x(t)$. Indeed, if we break down the time segment $[T_s, T_e]$ into N elementary time spaces of the length Δt_i $\left(i = \overline{0, N-1}\right)$ we will obtain the discrete mesh

$$\hat{T} \overset{def}{\equiv} \left\{ t_i :\ t_{i+1} = t_i + \Delta t_i \ \left(i = \overline{0, N-1}\right),\ t_0 = T_s,\ t_N = T_e \right\},$$

and after designating

$$x_i \overset{def}{\equiv} x(t_i),\ \tilde{x}_i \overset{def}{\equiv} X(t_i) = \frac{x(t_i)}{f_2(t_i, x(t_i))},$$

it is possible to write down the following recurrent implicit differenced scheme for determining the quantity $x(t)$ numerically:

$$x_{i+1} = f_1(t_i, x_i) \cdot \Delta t_i + f_2(t_i, x_i) \cdot \tilde{x}_{i+1}, \tag{13}$$

where random quantities $\tilde{x}_{i+1}$ are determined by the density of probabilities

$$\rho\left(t_i, \frac{x_i}{f_2(t_i, x_i)}; t_{i+1}, \tilde{\tilde{x}}\right).$$

Remark 2. *Mathematical model (5)-(9) constructed in the Section 2 can be solved analytically with the help of integrals of Stratonovich and Ito (see (Kuznetsov 2007)) assuming a Markov nature of the random process $X(t)$. If this assumption is not made (or can not be made due to specificity of the particular task of inventory control), the question of how to analytically integrate the stochastic differential equation (9) remains, unfortunately, still open, and as mentioned before research into this issue was not undertaken in the present paper. As shown in (Diend 1990), though, with certain additional conditions but without assuming the Markov nature of the random process $X(t)$ an effective approximation of a stochastic differential equation such as (12), particularly the equation (11), which is the equation (6) in the mathematical model (5)-(9) constructed in the Section 2.*

Remark 3. *The constructed recurrent differenced scheme (13) together with the initial condition (5) is a finite differenced mathematical model for defining one of possible trajectories of the random quantity $x(t)$, i.e. the constructed finite differenced model (13); (5) allows for defining approximate values of the quantity $x(t)$ at the moments of time $t_i :\ t_{i+1} = t_i + \Delta t_i \ \left(i = \overline{0, N-1}\right),\ t_0 = T_s,\ t_N = T.$*

4. STOCHASTIC CONTINUOUS MODELS FOR SIMULTANEOUSLY DEFINING VOLUMES OF CURRENT STOCK OF DIVISIBLE PRODUCTION AT SEVERAL INTERCONNECTED WAREHOUSES

The present section suggests two stochastic continuous mathematical models for defining volumes of current stock of divisible homogeneous and heterogeneous productions at several interconnected warehouses simultaneously. For achieving this aim, similarly to the Section 2, apparatus of mathematical physics is used and principle of continuous medium, the language of the theory of partial differential equations is chosen as a modeling language. Because of paper's space limitations there is, unfortunately, no opportunity to present the entire chain of argumentation and all calculations related to constructing these models "from scratch"; they are only mathematically represented in what follows, with minimal explanation. Also, it is necessary to underline that in the given section some definitions introduced and employed in the three previous sections, the definitions $x_i(t)$ $(i = 1, 2)$, in particular, have different values which are being declared as soon as they are introduced.

So, $m \in \mathbb{N}$ warehouses are under consideration, and it is assumed that dynamics of the volume of divisible homogeneous production in all m warehouses is subject to the stochastic differential equation (6) which was obtained in the Section 2. For the stochastic differential $dX(t)$ that is contained in the right-hand side of the equation (6), the quantity $X(t)$ will be viewed as a realized random quantity which assumed the given value $\tilde{x} = X(t)$ at the time $t \in [T_s, T_e]$, i.e. the given warehouse has the volume of divisible homogeneous production $\tilde{x} = x(t)$ at the fixed time $t \in [T_s, T_e]$; as the course of constructing equation (6) shows, this volume can comprise both determined and random constituent volumes. Then the random quantity $X(t+dt) = \tilde{\tilde{x}}$, where $0 < dt \ll 1,\ t+dt \le T_e$, designates a random volume of homogeneous production in a particular warehouse at the moment $t+dt$ under the condition that the volume $\tilde{x}$ of homogeneous production was present in this very warehouse at the previous moment t. Consequently, it can be said that the random quantity $X(t+dt)$ has the density of probability $\rho(\tilde{\tilde{x}}) = \rho(t, \tilde{x}; t+dt, \tilde{\tilde{x}})$.

Since the continuous mathematical model (5)-(9) constructed in the Section 2 assumed the existence of one warehouse where there was volume $x_s = x(t)\big|_{t=T_s}$, of divisible homogeneous foods at the initial moment of time $t = T_s$, for m interconnected warehouses there are obviously m initial conditions

$$x^{\{i\}}(t)\Big|_{t=T_s} = x_s^{\{i\}}, \quad i = \overline{1,m},$$

where $x^{\{i\}}(t)$ designates a random volume of the divisible homogeneous products in an i-warehouse at the time $t \in [T_s, T_e]$. That is why once these random initial volumes $x_s^{\{i\}}$, $i = \overline{1,m}$ were distributed on the axis OX of the Cartesian rectangular system of coordinates, these irregularly distributed initial volumes can be mentally identified with the distribution of the warehouses on the axis OX. This identification allows for constructing the required mathematical model. It is worth mentioning here that topology of the imagined distribution of warehouses on the axis OX does not have to match the typology of distributing initial quantities-volumes $x_s^{\{i\}}$, $i = \overline{1,m}$; this is natural and obvious.

After the above mentioned identification we have a certain set of interconnected warehouses (SIW), and we can construct a mathematical model for establishing the dynamics of random volumes of divisible homogeneous production in this SIW ignoring the dynamics of a random volume of divisible homogeneous production in any individual warehouse.

Let us consider a relatively short segment $[x(t), x(t)+\Delta x(t)]$ of the length $\Delta x(t)$ and introduce the functional $\Delta\Psi(t, x(t))$ of the function- volume $x(t)$ which describes the number of elements SIW that can be found in the segment $[x(t), x(t)+\Delta x(t)]$. In other words, $\Delta\Psi(t, x(t))$ is the number of warehouses distributed on a short segment $[x(t), x(t)+\Delta x(t)]$ of the length $\Delta x(t)$. Then $\dfrac{\Delta\Psi(t, x(t))}{\Delta x(t)}$ can be treated as probability of the warehouse with the volume $x(t)$ of production being on the segment $[x(t), x(t)+\Delta x(t)]$. Consequently, we can move over to the limit with $\Delta x(t) \to 0$ and define a new function

$$p(t, x(t)) \overset{def}{\equiv} \lim_{\Delta x(t)\to 0} \frac{\Delta\Psi(t, x(t))}{\Delta x(t)},$$

which is the density of distribution of warehouses according to random volumes $x(t)$ of divisible homogeneous production. Then the function

$$\Psi(t) \overset{def}{\equiv} \int_{x_1}^{x_2} p(t, x(t))\, dx(t)$$

designates the number of warehouses with random volumes $x(t) \in [x_1(t), x_2(t)]$ at the time moment $t \in [T_s, T_e]$.

It is easily seen that

$$\int_{T_s}^{T_e} \Psi(t)\, dt \equiv m;$$

$$\int_{-\infty}^{+\infty} p(t, x(t))\, dx(t) \equiv 1.$$

Now the density of distribution $p(t, x(t))$ of warehouses according to random volumes $x(t)$ of divisible homogeneous production is defined, and we can establish the law of distributing warehouses according to random volumes, i.e. to find out the rule that governs the change of the function $p(t, x(t))$. For this, the axis OX is divided into two parts, an arbitrary segment $[x_1(t), x_2(t)]$ and the view of this segment, i.e. the domain $(-\infty, x_1(t)) \cup (x_2(t), +\infty)$. As random volumes of productions in warehouses change with the course of time, it will mean in our case that warehouses will be moving along the axis OX in this course of time. This, in turn, means that during the segment of time $[t_1, t_2]$, $\forall t_1, t_2 \in [T_s, T_e]$ a certain number of warehouses will have random volumes of divisible homogeneous production that are no bigger than $x_1(t)$ and no less than $x_2(t)$, i.e. some warehouses will be located in the segment $[x_1(t), x_2(t)]$ whereas their remaining number will be outside this segment, or in the domain $(-\infty, x_1(t)) \cup (x_2(t), +\infty)$. Thus it will be quite correct if the equation of balance of warehouses for the segment $[x_1(t), x_2(t)]$ in the segment of time $[t_1, t_2]$ is presented in the following way (on analogy with a widely known approach in mathematical physics whereby mathematical models are constructed for heat conductivity, waves, diffusion, radiation, and other physical processes):

$$\Delta\Psi(t_1, t_2) \overset{def}{\equiv} \Psi(t_2) - \Psi(t_1) = \Psi^{\{1\}} + \Psi^{\{2\}} + \Psi^{\{3\}},$$

where $\Psi^{\{1\}}$ is the number of warehouses located in the segment $[x_1(t), x_2(t)]$ in the segment of time $[t_1, t_2]$ due to non-random replenishments and distributions of divisible homogeneous production; $\Psi^{\{2\}}$ is the number of warehouses located in the segment $\left[x_1(t), x_2(t)\right]$ in the segment of time $\left[t_1, t_2\right]$ due to random replenishments and distributions of divisible homogeneous production; $\Psi^{\{3\}}$ is the number of warehouses which get in the period $\left[x_1(t), x_2(t)\right]$ or get out of it in the period of time $\left[t_1, t_2\right]$ for the account of random losses (both normal/predicted and abnormal/extraordinary which were discussed in section 2) current stocks of the divisible homogenous production. The function $\Delta\Psi(t_1, t_2)$ in the left-hand side of (13) is calculated according to the formula

$$\Delta\Psi(t_1, t_2) \overset{def}{\equiv} \Psi(t_2) - \Psi(t_1) =$$
$$= \int_{x_1}^{x_2} p(t_2, x)\, dx - \int_{x_1}^{x_2} p(t_1, x)\, dx =$$
$$= \int_{x_1}^{x_2} p(t, x(t))\Big|_{t=t_1}^{t=t_2} dx = \int_{x_1}^{x_2} dx \int_{t_1}^{t_2} \frac{\partial p(t, x(t))}{\partial t} dt. \qquad (14)$$

It is obvious that the quantities $\Psi^{\{i\}}$ $\left(i = \overline{1,3}\right)$ can be negative, and this is then treated as a removal of warehouses from the segment $\left[x_1(t), x_2(t)\right]$. The final formulas for the functions $\Psi^{\{i\}}$ $\left(i = \overline{1,3}\right)$ are given below without conclusion (there is an elegant conclusion which is not given here due to the space constraints):

$$\Psi^{\{1\}} = \int_{t_1}^{t_2} \left\{ p(t, x(t)) \cdot \vartheta(t, x(t)) \right\}\Big|_{x(t)=x_2(t)}^{x(t)=x_1(t)} dt =$$
$$= \int_{t_1}^{t_2} dt \int_{x_1}^{x_2} \frac{\partial}{\partial x(t)} \left(p(t, x(t)) \cdot \vartheta(t, x(t)) \right) dx(t), \qquad (15)$$

$$\Psi^{\{2\}} = \int_{t_1}^{t_2} dt \int_{x_1}^{x_2} \left\{ -\frac{\partial}{\partial x} \left(a(x(t), t) \cdot p(t, x(t)) \right) + \right.$$
$$\left. + \frac{1}{2} \cdot \frac{\partial^2}{\partial x^2} \left(b(x(t), t) \cdot p(t, x(t)) \right) \right\}, \qquad (16)$$

$$\Psi^{\{3\}} = \int_{t_1}^{t_2} dt \int_{x_1}^{x_2} L(t, x(t))\, dx(t), \qquad (17)$$

where function $L(t, x(t))$ is the number of warehouses which for a single period of time, caused only by the random losses of the current stocks of the divisible homogenous production, will be moved to the single segment of the abscises OX, at which there are distributed the values of random volumes of all m warehouses at the moment of time $t \in \left[T_s, T_e\right]$; the function $\rho(z, s; x, t)$ is a transitional function of the probability density of a diffusion stochastic process $X(t)$ (Samarsky and Mikhailov 2002; Gikhman and Skorokhod 1982); the function $\vartheta(t, x(t))$ designates the change rate of the random volume $x(t)$ of the current stock of divisible homogeneous production in the set of interconnected warehouses (SIW) at the time t, and is determined by the stochastic equation

$$\vartheta(t, x(t)) = \frac{dx(t)}{dt} = S(t, x(t)) - C(t, x(t)),$$

where the functions $S(t, x(t))$ and $C(t, x(t))$ have the same values as mentioned in the Section 2. The functions $a(x(t), t)$ and $b(x(t), t)$ are calculated by the formulas

for $\forall \varepsilon > 0, \forall z \in \mathbb{R}^1$ $\quad a(t, x(t)) =$

$$= \lim_{\Delta t \to 0} \frac{1}{\Delta t} \cdot \int_{|x(t) - z(t)| \le \varepsilon} \left(x(t) - z(t) \right) \cdot \rho\left(x(t), t; z(t), t + \Delta t \right) dz(t),$$

for $\forall \varepsilon > 0, \forall z \in \mathbb{R}^1$ $\quad b(t, x(t)) =$

$$= \lim_{\Delta t \to 0} \frac{1}{\Delta t} \cdot \int_{|x(t) - z(t)| \le \varepsilon} \left(x(t) - z(t) \right)^2 \cdot \rho\left(x(t), t; z(t), t + \Delta t \right) dz(t).$$

Taking into account expressions (15)-(17) in formula (14), the following equation is obtained:

$$\int_{x_1}^{x_2} dx \int_{t_1}^{t_2} \frac{\partial p(t, x(t))}{\partial t} dt =$$
$$= \int_{t_1}^{t_2} dt \int_{x_1(t)}^{x_2} \frac{\partial}{\partial x(t)} \left(p(t, x(t)) \cdot \vartheta(t, x(t)) \right) dx(t) +$$
$$+ \int_{t_1}^{t_2} dt \int_{x_1}^{x_2} \left\{ -\frac{\partial}{\partial x} \left(a(x(t), t) \cdot p(t, x(t)) \right) + \right.$$
$$\left. + \frac{1}{2} \cdot \frac{\partial^2}{\partial x^2} \left(b(x(t), t) \cdot p(t, x(t)) \right) \right\} + \int_{t_1}^{t_2} dt \int_{x_1}^{x_2} L(t, x(t))\, dx(t),$$

which due to arbitrariness of the selected volume segment $\left[x_1(t), x_2(t)\right]$, arbitrariness of the selected time segment $\left[t_1, t_2\right]$, and in accordance with the First Mean Value Theorem (use of this theorem here is quite rightful because all its requirements are met) can be written in the following way:

$$\frac{\partial p(t, x(t))}{\partial t} = -\frac{\partial}{\partial x} \left(\left[a(t, x(t)) + \vartheta(t, x(t)) \right] \cdot p(t, x(t)) \right) +$$
$$+ \frac{1}{2} \cdot \frac{\partial^2}{\partial x^2} \left(b(t, x(t)) \cdot p(t, x(t)) \right) + L(t, x(t)). \qquad (18)$$

The resulting stochastic equation (18) is the parabolic type inhomogeneous particular differential equation, and together with the above mentioned functions $a(t, x(t)) \not\equiv 0$, $b(t, x(t)) \not\equiv 0$ and $\vartheta(t, x(t))$, as well as corresponding initial and boundary conditions (for instance, the Newton type boundary conditions, or Neumann boundary conditions, or non-located boundary conditions) it makes the required mathematical model for determining unknown density of distribution $p(t, x(t))$ of exactly $m \in \mathbb{N}$ warehouses according to random volumes $x(t)$ of divisible homogeneous production. It is not difficult to see that the equation (18) is a particular case of the widely known equation of Kolmogorov for the Markov stochastic process $X(t)$ with a transition function of the density of probability $\rho(z,s;x,t)$.

The next stochastic continuous model (with the Dirichlet boundary conditions) is an informal generalization (the corresponding conclusion is rather complex and therefore not presented in the given article) of the above mentioned model: it describes the dynamics of unknown density of distribution $p(t,x_1(t),...,x_n(t))$ of exactly $m\in\mathbb{N}$ warehouses according to random volumes $x(t)=(x_1(t),...,x_n(t))$ of divisible $n\in\mathbb{N}$ heterogeneous productions

$$\frac{\partial p(t,x(t))}{\partial t}=\frac{1}{2}\cdot\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{\partial^2}{\partial x_i\partial x_j}\big(b_{ij}(t,x(t))\cdot p(t,x(t))\big)-$$

$$-\sum_{i=1}^{n}\frac{\partial}{\partial x_i}\Big(\big[a_i(t,x(t))+\vartheta_i(t,x(t))\big]\cdot p(t,x(t))\Big)+$$

$$+\sum_{i=1}^{n}L_i(t,x(t)),$$

$$p(t,x(t))\big|_{t=T_s}=p_0(x_1,...,x_n),\ x_i\in\mathbb{R}^1\ \ \forall i=\overline{1,n};$$

$$p(t,x(t))\big|_{x_i(t)=l_i^{\{1\}}-0}=p_i^{\{1\}}(t),\ l_i^{\{1\}}\in\mathbb{R}^1\ \ \left(i=\overline{1,n}\right);$$

$$p(t,x(t))\big|_{x_i(t)=l_i^{\{2\}}-0}=p_i^{\{2\}}(t),\ l_i^{\{2\}}\in\mathbb{R}^1\ \ \left(i=\overline{1,n}\right),$$

where

$$x(t)=(x_1(t),...,x_n(t))\in\bigcup_{i=1}^{n}\left[l_i^{\{1\}},l_i^{\{2\}}\right];$$

the function $x_i(t)$ $\left(i=\overline{1,n}\right)$ describes the random volume of i-th divisible production at the time moment $t\in[T_s,T_e]$; the function $\vartheta_i(t,x(t))$ describes the change rate of the random volume $x_i(t)$ of the current stock of i-th divisible production in the set $m\in\mathbb{N}$ of interconnected warehouses at the time moment t; the functions $a_i(x(t),t)$ $\left(i=\overline{1,n}\right)$ and $b_{ij}(t,x(t))$, $\left(i=\overline{1,n};\ j=\overline{1,n}\right)$ are calculated according to the formulas

$$a_i(t,x(t))=$$

$$=\lim_{\Delta t\to 0}\frac{1}{\Delta t}\cdot\int_{B_\varepsilon(z(t))}\big(x_i(t)-z_i(t)\big)\cdot\rho(x,t;z,t+\Delta t)\,dz(t),$$

$$b_{ij}(t,x(t))=$$

$$\lim_{\Delta t\to 0}\frac{1}{\Delta t}\cdot\int_{B_\varepsilon(z(t))}\big(x_i(t)-z_i(t)\big)\cdot\big(x_j(t)-z_j(t)\big)\cdot dz(t),$$

where

$$z(t)\overset{def}{\equiv}\{z_1(t)...z_n(t)\};\ \ x(t)\overset{def}{\equiv}\{x_1(t),...,x_n(t)\};$$

the function $\rho(x,t;z,t+\Delta t)$ is a transition function of the density of probabilities of the diffusion stochastic process $X(t)\overset{def}{\equiv}(X_1(t),...,X_n(t))$ (Samarsky and Mikhailov 2002; Gikhman and Skorokhod 1982), and $B_\varepsilon(z(t))\overset{def}{\equiv}\left\{x(t):\ \|x(t)-z(t)\|_{\mathbb{R}^n}\le\varepsilon\right\}$ is the closed ε-neighborhood of the point $z(t)$.

CONCLUSIONS

The present paper studies construction of unsteady stochastic ODE and PDE models for calculating the volume of current stock of divisible productions "from scratch" using apparatus of mathematical physics. The constructed models are new ones and can be used for on-line monitoring of the dynamics of the divisible productions random volumes. Further guidelines of the current research are the development and investigation of optimization inventory control tasks using cost criteria on the base of on-line monitoring of multiproduct stock of divisible productions in one or in several interrelated warehouses.

REFERENCES

Kopytov, E., Muravjov, A., Greenglaz, L., Burakov, G, 2007. Investigation of two strategies in inventory control system with random parameters. *Proceedings of the XXI European Conference on Modelling and Simulation (ECMS-2007)*, 566-571. June 04-06, 2007, Prague, Czech Republic.

Ashmanov, S.A., 1980. *Mathematical Models and methods in Economics*. Moscow: Lomonosov MSU Press.

Nikaido, H., 1968. *Convex structures and economic theory*. New York-London: Academic Press.

Tikhonov, A.N., Samarsky, A.A, 2004. *Equations of Mathematical Physics*. Moscow: Lomonosov MSU Press.

Ito, K., 1987. *Selected papers*. New York: Springer Press.

Milstein, G.N., 1995. *Numerical integration of stochastic differential equations*. New York-London: Kluwer Academic Publishers.

Kuznetsov, D.F., 2007. *Stochastic Differential equations: theory and practice of numerical solutions*. St. Petersburg: Polytechnic University.

Diend, I., 1990. On approximation of Ito stochastic equations. *Mathematical Transactions*, 181 (6): 743-750.

Samarsky, A.A., Mikhailov, A.P., 2002. *Mathematical Modelling*. Moscow: Fizmatlit Press.

Gikhman, I.I., Skorokhod, A.V., 1982. *Stochastic differential equations and their applications*. Kiev: Naukova Dumka Publishers.

Kopytov, E., Guseynov, Sh., Puzinkevich, E., Greenglaz, L., 2010. On some continuous models for determining the volumes of current supplies of divisible productions. *Proceedings of the International Symposium on Stochastic Models in Reliability Engineering, Life Science and Operations Management (SMRLO10)*, 583-585. February 09-11, 2010, Beer Sheva, Israel.

Authors Index