THE 20TH INTERNATIONAL CONFERENCE ON HARBOR, MARITIME & MULTIMODAL LOGISTICS MODELLING AND SIMULATION

SEPTEMBER 17 - 19 2018

BUDAPEST, HUNGARY

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2018

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WELCOME MESSAGE 2018

It is a huge pleasure and honor to welcome all the attendees to the 20th edition of the International Conference on Harbor, Maritime and Multimodal Logistics Modeling & Simulation (HMS 2018) in the wonderful framework of Budapest.
This year the HMS International Program Committee has selected high quality scientific articles that show how scientists working in the "Logistics research arena" are active in defining new methodologies and implementing real practical 4.0 solutions able to improve supply chains, distributions and transportations. As it happens in the real world economy where marine ports play the role of the major logistic hubs, this is also reflected by the HMS articles where, also this year, we find a continuous (and successful) effort to investigate strategic, tactical and operational problems in marine ports. HMS articles also show that, while global logistics is standing even more on marine ports worldwide, the urban logistics is increasing its importance due to the new possibilities offered by ITS and electric/hybrid vehicles. Furthermore, the focus on traditional logistic topics (e.g. warehouses picking, logistics monitoring systems, etc.) not only shows that Modeling & Simulation (M&S) can still provide valuable and significant contributions but these improvements are even amplified when M&S is combined with new discipline such as strategic engineering (e.g. to redefine the design of crucial elements for industrial plants, offshore platforms and underwater facilities).
Therefore, thanks to the work done by authors, IPC members and reviewers, HMS offers the attendees with the possibility to experience a truly thematic environment and, for those researchers interested in enlarging their "vision", as tradition, also this year HMS is co-located with the International Multidisciplinary Modeling & Simulation Multi-Conference (I3M). The attendees can take advantage of a multidisciplinary environment where Modeling & Simulation applications, theories and methodologies are applied to multiple sectors from Industry to Logistics, from Automation and Controls to Defense and Homeland Security, from Healthcare to Food Operations, from Energy to Environmental Sustainability.
Once again, welcome to HMS 2018 and welcome to Budapest!

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The HMS 2018 International Program Committee (IPC) has selected the papers for the Conference among many submissions; therefore, based on this effort, a very successful event is expected. The HMS 2018 IPC would like to thank all the authors as well as the reviewers for their invaluable work.
A special thank goes to all the organizations, institutions and societies that have supported and technically sponsored the event.

I3M 2018 Internal Staff

This International Workshop is part of the I3M Multiconference: the Congress leading **Simulation around the World and Along the Years**

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MODELING AND DYNAMIC SIMULATION OF PROPULSION PLANT FOR OCEAN-GOING FISHING VESSEL

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ABSTRACT

Considering the complexity of propulsion plant and the multiple operating conditions for fishing vessel, the modeling and simulation of ship engine propeller and net for the ocean-going fishing vessel are investigated. According to the matching theory of ship engine propeller and net, the relationships of them are analyzed. Furthermore, the motion balance equation and dynamic equilibrium equation are built for the translation system and rotation system of fishing vessel which can indicate the changing trends of propeller rotational speed or ship speed and propeller torque of thrust. Based on this, by setting up the simulation models of various subsystems, the simulation model of propulsion plant are built for the ocean-going fishing vessel. A trawler is considered to perform simulation tests in which start-up condition, normal navigation condition and trawling condition are taken into account. The simulation results illustrate the correctness and validity of modeling and simulation for propulsion plant system.

Keywords: Modeling, Simulation, Fishing vessel, Propulsion plant.

1. INTRODUCTION

The propulsion plant is the most important component for the ocean-going fishing vessel. Its operating characteristics are the processes of matching for ship engine propeller and net. So, the researches of simulation and optimization design for the propulsion plant have been paid much more attention. Chen[1] presented an experimental apparatus for dynamically simulating marine propeller load. Li[2] gave a Chebyshev fit expression across four quadrants for a propeller in Deep Submergence Vehicle and realized the all-round movement simulation of DSV. Shun[3] proposed a modeling method and a zero-dimension transient model for large marine propulsion plant. Liu[4] put forward the method of designing the power plant by using the simulation system of power plant. All above researches have obtained fruitful results in the simulation and design of marine propulsion system. However, the modeling and dynamic simulation of ship engine propeller and net for the ocean-going fishing vessel should be investigated further. So, in the paper, the dynamic simulation method is developed to indicate the changing trends of propeller rotational speed or ship speed and propeller torque of thrust for the ocean-going fishing vessel.

2. MATCHING THEORY OF SHIP ENGINE PROPELLER AND NET FOR THE OCEAN-GOING FISHING VESSEL

2.1. Propeller's Propulsion Characteristics

Without considering the impact of thrust deduction, wake and wake's non-uniform, the propeller characteristics are generally expressed as:

$$\begin{aligned} K_Q &= \frac{Q}{\rho n^2 D^5} \\ K_T &= \frac{T}{\rho n^2 D^4} \\ J &= \frac{V_a}{nD} \\ \eta &= \frac{TV_a}{2\pi n Q} = \frac{K_T}{K_Q}\cdot\frac{J}{2\pi} \end{aligned} \tag{1}$$

Where, K_T is the thrust coefficient, K_Q the torque coefficient, J the advance coefficient, η the efficiency, D the diameter of propeller, V_a the axial velocity, n the rotational velocity, ρ the fluid density, T the thrust and Q the torque

Based on propeller design theory, K_T and K_Q can be obtained by the diagram analysis method. For realizing the mathematical analysis and computer programming of the propeller, the regression coefficient method[5]is adopted and for an AU-series propeller with different blade number, the regression polynomials are expressed as follow:

$$\begin{aligned} K_T &= \sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} A_{ijk}(P/D)^i (J)^j (A_E/A_0)^k \\ 10K_Q &= \sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3} B_{ijk}(P/D)^i (J)^j (A_E/A_0)^k \end{aligned} \tag{2}$$

Where, P/D is pitch ratio of propeller, A_E/A_0 disk ratio of propeller. And A_{ijk} , B_{ijk} , i , j , k are corresponding regression coefficients.

2.2. Fishing Vessel's Resistance Characteristics

Considering the trawler, The hydrostatic resistance can be divided into friction resistance R_f , vortex resistance R_e and wave resistance R_w. Though the proportion of resistance component in the overall resistance is not the same under different circumstances, based on ship model test, the resistance of dull R_1 can be described as:

$$R_1 = c_T \cdot \frac{1}{2}\rho S V_S{}^2 = (c_f + c_e + c_w)\cdot \frac{1}{2}\rho S V_S{}^2 \quad (3)$$

Where c_T , c_f , c_e , c_w are total resistance coefficient, friction resistance coefficient, vortex resistance coefficient and wave resistance coefficient, respectively. S is ship soaking area, V_S the trawler's speed.
Then, the effective power of the hull is:

$$N_{R_1} = R_1 \cdot V_S = c_T \cdot \frac{1}{2}\rho S V_S{}^3 \quad (4)$$

When the trawler is trawling or hauling, according to net model test, the resistance of net R_2 and resistance power N_{R_2} can be expressed as:

$$\begin{aligned} R_2 &= \mathrm{k}_1 L C \mathrm{V_t}^{1.5}\mathrm{d/a} \\ N_{R2} &= R_2 V_{\mathrm{t}} / 1020 \end{aligned} \quad (5)$$

Where, k_1 is the allocation coefficient, L the net's length, C the net's girth, d/a the ratio of string's diameter and foot's length for the net, V_t the relative trawling speed of the net.

When the trawler is hauling, the power required for the winch N_3 is represented approximately as:

$$N_3 = \alpha R_H V_2 \mathrm{k}_3 / 1020 \quad (6)$$

Where α is the sea condition coefficient, R_H the winch's resistance, V_2 the winch's speed, k_3 the winch's efficient.

Thus, when the trawler is hauling, the power required for the trawler N_e is:

$$N_{\mathrm{e}} = (N_{R1} + N_{R2}) / \mathrm{k}_2 + N_3 \quad (7)$$

Where k_2 is the towing efficient of the propeller.

2.3. Interaction of Propeller and Dull

When the trawler is sailing on the sea, owing to the existence of wake, the propeller's speed relative to water is different from the trawler's speed. That is:

$$V_A = (1-w)\cdot V_S \quad (8)$$

Where w is wake coefficient.
At the same time, the properties of propeller in still water and installed behind the trawler are different because of the wake's non-uniform. Assuming the advance coefficient J is constant, the impact of them can be reflected in:

$$\begin{aligned} i &= \frac{i_1}{i_2} \\ i_1 &= \frac{K_T(behind\ \ the\ \ trawler)}{K_T(in\ \ still\ \ water)} \\ i_2 &= \frac{K_Q(behind\ \ the\ \ trawler)}{K_Q(in\ \ still\ \ water)} \end{aligned} \quad (9)$$

Where i , i_1 and i_2 are thrust, torque and efficiency influence coefficients of wake's non-uniform, respectively.
In addition, only a portion of propeller thrust T is used to overcome ship resistance R because of thrust deduction. That is:

$$T_e = R = T(1-t) \quad (10)$$

Where t is thrust deduction coefficient.

3. MATHEMATICAL MODEL OF SHIP ENGINE PROPELLER AND NET FOR THE OCEAN-GOING FISHING VESSEL

For the propulsion plant of fishing vessel, the main engine drives the propeller directly or through the transmission and the propeller produces thrust which pushes the ship forward by the thrust shaft and thrust bearing. Therefore, the ship propulsion system includes two inertial systems of the propulsion plant's rotating part and the ship's linear motion.

3.1. Ship Translation System Model

According to the theory of ship dynamics, the following dynamic equation can be established for the ship translational system:

$$\begin{aligned} (m+\Delta m)\frac{dV_S}{dt} &= T_e - R \\ R &= R_1 + R_2 + R_H \end{aligned} \quad (11)$$

Where m is the ship mass and Δm is the entrained water mass.

3.2. Ship Rotation System Model

The dynamic equation can be built for the rotating part of inertial system, which can be expressed as:

$$2\pi I \frac{dn_R}{dt} = M_d - M_p \tag{12}$$

Where I is the equivalent rotational inertia of the propulsion plant, n_R is the rotational velocity of rotating part, M_d is the output torque of main engine and M_p if the load torque of propeller.

Based on the relations of performance parameters for main engine, the output torque of main engine can be reflected in:

$$M_d = \frac{1000 H_u i g_c \eta_e}{\pi \tau} \tag{13}$$

Where H_u is the fuel calorific value, i is the cylinder number, g_c is the fuel injection for per cycle, η_e is the efficiency, τ is the stroke number.

4. SIMULATION MODEL OF SHIP ENGINE PROPELLER AND NET BASED ON SIMULINK

Based on MATLAB/SIMULINK, the simulation model of ship engine propeller and net is established.

4.1. Subsystem Model of Resistance

Input the resistance coefficient c and ship speed V_S, output the ship resistance R_S, the simulation model of resistance is shown in Fig.1.

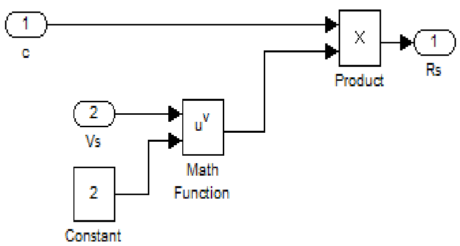

Figure 1: Subsystem Model of Resistance

4.2. Subsystem Model of Advance Coefficient

Input is the axial velocity of propeller V_P, the diameter of propeller D_P and the rotational velocity of propeller n_P. Output is the advance coefficient J. The subsystem model of advance coefficient is shown in Fig.2.

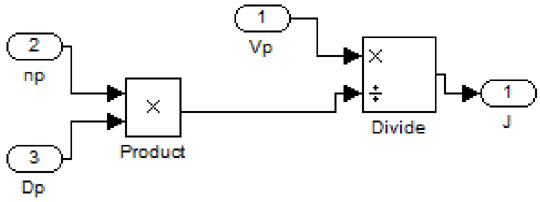

Figure 2: Subsystem Model of Advance Coefficient

4.3. Subsystem Model of Ship Speed

Input is the ship resistance R_S, effective thrust of propeller T_e and the ship mass m. Output is ship speed V_S. The subsystem model of ship speed is shown in Fig.3.

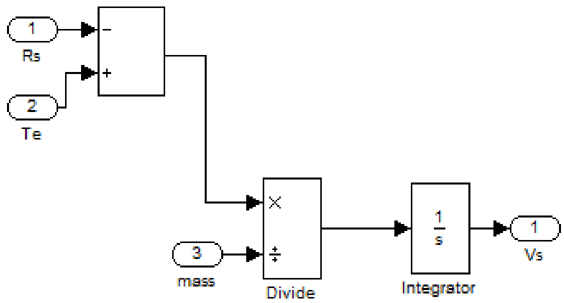

Figure 3: The Subsystem Model of Ship Speed

4.4. Thrust Deduction Model

Input the thrust of propeller T, output effective thrust of propeller T_e, the thrust deduction model is shown in Fig.4.

4.5. Subsystem Model of Thrust Coefficient and Torque Coefficient

Input is the advance coefficient J, the pitch ratio of propeller P/D and the disk ratio of propeller A_E/A_0. Output are thrust coefficient K_T and torque coefficient K_Q. The subsystem model of thrust coefficient and torque coefficient are shown in Fig.5 and Fig.6, respectively.

4.6. Subsystem Model of Thrust

Input is the sea water density ρ, the axial velocity of propeller V_P, the diameter of propeller D_P, the rotational velocity of propeller n_P and thrust coefficient K_T. Output is the thrust T_P. The subsystem model of thrust is shown in Fig.7.

4.7. Subsystem Model of Torque

Input is the sea water density ρ, the axial velocity of propeller V_P, the diameter of propeller D_P, the rotational velocity of propeller n_P and Torque coefficient K_Q . Output is the torque M_P . The subsystem model of torque is shown in Fig.8.

4.8. Simulation Model of Ship Engine Propeller and Net

According to the above-mentioned subsystem models and their mathematical relationships, the simulation model of ship engine propeller and net can be established and shown in Fig.9.

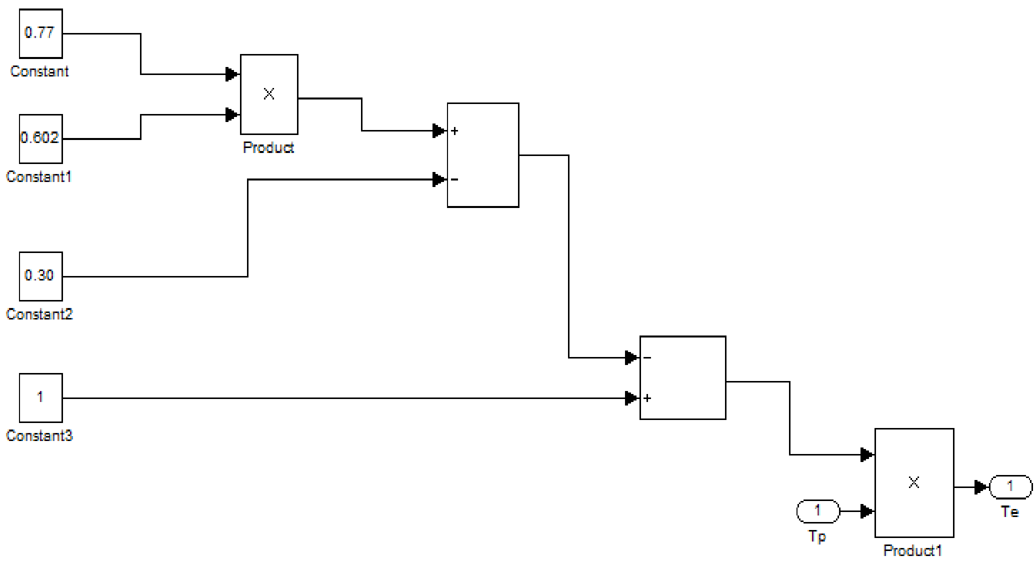

Figure 4: Thrust Deduction Model

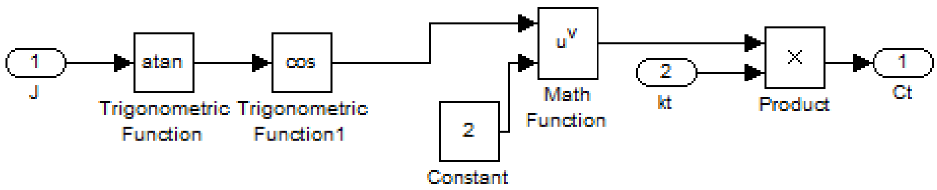

Figure 5: Subsystem Model of Thrust Coefficient

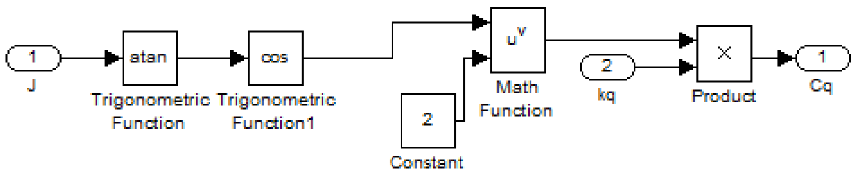

Figure 6: Subsystem Model of Torque Coefficient

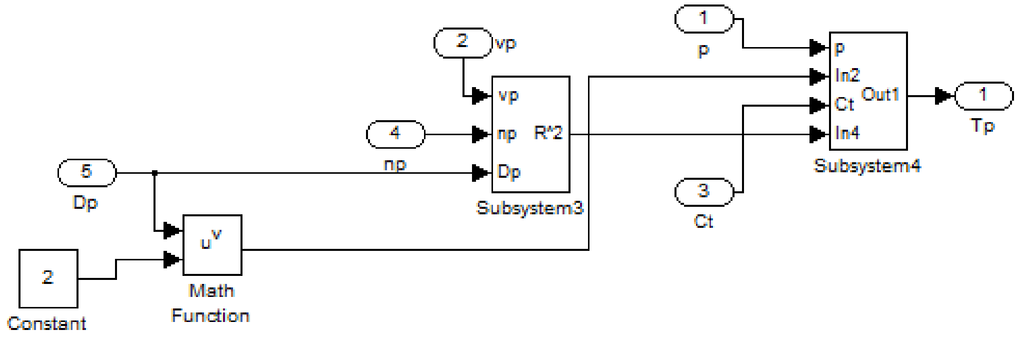

Figure 7: Subsystem Model of Thrust

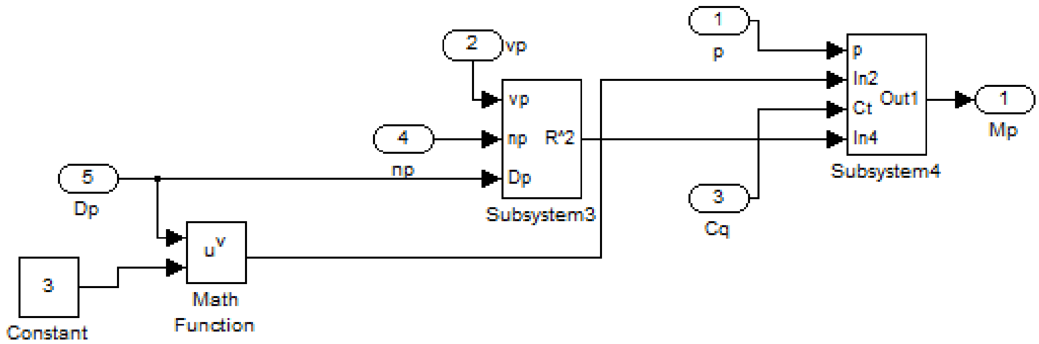

Figure 8: Subsystem Model of Torque

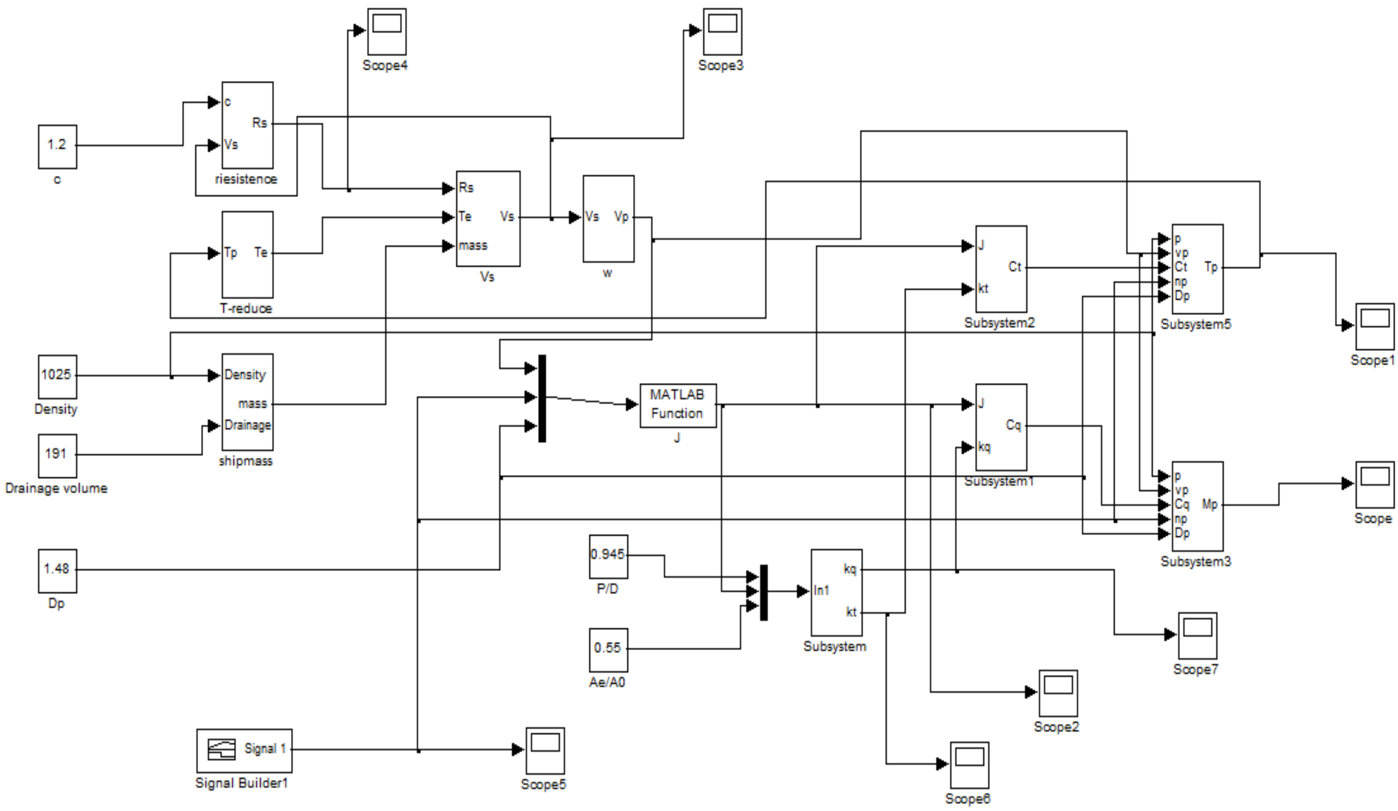

Figure 9: Simulation Model of Ship Engine Propeller and Net based on Simulink

5. SIMULATION EXAMPLE

Considering a 119 gross ton trawler , the main parameters are presented in table 1.

Table 1: The Main Parameters

Drainage volume	$191m^3$
Propeller diameter	1.48m
Pitch ratio	0.945
Disk ratio	0.55
Design speed	11.3kn
Trawl speed	4kn
Propeller rotational velocity	5.32 r/s
Cruising endurance	2700 n mile

5.1. Model Accuracy Verification

After running the simulation model of ship engine propeller and net, the propeller rotational velocity curve and ship speed curve are obtained and shown in Fig.10 and Fig.11. The ship speed's change is lagging behind that of propeller rotational velocity, which can be seen from the figures and is line with the fact of the ship's huge inertia.

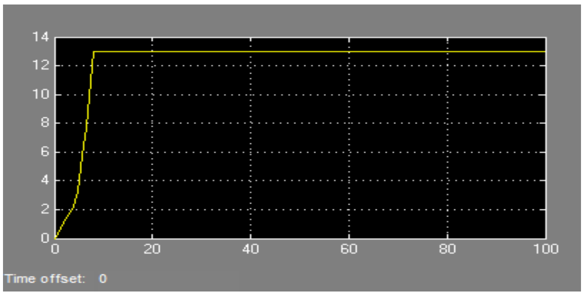

Figure 10: the Curve of Propeller Rotational Velocity

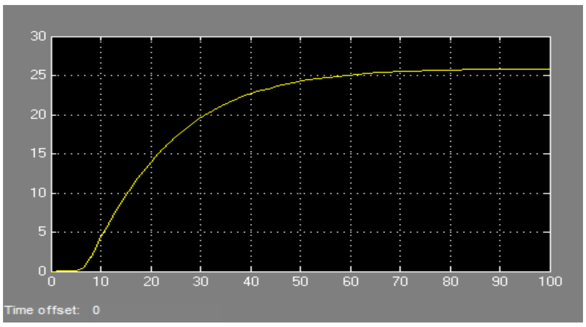

Figure 11: the Curve of Ship Speed

The relationship between thrust coefficient, torque coefficient and advance factor are shown in Fig.12. With the increasing of the advance factor, the thrust coefficient and torque coefficient decrease, which is coincided with the results of the open-air propeller model test.

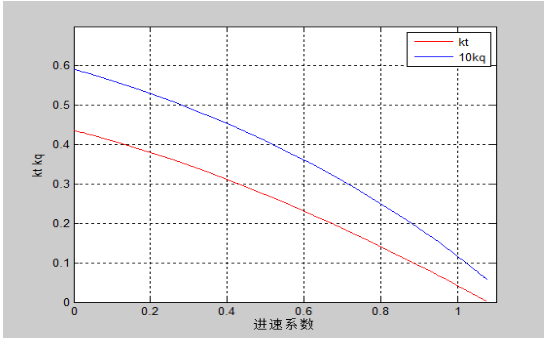

Figure 12: the Curve of Thrust Coefficient and Torque Coefficient

5.2. Dynamic Simulation of Trawler under Various Operating Conditions

Assume that the trawler experience start-up condition, normal navigation condition and trawling condition, respectively. The parameters of various conditions are shown in Table 2.

Table 2: The Parameters of Various Conditions

	Time (s)	Rational velocity(r/s)	
1	0-20	0	Stationary state
2	20-26	0-1	First Acceleration
3	26-126	1	
4	126-135	1-3.4	Second Acceleration
5	135-368	3.4	
6	368-410	3.4-5.32	Third Acceleration
7	410-800	5.32	
8	800-1200	5.32-2	Deceleration
9	1200-3000	2	Micro Speed

Using the simulation model of ship engine propeller and net, the curves of propeller rotational velocity and ship speed are shown in Fig. 13 and Fig.14, respectively. Fig.15 is the curve of propeller torque. Fig.16 is the curve of ship resistance.

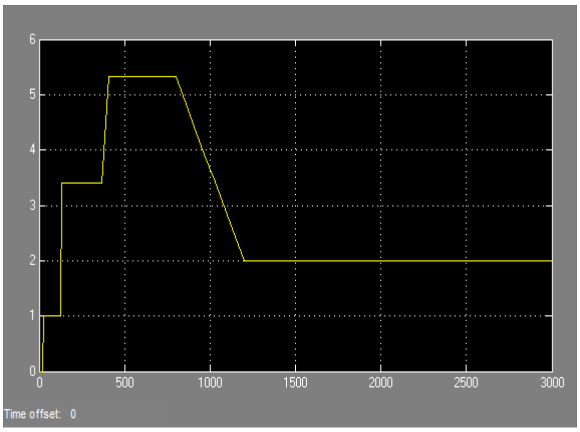

Figure 13: The Curve of Propeller Rotational Velocity

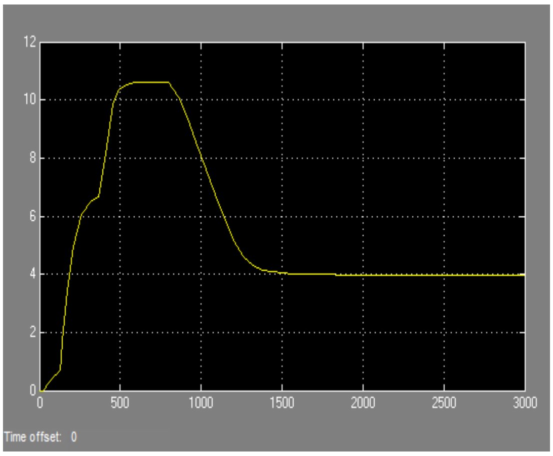

Figure 14: The Curve of Ship Speed

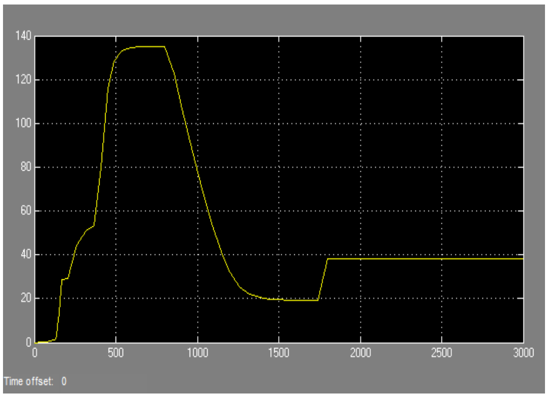

Figure 15: the curve of ship resistance

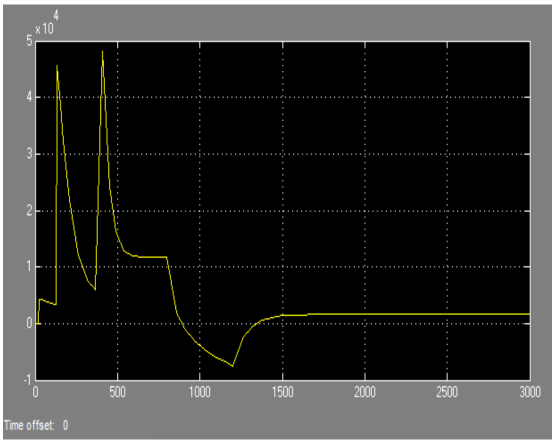

Figure 16: The Curve of propeller torque

From the Fig.13, Fig.14 and Fig.15, it can be seen that the changing trends of propeller rotational velocity and ship speed are same. From 0-600s, both the ship speed and ship resistance are increasing, and stabilize at their maxima. From 800-1531s, the fishing vessel arrives at the scheduled fishing ground, the speed decreases gradually and the ship resistance also shows a downward trend. From 1531-3000s, the fishing vessel sails at a slight speed for the fishing condition, and the ship resistance increases suddenly at 1740s because the nets start operating.

For the torque curve (Fig.16), three abrupt changes appear from 0 to 600s, which is corresponded to the changing law of speed and rotational velocity. Then the torque continues to drop and a negative value arises after 895s that cause the ship decelerate. Finally, the torque rises gradually and remains at 1700NM because the rotational velocity stabilizes at 2 r/s.

6. CONCLUSIONS

The modeling and simulation of ship engine propeller and net for the ocean-going fishing vessel are investigated in this work. According to the matching theory of ship engine propeller and net, the motion balance equation and dynamic equilibrium equation are built for fishing vessel indicating the changing trends of propeller rotational speed or ship speed and propeller torque of thrust. Based on this, the simulation model of propulsion plant are built for the ocean-going fishing vessel. A trawler is considered to perform simulation tests in which start-up condition, normal navigation condition and trawling condition are taken into account. The simulation results illustrate the correctness and validity of modeling and simulation for propulsion plant system. The ship speed's change is lagging behind that of propeller rotational velocity, which is line with the fact of the ship's huge inertia. Thus can be used for the optimization design of propulsion plant for the ocean-going fishing vessel.

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REFERENCES

Chen S. R., Zhang J. J. and Li D. P. Experimental apparatus for dynamically simulating marine propeller load. Ship engineering. 2002, 5 :34-37.

Li D. P. Wang Z. Y. and Chi H. H.. Chebyshev fit of propeller properties across four quadrants and realization of all-round movement simulation along X-shift of DSV. Journal of system simulation. 2002, 14(7): 935-938.

Sun J. B., Guo C. and Zhang X.. Research on modeling and simulation of large marine propulsion plant. Journal of system simulation. 2007,19 (3): 465-469.

Liu Y. B., Ma J. and Wang M. X.. Application of simulation technology to design of power plant. Journal of naval university of engineering. 2007, 19(1): 19-22.

Chen K. Y. Ship design practical handbook. China Communications Technology Press, 2007.

AGENT-BASED SIMULATION OF RESTAURANT DELIVERIES FACILITATING CARGO-BIKES AND URBAN CONSOLIDATION

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ABSTRACT
Last-mile distribution in urban areas is challenged by congestion and restriction for motorized traffic. To support operations, this work investigate the impact of operating urban consolidation points and facilitating cargo-bikes for urban last-mile distribution. Motivated by sample setting originating from the food delivery industry, a decision support system combining agent-based simulation with heuristic optimization procedure is developed. It considers a logistics provider who performs the last-mile delivery for multiple competing restaurants in an urban area. Therefore, both demand and the availability of cargo-bikes, which are operated by freelancers, are subject to randomness. Computational experiments investigate the impact of the available amount of cargo-bike drivers as well as the number of operated consolidation points, highlighting the importance of facilitating simulation models to support operations in highly dynamic and uncertain settings.

Keywords: agent-based simulation, cargo-bikes, consolidation, food logistics

1. INTRODUCTION

Within urban city centers, daily logistics operations are subject to a wide range of uncertainties such as sudden demand and uncertain traffic situations. As a consequence, routing and consolidation decisions often need to be made in real-time, particularly, as delivery durations are gaining importance and are often commonly identified as a key factor to achieve competitive advantages (Manning et al. 2015). Within this work, a highly dynamic setting originating from urban food deliveries is considered as a sample case, where both the timing and amount of orders as well as the number of available delivery staff are major sources of uncertainty. It deals with the delivery of meals from restaurants to consumer homes. Over the last years, various business models (e.g., Deliveroo 2017; foodora 2017; UberEATS 2017) entered this market offering customers the opportunity to order food from a wide-range of restaurants. For restaurant providers, such services enable one to reach more customers and, consequently, increase order volumes and market shares. Furthermore, giving customers the possibility to order food online potentially results in better order accuracy and lower staff requirements (Kimes 2011).
Additionally, it often allows one to consolidate logistics operations with other, potentially competing, restaurant providers. As previously shown, horizontal cooperation can lead to major reductions in cost and emission (Cruijssen et al. 2007), while further allowing companies to improve service quality (Serrano-Hernandez et al. 2018). Therefore, instead of each restaurant provider operating own staff to deliver goods to customers, shipments are consolidated by a third-party provider. In this context, cargo-bikes gained substantial importance within urban city centers, particularly in areas with restricted access for motorized vehicles. These cargo-bikes are often operated by freelancers (Rudolph and Gruber 2017), adding an additional layer of uncertainty to the system as capacities and availabilities can differ substantially throughout the day and year.
Consequently, to evaluate the impact of operating such urban last-mile distribution concepts facilitating cargo-bikes and urban consolidation, studies focusing on the specific characteristics of such systems are required. Simulation-based decision support systems (DSS) are promising ways to facilitate sustainable transportation within urban city centers. Such tools enable decision-makers to evaluate various consolidation and last-mile distribution strategies in a flexible and risk-free manner to derive related managerial and policy implications. Additionally, derived findings assist transferring routing and scheduling procedures to real-world operations. Based on the DSS described in Fikar et al. (2017), this work provides insights on the development and evaluation of online consolidation strategies for urban last-mile distribution. Therefore, computational experiments based on a test-setting originating from urban food deliveries in Vienna, Austria, are investigated.
The remainder of this article is structured as follows: A review of related literature in provided in Section 2. Section 3 describes the studied problem setting in detail. The general structure of the DSS is introduced in Section 4. Section 5 introduces the computational

experiments, presents results and discusses main findings. Concluding remarks are provided in Section 6.

2. RELATED LITERATURE

Urban consolidation strategies are investigated from various perspectives within literature. Results of a trial combination of electric vehicles with an urban consolidation points in Central London is presented in Browne et al. (2011). Therefore, diesel vehicles were substituted by operating urban consolidation points and facilitating cargo-bikes and electric vehicles for last-mile distribution. Major reduction in both travel distances and CO_2 are reported. Paddeu (2017) focuses on the user perspective of an urban consolidation point established 2002 in Bristol, United Kingdom. Participating retailers were surveyed concerning benefits, drawbacks and experiences with the concept. Results indicate a high level of confidence in the system, however, also highlighted the dependence on government subsidies. Such financial implications of urban consolidation points are in detail analyzed in Janjevic and Ndiaye (2016). The authors develop a framework to assess financial viability of urban consolidation points. A wide-range of corresponding expenses are investigated, categorized into vehicle and equipment-related costs. An application of the framework for an urban consolidation points in Brussels, Belgium, indicates that human resources are the most critical cost factor. While profitability can theoretically achieved, the authors note that an efficient usage of resources is crucial. This further highlighting the need of tailored decision support systems.

Routing and scheduling of daily operations facilitating such consolidation strategies within urban logistics operations are investigated in various works, however, mainly focusing on a static perspective where no uncertainty in the amount and timing of shipping requests is assumed. Chao (2002) introduces the truck and trailer routing problem. It considers a set of customers which can only be visited by trucks without trailer due to driving restrictions. Consequently, the option of decoupling the trailer is integrated is integrated in the optimization problem. A survey on two-echelon routing problem is given in Cuda et al. (2015). Such problems jointly investigate optimizing the transport of goods to consolidation points and last-mile distribution to final customers. Within an urban context, Fikar (2018) introduces an agent-based DSS to investigate food losses in urban e-grocery distribution systems. Products are stored at retail locations throughout the city from where products are picked-up for final delivery to customers' premises. The combination of cargo-bikes and urban consolidation points is studied in Anderluh et al. (2017). Computational experiments highlight the benefits of such a concept and further discuss the impact of synchronizing vans and cargo-bikes for transshipment at consolidation points. A static perspective is considered, i.e., all requests are known at the start of the planning horizon, and no uncertainty in vehicle fleet size or shipping requests is included. An overview of recent research focusing on such stochastic and dynamic vehicle routing problem, i.e., problems where shipping requests are uncertain or revealed over time, is provided in Pillac et al. (2013) and Ritzinger et al. (2016). No article reviewed in these papers explicitly considers the impact of combining cargo-bikes with urban consolidation points in a highly dynamic urban setting.

3. PROBLEM DESCRIPTION

The problem investigated in this work originates from urban food deliveries. It considers a logistics provider, who performs the last-mile distribution of cooked food items from multiple competing restaurants to customers, and it operating in a dense urban city center subject to traffic restrictions. For distribution, both vans and cargo-bikes are available. Vans are used to bring goods close to the city center, while cargo-bikes perform the final delivery to customer. For transshipment between the two vehicle types, urban consolidation points are operated to before transshipments. An overview of the problem setting is given in Figure 1. For simplification, it differentiates between transports in the periphery of the city and within the city center. Long transports are done by the motorized vehicles which transport goods from the restaurants to the urban consolidation point. Within the city center, deliveries are performed by cargo bikes, which both pick up orders from close-by restaurants and perform final deliveries. Therefore, the corresponding solution procedure has to develop routes and further decide which items are picked up by which vehicle type throughout a single day of operation.

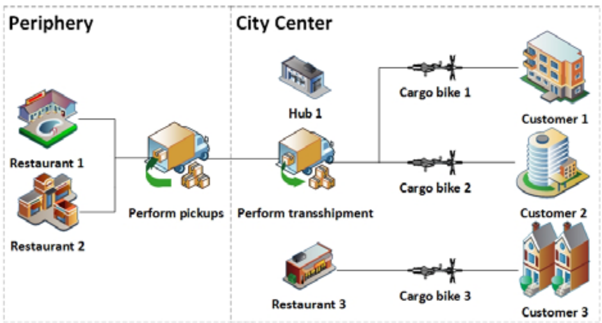

Figure 1: Simplified example of the problem setting investigated in this work

The objective is to reduce delays, i.e., deliver all requests with a stated maximum delivery time, and minimize the total kilometer driven, in lexicographic order. Customer orders occur randomly throughout the day of operation. Such orders are defined with a final delivery location, a maximum delivery duration and further with a list of restaurants which can serve this request. For delivery, the providers hires freelancers operating cargo-bikes in the city, whose availability is subject to dynamics. During the day of operations, such drivers dynamically log into the system to accept shipment requests for a limited time duration. The provider further operates urban consolidation points to assist operations. These points are facilitated for transshipments of food products between cargo-bikes and motorized vehicles. Therefore, the logistics provider owns multiple motorized vehicles, e.g., vans or city cars, which are facilitated to transport products close to the city center, where the products are transshipped to the cargo-bikes for final delivery. Consequently, the following decisions have to be made by the solution procedure in real-time at multiple points during the day: (i) which restaurant should prepare a demand request; (ii) which vehicle should at what time collect this order; and (iii) if the order should be consolidated or directly shipped to the customers.

4. METHOD

An agent-based DSS is used to evaluate the developed distribution concept. Through an interface with a database, input data is loaded into the system such as geographic locations of restaurants as well as home locations of cargo-bikes drivers and customers. To calculate travel paths for both motorized vehicles and cargo-bikes, real-world network data derived from OpenStreetMap (2017) is used. Therefore, the open-source Java library GraphHopper (2017) is used to find shortest paths from origin to destination. An integrated heuristic optimization procedure schedules service requests to delivery vehicles, performs coordination decisions and further optimizes vehicle routes dynamically throughout the planning period. Implemented simulation techniques further allows one to generate a wide range of scenarios by generating customer orders and altering the availability of cargo-bike drivers. Figure 2 gives an overview of the general procedure of the DSS. For implementation details, refer to Fikar et al. (2017).

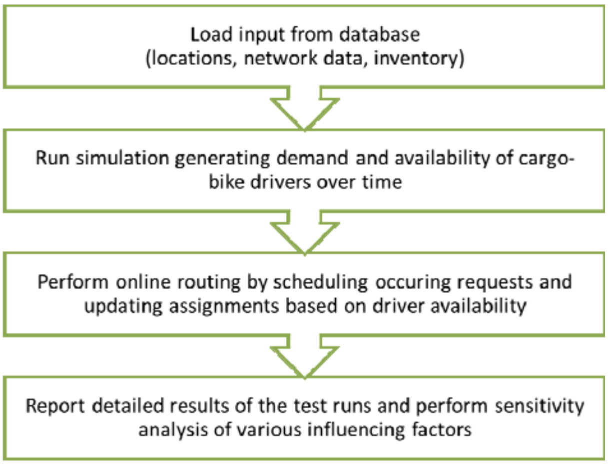

Figure 2: Overview of the DSS used to evaluate the developed last-mile distribution concept

To initiate the system, the user defines a list of locations and loads these into the database connected with the DSS. Each location is defined with a name, geographic coordinates, i.e., latitude and longitude, as well as fields indicating if the location acts as a restaurant, cargo-driver or customer location within the system. At runtime, these locations are loaded into the system and matched to the closest street segment on the imported road network. Additionally, the user sets parameters indicating the number of available motorized vehicles, the arrival rate of demand and cargo-bike drivers throughout the day as well as maximum capacity and travel speeds. Furthermore, a guaranteed delivery duration is set, which indicates how much time between order placement and delivery is acceptable. Any delivery past this time threshold, is indicated as a delay and penalized in the objective function.

A single day of operations is simulated with order being placed between 9 a.m. and 9 p.m. Both orders and cargo-bike drivers appear throughout this time based on Poisson-distributed arrival rates. If a new request occurs, the heuristic optimization procedure is run to perform routing and coordination decisions in real-time. It is based on a combination of an insertion heuristic with a local search procedure. A two-stage procedure is implemented, which in the first step performs routing decisions ignoring the option of transshipping goods at an urban consolidation point. Such potential transshipments are evaluated in the second stage of the procedure and, if beneficial, inserted in the routes. The best found solutions is scheduled and the simulation continues until the next change to this systems occurs, i.e., the number of cargo-drivers change or new order requests occur. At this time, the optimization procedure is rerun to perform relevant rerouting actions.

Either a single simulation run or a computational experiment run can be started to investigate the impact of one or more influencing factors. The former allows one to focus on a single setting in detail. Therefore, vehicle routes, shipment assignments and coordination are animated over time within the graphical user interface, which is shown in Figure 3. It further gives implications on the utilization of different consolidation points, restaurants and cargo-bike drivers throughout the simulation period. Nevertheless, as this setting only represents a single simulation run, it is subject to stochasticity. In contrast, a computational experiments runs multiple simulation replications and reports aggregated statistics to the users of the entire simulation period. Additionally, by varying individual parameters such as the guaranteed delivery time or availability of cargo-bikes, impacts can be studied in detail and promising configurations of the system derived.

(a) Single run. (b) Experiment.

Figure 3: Graphical user interface

5. RESULTS AND DISCUSSION

For the computational experiments, the city of Vienna is taken as a sample setting. In total, 255 restaurants locations and 59 potential urban consolidation points are modelled. For potential locations of such urban consolidation points, major parking garages in the area where considered. To model demand, the city is split into 1,525 electoral districts (Stadt Wien, 2016). The demand area is restricted to an area in the center of the city where major restriction for motorized traffic are present, representing a potential of 117,378 customers. 24 vans are considered for transportation. The expected amount of cargo-bike operating hours is set to 528 hours and the expected number of orders to 1,761 per day within the simulation experiment. Each order can be prepared at an average of three random restaurants for pickup and has to be delivered within 45 minutes after placement of the order. A delay of 15 minutes to prepare the order at the restaurant is assumed. Parameters are set according to the values recommended in Fikar et al. (2017). For each investigated problem setting, 100 replications of the simulation are run with average results reported in this work. All input files and detailed solution files are available at http://short.boku.ac.at/instances.

Figure 4: Study region. Dots indicates restaurant locations and green-shaded area where demand occurs.

Results of a wide range of computational experiments indicate that two factors are of high importance for a successful implementation of urban consolidation points within urban food deliveries. Firstly, having a sufficient number of cargo-bike drivers available at all times is crucial to enable efficient operations. Figure 5 highlights the impact on delay and traveled kilometers of increasing the number of available cargo-bike driver hours within the simulation to a maximum of 1,056 hours, while simultaneously varying expected orders between 1,761 and 2,817 orders. Having more cargo-drivers available allows one to reduce delays and travel distance. Increasing the available number of cargo-bike hours slightly, leads to a large decrease in both average delays of shipments and average kilometer travelled per order. Starting at around 700 hours of cargo-bike operations, no further gains concerning delays is gained, however, travel distance still continues to decrease until around 1,000 hours. Consequently, logistics providers utilizing freelancers for urban last mile-distributions are required to closely investigate the availability of drivers as this factor substantially impacts both cost and service quality.

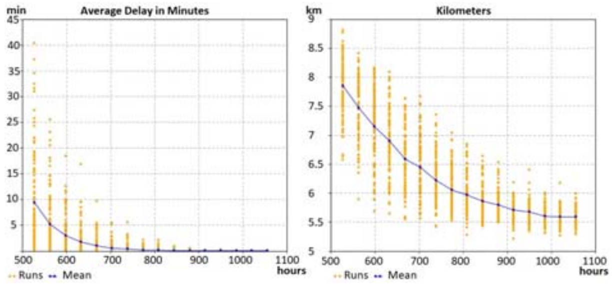

Figure 5: Impact of the amount of available cargo-bike driver hours

Secondly, the amount of consolidation points operated is of high importance. Therefore, the number of operated consolidation points was varied between zero and 59 within the simulation runs. In each run, a random set of hubs is operated. Results are shown in Figure 6. Operating a single consolidation points, i.e., enabling urban transshipments, reduces delays substantially. Average travel distances per order, however, increase by more than 50 % as additional detours are required to perform transshipments. Operating additional consolidation points enables the logistics providers to substantially reduce both travel distance and delays. Starting at around 10 consolidation points, these improvements diminish. Consequently, even if only a small number of consolidation points is operated, the points allow logistics providers to considerably improve service quality at the cost of increased travel distances for additional detours to perform transshipments.

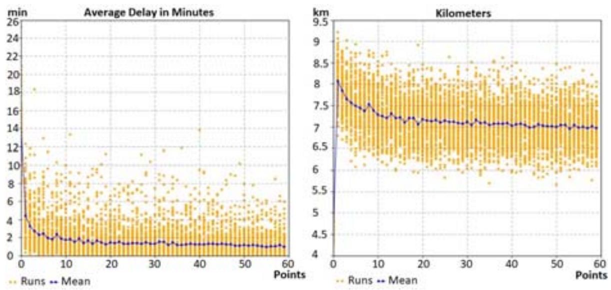

Figure 6: Impact of the number of operated consolidation points

Figure 7 plots the utilization of the individual consolidation points for a single day of operations. Therefore, the size of the circle indicates the number of shipment transshipped at these locations with a larger circle denoting a higher amount of shipments. Orange dots show the demand area, while green and red squares denote cargo-bikes and vans respectively. Additionally, red circles indicate the number of shipment requests served by the individual restaurants. The results show that consolidation points situated on major transport link and on the border of the demand area are predominately selected. Consequently, the simulation highlights the potential of setting up urban consolidation points at the periphery of the demand area to transship goods from motorized vehicles to cargo-bikes. As a result, long transports are performed by city cars or vans to save time, while the last-mile distribution in the area where restrictions for motorized vehicles exists, are performed by cargo-bikes. This enables the logistics provider to reduce delays and further to facilitate sustainable modes of transport for urban food deliveries.

Figure 7: Utilization of urban consolidation points (blue) with larger circles indicating a high amount of transshipments.

6. CONCLUSIONS

Urban consolidation and cargo-bikes are viable options to improve last-mile distribution in highly restricted and congested urban city centers. To facilitate the implementation and set-up of last-mile distribution systems, the presented DSS provides decision-makers the option to investigate different layouts and service offers in a wide range of problem settings. In this work, an agent-based simulation generates demand, while implemented vehicle routing and geographic information systems plan delivery routes and times. Particularly, as shown in the computational experiments, such last-mile distribution systems work well when further supported by motorized vehicles to assist in times of high demand or low available of cargo-bike drivers. As a result, cargo-bikes are facilitated for the final delivery to the customer on short distances, while longer distances are done by city cars or vans. For transshipment, existing infrastructure such as secured parking areas or public loading zones show promising results.

Future work focuses on the extension of the DSS by product specific parameters such as perishability or cooling requirements. This enables one to expand the application field of the DSS to related services such as e-groceries, i.e., the home delivery of food products, an industry with high growth rates, complex research questions and major implications on urban traffic. Additionally, to support future implementations, integrating inventory and replenishment strategies are of interest to enable a holistic view on logistics processes considering warehousing, order picking and last-mile distribution. Therefore, interfaces to existing inventory and warehouse management systems need to be developed to better integrate developed simulation procedures in daily operations.

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REFERENCES

Anderluh A., Hemmelmayr V.C., Nolz P.C., 2017. Synchronizing vans and cargo bikes in a city distribution network. Centr. Eur. J. Oper. Res. 25, 345–376

Browne M., Allen J., Leonardi J., 2011. Evaluating the use of an urban consolidation centre and electric vehicles in central London. IATSS Research 35, 1–6.

Chao I.M., 2002. A tabu search method for the truck and trailer routing problem. Computers & Operations Research 29, 33–51.

Cruijssen F., Cools M., Dullaert W., 2007. Horizontal cooperation in logistics: Opportunities and impediments. Transportation Research Part E: Logistics and Transportation Review 43, 129–142.

Cuda R., Guastaroba, G., Speranza M.G., 2015. A survey on two-echelon routing problems. Computers & Operations Research 55, 185-199.

Deliveroo, 2017. Deliveroo: Takeaway Delivery from Premium Restaurants near you. Available from: https://deliveroo.co.uk/ [accessed 7 February 2018].

Fikar, C., Hirsch, P., Gronalt, M., 2018. A decision support system to investigate dynamic last-mile distribution facilitating cargo-bikes. International Journal of Logistics Research and Applications 21(3). 300-317.

Fikar, C., 2018, A decision support system to investigate food losses in e-grocery deliveries. Computers and Industrial Engineering 117, 282-290.

foodora, 2017. foodora delivery service | We deliver, you enjoy! Available from: www.foodora.at [accessed 7 February 2018].

GraphHopper, 2017. Graphhopper route planner. Available from: https://graphhopper.com/ [accessed 7 February 2018].

Janjevic M., Ndiaye A., 2017. Investigating the financial viability of urban consolidation centre projects. Research in Transportation Business & Management 24, 101-113.

Kimes S.E., 2011. The Current State of Online Food Ordering in the U.S. Restaurant Industry. Cornell Hosp. Rep. 11, 6–18.

Manning S., Larsen M.M., Bharati P., 2015. Global delivery models: The role of talent, speed and time

zones in the global outsourcing industry. Journal of International Business Studies 46, 850–877.
OpenStreetMap, 2017. OpenStreetMap. Available from: https://www.openstreetmap.org/ [accessed 7 February 2018].
Paddeu D., 2017. The Bristol-Bath Urban freight Consolidation Centre from the perspective of its users. Case Studies on Transport Policy 5, 483–491.
Pillac V., Gendreau M., Guéret C., Medaglia A.L., 2013. A review of dynamic vehicle routing problems. European Journal of Operational Research 225, 1–11.
Ritzinger U., Puchinger J., Hartl, R.F., 2016. A survey on dynamic and stochastic vehicle routing problems. International Journal of Production Research 54, 215–231.
Rudolph C., Gruber J., 2017. Cargo cycles in commercial transport: Potentials, constraints, and recommendations. Research in Transportation Business & Management 24, 26-36.
Serrano-Hernandez, A., Hirsch, P., Faulin, J., Fikar, C., 2018. The role of horizontal cooperation to improve service quality in last-mile distribution. International Journal of Simulation and Process Modelling, in press.
Stadt Wien, 2016. Wahlen in Wien: Wahlsprengel [Elections in Vienna: Electorial districts]. data.gv.at - offene Daten Österreichs. Available from: https://www.data.gv.at/katalog/dataset/79c1030d-5cf6-4d58-ade6-02f66fb4dffb [accessed 7 February 2018].
UberEATS, 2017. UberEATS Delivers Fast. Available from: www.ubereats.com [accessed 7 February 2018].

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ON THE REAL TIME LOGISTICS MONITORING SYSTEM DEVELOPMENT USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT
In this article, we consider the creation of a monitoring system for observing the parameters of logistics systems in real time in the conditions of data deficit.
Our approach to the creation of such a monitoring system is based on the use of artificial neural networks for the classification of information entering the system. As well, the apparatus of colour stochastic Petri nets were used for data generation that is necessary for training the neural network.

Keywords: monitoring system, neural networks, Petri nets, SCPN, supply chain management.

1. INTRODUCTION

As part of the globalization process and the increasing degree of integration in logistics systems, there is a tendency of a complication of existing supply chains.
Thereby, the issue of monitoring the parameters of logistics systems and calculating the reliability of supply chains is becoming more acute, because with high dynamics of the processes taking place in such complex systems, the probability of failures caused by the human factor increases.
However, as noted in several studies (Short et al. 2015, Heras-Saizarbitoria and Boiral 2013), there is a number of difficulties associated with monitoring the parameters of supply chains.
Firstly, not all companies can afford development and implementation of high-quality monitoring systems (MS), for example, in the analysis (Short et al. 2015) it is noted that only about 60% of US small and medium-sized businesses embedded and using MS.
Secondly, the availability and quality of the MS directly depend on the ERP-system used in companies.
Thereby, for small and medium-sized companies it is not economically favourable to buy expensive ERP-systems, which include the ability of advanced parameters monitoring. Which leads to using of limited, in terms of monitoring, ERP-systems. As a rule, MS, typical for such ERP-systems is sufficiently simplified and only allows to manually observe the basic performance of the company.
Thus, it becomes clear that it is necessary to develop the MS, which would meet the following stated requirements:

- Real-time monitoring;
- Scalability;
- Low development and implementation costs;
- Cross-platform;

In this case, main functions of the MS can be defined as follows:

- Data collection and storage;
- Fluctuation detection;
- Classification (diagnostics) of fluctuations;
- Information Output.

Creating such MS will allow solving a number of problems described above. Thus, real-time monitoring will significantly reduce the amount of time required to make managerial decisions; scalability and cross-platform will significantly reduce deployment time of such MS.
In its turn, the task of network monitoring is highly specialized and has many possible solutions which are depended on final execution, which leads to the difficulties of creating universal methods for evaluation of the system's behavior (Giua and Seatzu 2015).
However, this problem can be avoided by using more universal approaches to data analysis and automation of Input-Output processes underlying of the MS.

One of the most universal approaches, that can be used to solve this problem, is the use of artificial neural networks (ANN). It is possible to highlight a number of basic advantages of ANN that allow it to be successfully applied to the problem considered in this paper: scalability, the ability to solve complexly formalized problems, low amount of errors in solving problems of classification and clusterization (Sukthomya and Tannock 2005; Sudha et al. 2016; Modaresi and Araghinejad, 2014).
One of the important features of ANN is the need for a large amount of data required for network training (Srivastava et al. 2014), however, it is not always possible to obtain this data. In this case, the most effective are two approaches: artificial generation of data on specified parameters (if data are completely absent), using of real and generated data jointly (Sukthomya and Tannock 2005).
Analysis of the literature has shown that the most popular method of data generation is the use of conditional random number generators with a given distribution (CRNG) (Miron et al. 2017, Seidlova et al. 2017).
However, this approach has a significant drawback: CRNG and the data produced by them do not always fully reflect the behavior of the modeled object, and as a consequence, when using the ANN, trained on this type of data on real objects, there is a high probability of errors occurring at the new data classification (Rajkumar and Bardina 2003). Therefore, the use of simulation modelling to generate input data seems more justified than the use of the CRNG.
In this article, we were faced with the task of developing MS in conditions of a data deficit coming from a real object. It was required that the MS could carry out the real-time classification and output to the operator information about the state of the logistics system. To implement this approach, we decided to use the ANN to classify the input data.
As a tool for generating data for training of ANN, we used the apparatus of stochastic coloured Petri nets (SCPN).
Since the SCPN has the following advantages:

- Opportunity to the simultaneous modelling of multiple parameters of the analyzed system (Wells 2002, Desel and Reisig 2015);
- Accounting of synchronization processes (Van der Aalst 1992);
- A low relative error of the created models with regard to the objects being modelled (Mazzuto 2012, Ullah 2011).

SCPN were used in the simulation modelling phase of the system under study, as well as in the generation of data for INS training.
The data for MS work is the stock level (SL) in the warehouse, as well as the delivery time (DT) for three different goods.
The process of creating an SCPN, learning, and testing of neural network, as well as the final classification is performed in the Wolfram Mathematica 11.3.

2. RESEARCH METHODOLOGY

Our approach to MS implementation is based on the classification of input datasets using neural networks. Wherein, the operating principle of the completed algorithm can be represented as the following sequence of steps: launched SCPN outputs data for ANN deployed in the Mathematica. This data includes information about the level of stock and the delivery time of the current consignment for three product names. After data receiving state of the system is classified by the ANN. Due to the fact that in most cases dynamics of changes in the SL varies for the specific product (or group of products), therefore, for the successful functioning of the MS, it is necessary to create an ANN for each product/group of products separately.

At the last stage, classified data with a note about the current state of the system is sent in the output window. A schematic representation of this process is shown in Figure 1.

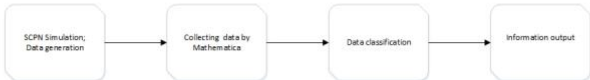

Figure 1. Schematic representation of the MS

The universality of the proposed approach is the ability to analyze any relevant data generated by SCPN. The input of the ANN can be fed with absolutely different data: a number of tokens in any position, a probability of the transition firings, and others. The neural network at the output will provide information about the value obtained and will display information about the system status on the screen.
However, before the algorithm starts, neural network should be trained on the test data obtained during the functioning of the SCPN. Accordingly, for each set of input data, training and control samples should be created to teach and validate results of the MS working.
Thus, for the correct operation of the MS, it is necessary to map the simulated object to the Petri net (Jensen and Kristensen 2009) to create data sets for the ANN, train the network, define rules and types of states described for further classification, check the reliability of classified data with a control data set. After completing the above steps, the monitoring system will be able to classify the new data fed into the input and detect situations in which the system is unstable.

3. SUPPLY CHAIN MODEL

To demonstrate a feasibility of the proposed approach, a supply chain model was developed, which was displayed in SCPN. Figure 2 shows a schematic representation of this logistics system.

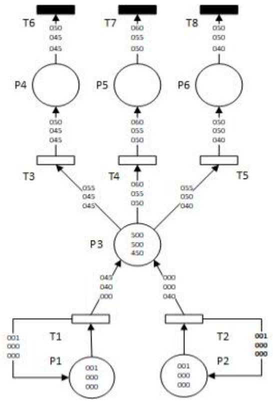

Figure 2. Supply Chain Model

The observed system consists of two suppliers (positions P1, P2), a consolidation warehouse (position P3), and three production plants (positions from P4 to P6). To produce one unit of finished goods, it is required to use three goods: A, B and C. At the same time, production facilities need different quantities of goods. This model of the logistics SCPN operates with 3 colours, values of which are encoded in the form of columns (parameters of arcs and positions), the first row in the column indicates the number of black tokens, the second one is red, the third is blue.

Parameters of the model, such as: DT, number of supplied products and the number of products required to create one unit of final product, varied depending on the scenario of the logistics system functioning.

At the stage of the system initialization, it is necessary to set an initial marking, namely to determine the balance of goods "A", "B" and "C" in the supplier's warehouse. The presence of tokens in positions P1 and P2 indicates a possibility of products supplying to a consolidation warehouse. After firing T1 and T2 transitions, tokens are duplicated in the above transitions, thus, suppliers can again carry out the delivery of products to a warehouse. With a firing of T3-T5 transitions, goods are sent from consolidation warehouse to production facilities. After delivery of goods to plants is finished products are sent further along the supply chain.

The transition rate parameter characterizes DT to the consolidation warehouse, as well as the DT products to the specific plant.

Four scenarios were developed that can characterize work of an above-described system: normal, negative, critical, and exceeding. Each of scenarios included setting up and analyzing parameters. In this case, 7 parameters were subject to change, their values for each scenario are presented in Table 1. Figure 3 schematically shows classification rules for SL (fig. 3a) and DT of goods (fig. 3b).

In this article, the parameters were chosen on the basis of the performance indicators, based on SCPN model, from ideal to critical condition of the system, when the number of failures in the movement of goods in the system reaches a maximum theoretical level. It is assumed that in practice, these scenarios will be determined on the basis of an expert assessment method, which will be based on data on the current state of the system, on the basis of economic and mathematical models and other economic methods for the performance evaluating of the economic systems. Also, these scenarios should be related to goals of further optimization, when simulating real complex logistic systems, it is possible to use parameters such as Key Performance Indicators.

Table 1: Parameter Values

Parameter /Scenario	Value	1	2	3	4
Q_A	Initial SL for product "A"	500	450	350	600
λ_1, λ_2	DT to warehouse	1	0,5	0,33	1.5
$\lambda_3, \lambda_4, \lambda_5$	DT to plants	1	0,5	0,33	1.5
$EOQ_{A,B}$	The order size of goods A and B	60; 30	45; 40	40; 35	65; 35

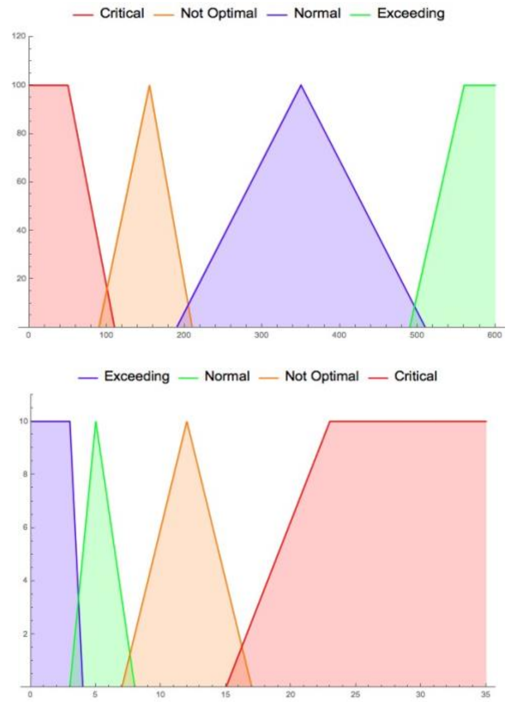

Figure 3. Rules Scale
a) Stock level b) Delivery time

The datasets that were created during the work of the SCPN under the given scenario are a matrix of dimension $m \times 2$, in which the first column contains information about the SL of the product goods in the warehouse, the second column denotes the DT of the current batch of goods. Each dataset contains 999 measurements.

4. REAL-TIME MONITORING SYSTEM DEVELOPMENT.

After creating datasets for each of the goods, these sets were divided into two samples: training and validation. It needed to be remarked, that samples were separated as follows: training dataset contains 80% of measurements, and validation dataset includes 20% measurements, respectively.

Further, using the "Classify" function built into the Mathematica language, three neural networks were created for each product, then these ANN's were trained on test samples. In the settings of the function, the method was set to "Neural Network", the performance target is "Quality". Neural network depth: 2 layers, use of genetic algorithms: on, the maximum number of epochs: 700, activation function: "*LogisticSigmoid*". Part of the code of the program, with the initialization of function "Classify" for product "A" is shown in Listing 1.

```
classifyA = Classify [tset, ValidationSet -> valset,
            Method -> {"NeuralNetwork",
             AcivationFunction -> LogisticsSigmoid,
             MaxTrainingRounds -> 700,
                NetworkDepth -> 2},
    PerformanceGoal -> "Quality", TargetDevice -> CPU]
```

Listing 1. Initialization of ANN

At the stage of network training, main algorithms of neural networks are tested. To simplify and accelerate development and testing process, the SCPN's are also developed in the Wolfram Mathematica environment. A homogeneous environment simplifies the exchange of data, and a wide range of tools for this environment allows to test a whole range of possible neural network configurations before you start developing a full-fledged software product. The properties of the neural network are shown in Table 2.

Table 2: Classifier information

Method	Neural Network
Number of classes	4
Number of training examples	999
L1 regularization coefficient	0
L2 regularization coefficient	0.1
Number of hidden layers	2
Hidden nodes	9,9
Hidden layer activation functions	LogisticSigmoid
CostFunction	True

As can be seen from the table above, and, it should be taken into account, function "*Classify*" has a lot of options which can be specified depending on user needs, however, if the user does not specify certain options, they are chosen automatically by Mathematica kernel.

In our case we did not specify the number of neurons in hidden layers in settings of the function, nonetheless, the optimal quantity of the neurons was chosen automatically and set to 9 in each hidden layer. Besides, the Mathematica system has set up parameters of input and output layers in the same way. A neural network includes one input layer including one neuron and an output layer also containing one neuron. The representation of the obtained neural network is shown in Figure 4.

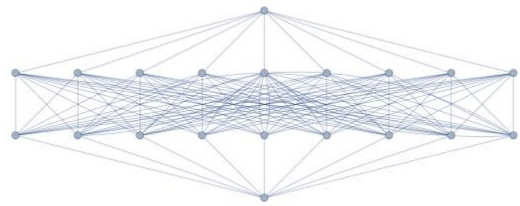

Figure 4. Representation of the ANN

Important information about results of training a neural network is evaluation time. This parameter depends primarily on the sample size and the computing performance of the device. In addition, it should be noted that the training of the neural network was performed on the CPU, while the GPU was not involved. Table 3 shows the training time for each network. The total training time for all products was 32 minutes.

A critical parameter characterizing the operation of the neural network is an accuracy of the classifier, since if an accuracy of training is insufficient, results of monitoring system's work will not reflect the behaviour of the model. Data on the accuracy of the ANN operation for each product are also given in Table 3.

Table 3: Training time and accuracy of ANNs.

Classifier name	Time, sec.	Accuracy
ClassifyA	654.230	0.9534
ClassifyB	690.702	0.9481
ClassifyC	634.034	0.9703

After completion of creation of three classifiers, they were tested for data that was not included in training and validation datasets. This sample counts 200 measurements for each product created by the SCPN. The results of classifier work for the test data set (product "A") from measurement 70 to 75 are shown in Table 4.

Table 4: Testing results.

SL/DT	Classification Result
15; 34	Critical
60; 28	Critical
5; 28	Critical
50; 22	Critical
95; 16	Not optimal

In the case of goods "A" and "B", accuracy on the test set of data was 1. The accuracy of ANN for the goods "C" was 0.999. The next step in creating a monitoring system was a dynamic update of data for the correct operation of the classifier.
Wherein, synchronization of data between Petri nets and neural networks is carried out through a file and a flag variable. When writing data from Petri nets to the file, the flag value is set to true. Part of the software system that is responsible for launching neural networks, monitors changing of this flag and if the flag value is true, reads data from the file and sends input vectors to the neural network. Next, it changes the flag value to false.
Let us take as an example the work of the real-time classification of product "A". Values of SL and DT for the product "A" are fed to the input of ANN. At the time of the last record of data in the file, 145 units of the product "A" were in the warehouse, and DT for the consignment of the product was 8 hours.
These data were read and classified by the ANN, after that information of the warehouse current state for the product "A", as well as the last value of SL and DT was displayed. According to previously defined classification rules, the "Not Optimal" value was expected at the output of the classifier, since both the stock level and the delivery time of the product consignment were not optimal.
Figure 5 shows the real-time classification of product "A".

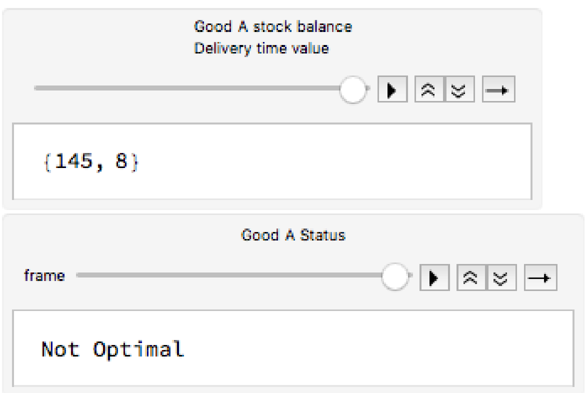

Figure 5. Real-time classification.

As can be seen from the figure, when new data on the goods that the Petri net generates are received, the classifier successfully performs analysis of values obtained, according to established rules.

5. CONCLUSIONS

In this paper, we developed and applied an algorithm for interaction between the SCPN and ANN to create a real-time MS. The complex approach to the creation of this system allows solving a number of problems at once.
Firstly, due to use of simulation modelling and the SCPN, the problem of lack of data for the training of ANN is removed.
Secondly, due to the short time that is required to develop such type of a system, it becomes possible to accelerate the process of introducing a ready-made software product to customer's enterprises. And thirdly, due to the presence in the Mathematica system of built-in translators for programming languages such as: Java, Python, C++, it becomes possible to create cross-platform software with minimal development costs.

6. FURTHER RESEARCH

Later, after carrying out all the basic tests of interaction between Petri nets and neural networks, it is planned to introduce Kohonen self-organizing maps (2001), aimed at solving clustering and visualization problems.
The implementation of application software is planned in the Python programming language, using the TensorFlow library. This library is a second-generation computer learning system: Google Brain. This library implementation runs on a number of parallel processors, both CPU and GPU (using CUDA libraries) (Flavors 2016). TensorFlow is capable of running on 64-bit architectures of Linux, macOS, Windows operating systems, as well as on mobile computing platforms Android and iOS.
A lot of supported platforms, small resource-consuming and compact will allow implementing, on the basis of this library, a cross-platform service-oriented application. In turn, extensive documentation and a large community will lead to rapid development and rapid implementation of new functionality in the application.
The planned architecture in this application is a service-oriented architecture (SOA). Generalized and resource-intensive calculations that do not require modification for each individual user are planned to be performed on remote computing servers. Also, such a solution will limit access to indirect data received from a real object, on the basis of which modelling will be carried out.
The results of calculations are planned to be output to a web interface, accessible from any browser of a mobile device or a stationary computer. This solution can be placed both on the Intranet, in case if the data is confidential, and on the Internet, which will allow for quick access to data for employees outside the enterprise.

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REFERENCES
Aalst W. M. P. Van Der, 1992. Timed coloured Petri nets and their application to logistics. Thesis (PhD). Eindhoven University of Technology.

Desel J. and Reisig W., 2015. The concepts of Petri nets. Software and Systems Modelling, 14(2), 669–683.

Flavors C.M. Giarnettia S., Leccesea F., Orionia B., Oreggiab M., Puccia C., Ramettaa S., 2016. Mapping by Kohonen network classification of Panel Tests of Extra Virgin Olive Oil. Measurement, 78, 366–372.

Giua A. and Seatzu C., 2015. Petri nets for the control of discrete event system. Software and Systems Modelling, 14 (2), 693-701.

Heras-Saizarbitoria I. and Boiral O., 2013. Research agenda on management system standards. International Journal of Management Reviews, 15(1), 47–65.

Jensen K. and Kristensen L.M., 2009. Coloured Petri Nets. Modelling and Validation of Concurrent System. New York: Springer-Verlag Berlin Heidelberg.

Kohonen T., 2001. Self-organizing maps. New York: Springer.

Mazzuto G., Bevilacqua M., Ciarapica, F.E., 2014. Supply chain modelling and managing, using timed coloured Petri nets: a case study. International Journal of Production Research, 50 (16), 4718-4733.

Miron M., Janer J., Emilia G., 2017. Generating data to train convolutional neural networks for classical music source separation. Proceedings of the 14th Sound and Music Computing Conference, 227–233. July 5-8, Espoo, Finland.

Modaresi F. and Araghinejad S., 2014. A comparative assessment of support vector machines, probabilistic neural networks, and K-nearest neighbor algorithms for water quality classification. Water Resources Management, 28(12), 4095–4111.

Rajkumar T. and Bardina, J., 2003. Training data requirement for a neural network to predict aerodynamic coefficients. NASA Ames Research Center, 1-12.

Seidlova R., Pozivil J., Seidl J., Malecl L., 2017. Synthetic data generator for testing of classification rule algorithms. Neural Network World, 2 (2017), 215–229.

Short J.L., Toffel M.W., Huggil A.R., 2015. Monitoring Global Supply Chains. Harvard Business School, 1-14.

Srivastava N., Hinton G., Krizhevsky A., Sutskever I., Salakhutdinov R., 2014. Dropout: A Simple Way to Prevent Neural Networks from Overfitting. Journal of Machine Learning Research, 15 (2014), 1929-1958.

Sudha L., Dillibabu R., Srivatsa Srinivas S., Annamalai A., 2016. Optimization of process parameters in feed manufacturing using artificial neural network. Computers and Electronics in Agriculture, 120 (2016), 1–6.

Sukthomya W. and Tannock, J., 2005. The training of neural networks to model manufacturing processes. Journal of Intelligent Manufacturing, 16, 39–51.

Ullah H., 2011. Petri net versus queuing theory for evaluation of FMS. Assembly Automation, 31 (1), 29–37.

Wells L., 2002. Performance Analysis using Coloured Petri Nets. Thesis (PhD). University of Aarhus.

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A DISCRETE EVENT SIMULATION TO INVESTIGATE UNLOADING OPERATIONS IN AN URBAN RETAIL STREET

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ABSTRACT
This paper explores on- and off-street parking for unloading operations in an urban retail street. A discrete-event simulation is developed introducing a comprehensive model to investigate urban freight unloading operations and to assess managerial and policy implications. To consider both the environmental and economic impact, the problem settings is investigated considering the impacts on lead times, delays and emissions. Therefore, various emission factors based on vehicle load, waiting times and driving mode are integrated. First results indicate the influence of improved unloading operations on lead time and emissions.

Keywords: unloading operations, freight transport, simulation, emissions

1. INTRODUCTION

Demand for deliveries and pickups in urban areas is substantially increasing (Cherrett et al. 2012) resulting in more traffic as well as major delays due to congestion and limited parking spaces. As more and more people are living in urban areas, e.g., 72 % of the European population (UN-Habitat 2016), solutions are required to limit negative externalities of traffic such as noise and air pollution. Transport is one of the largest emitters of greenhouse gas (GHG) emissions (IPCC 2014) and freight transport contributes to a considerable part.
According to de Abreu e Silva and Alho (2016), such negative externalities can result from infrastructure inefficiencies, particularly, parking problems.
The two main stakeholders who can influence the urban freight transport conditions are governmental bodies or city councils, who operate and, thus, control the infrastructure (Marcucci, Gatta, and Scaccia 2015), and retailers, who receive freight (Gatta, Marcucci, and Le Pira 2017). Considering the problems and inefficiencies urban freight transport faces when it comes to parking and especially unloading in busy retail streets, many questions arise for businesses and local governments. Therefore, it is of importance to explore on- and off-street parking and unloading operations in an urban retail street. Particularly important for successful urban freight deliveries is the optimization of loading and unloading infrastructure, which facilitates access to stores and parking of vehicles. Additionally, dwell times i.e., the time freight vehicles spend on the unloading infrastructure while boxes are unloaded, of freight vehicles are closely linked to such infrastructure decisions. Impacts of loading and unloading locations are investigated in Cherrett et al. (2012) and Allen, Browne, Cherrett, and McLeod (2008). The authors highlight the impact of on-street locations on traffic delays, however, note that even off-street locations can cause traffic problems if access for the freight vehicle is challenging and requires complex manoeuvres.
Consequently, investigating loading and unloading infrastructure is of importance to facilitate efficient urban freight deliveries and to reduce delays and environmental impact. As daily operations, however, are highly uncertain, simulation-based decision support systems (DSS) have to be developed to support deriving related decisions and provide managerial and policy implications. The presented model aims to support decision makers in assessing different implications with regard to emissions (local, regional and global) and time in order to improve urban freight unloading operations in the future. The contribution of this work is to introduce a DSS to investigate urban freight unloading operations and to present first results and implications thereof. The remainder of this paper is structured as follows: Section 2 introduces the developed DSS. Computation experiments are provided in Section 3. Preliminary results are discussed in Section 4 and concluding remarks given in Section 5.

2. METHOD

To address the decision-making problem of assessing different outcomes of different unloading infrastructures and unloading operations, a discrete-event simulation model was generated. Within this simulation, in order to supply goods to a retail street, a certain number of vehicles enter the street during the course of a day. Each receiver, i.e., a store, may have an unloading infrastructure in front of its building where delivery vehicles can stop to unload. If available, this infrastructure has a capacity to load and unload one delivery vehicle at a time. When a delivery vehicle arrives, a limited number of staff supports the unloading of the vehicle. There are two main types of unloading infrastructure: loading zones and loading bays.

Loading zones resemble common parking spaces for passenger cars, may however differ in length and width. A loading bay borders a platform for loading trucks also known as loading dock it can only be used by vehicles unloading to this specific store.

The aim of the presented model is to analyse the following elements for the given problem:

- optimal mix of loading zones and loading bays;
- availability and number of staff at each receiver (store) assisting with unloading tasks; as well as the detailed impact of operations on
- emissions and
- time

Consequently, by running the simulation, city planners and local businesses can investigate the following questions: (i) Should city planners encourage businesses to build loading ramps to reduce total vehicle emissions? (ii) Should city planners encourage businesses to provide unloading equipment or additional staff for unloading to reduce emissions? (iii) Should businesses provide unloading equipment or additional staff for unloading for efficiency reasons?

2.1. Discrete-Event Simulation

The model consists of seven main components (entities and resources); vehicles, boxes, street-segments, stores, staff, equipment at stores and drivers.

Vehicles transport boxes through the street, which is made up of multiple street-segments, to their point of delivery which is a specific store. At the store the boxes are unloaded. Unloading is done by the vehicles driver and staff of the receiving store. Each vehicle is loaded with a number of boxes which have one (common) destination store within the street. The number of boxes loaded on the vehicles depends on the destination and cannot exceed the maximum capacity of the vehicle. As soon as the vehicle is loaded it enters its first street-segment. Each vehicle passes several street-segments until it arrives at a street-segment which is suitable for making a delivery to the given store, where it stops and all boxes are unloaded. There are different parking strategies for vehicles which deliver to a store with a loading zone and those delivering to a store with a loading bay. Vehicles which have the possibility to unload using a loading bay always use the loading bay for unloading as this is more direct and, thus, faster than unloading using a loading zone. Other vehicles stop directly in front of the receiving store or use unloading infrastructure a maximum of one street-segment away, it is also possible for vehicles to use unloading infrastructure at the opposite side of the street.

In case a loading bay is occupied a vehicle which needs to deliver to the associated store cannot unload. Thus, the vehicle waits on street for the infrastructure to become idle. During this time the vehicle blocks other vehicles which want to pass. However, the vehicle can be overtaken in case there is no oncoming traffic. Each vehicle waiting for delivery only waits for a certain time until it moves on as it assumingly has other collections or deliveries to make outside the considered street. In case the vehicle has waited for the given time and the loading bay is still occupied it drives on until it reaches the end of the simulated street. The vehicle drives an extra round and then enters the street again where it first started. Seven criteria which influence dwell times i.e., the times vehicles spent at the unloading infrastructure, according to Allen et al. (2000) in Cherrett et al. (2012) are included in the model:

- distance,
- locations (i.e., off-street vs on street),
- size of the delivery,
- means of getting goods off the vehicle and conveying them to the premises and
- the number of people performing the delivery,
- assisting staff at the receiving establishment and
- other deliveries/collections at the same time at one receiving establishment.

Distance is included by the loading space a vehicle chooses. Off vs. on-street parking and, thus, location is explicitly included by the differentiation between loading zones and loading bays.

The size of the delivery (i.e., the number of boxes delivered) may be larger or smaller, and is larger for trucks than for vans. The number of people performing the delivery and the assistance of staff with unloading is included by simulating different numbers of staff who unload together with the driver. Staff only unloads vehicles supplying its own store.

Other deliveries at the same store are taken into account as unloading equipment and assisting staff can be used less if there are other deliveries at the same time. For the simulation experiments we used the following elements and assumptions:

- Each street segment has a length of 2 meters
- Each equipment can only be used if there is staff or a driver available to use it
- Each equipment can carry a maximum number of loading units, which is defined in the scenarios.
- Drivers and staff need a certain amount of time to travel to and from the store carrying loading units, this time increases with distance (Martin 2014).
- There are two types of freight vehicles entering the street light vans and heavy trucks
- Vans are light good vehicles with a laden weight up to 3.5 tonnes. We assume a fleet of vehicles with a Euro 6 Standard.
- Trucks are heavy trucks are heavy-duty vehicles with a laden weight up to 7.5 tonnes. We assume a fleet of vehicles with a Euro VI Standard.
- Heavy and light trucks differ due a number of aspects shown in Table 1.

Table 1: Differences between Vans and Trucks

	Van	Truck
maximum loading volume [boxes]	100	300
Average speed when not hindered [km/h]	46.64	41.44
Average speed when hindered [km/h]	12.73	11.79
Emission factors	Different for all emissions, emission factors change for trucks depending on their load factor	Different for all emissions

2.2. Emissions

Within the simulation, emission calculations are based on the emission factors of the traffic situation emissions model HBEFA (Handbook for Emission Factors for Road Transport), which is used widely within Europe (Grote et al. 2016). For the two vehicle types we used unweight emission factors for EURO 6 (vans) and EURO VI (trucks) group data respectively. It is important to notice that we not only include emissions of Carbon dioxide (CO2) which is the best known GHG and responsible for climate change to a great extent but also local and regional emissions. We include Particulate matters (PM) also known as fine dust with local effects, Carbon monoxide (CO), Nitrogen oxide (NOx) and Hydrocarbons (HC) which all have local and regional effects and indirectly act as a GHG.
Emission factors are the average amount/mass of a pollutant emitted per length driven by a vehicle. In HBEFA emission factors are given in gram per kilometre (g/km). As emission factors also depend on the speed of the vehicles we use emission factors for collection roads in urban areas with a maximum speed of 50 km/h. Within our model we assume a 20 meter length for each street segment and divide the appropriate factors accordingly. Unfortunately no idling emission data is available for freight vehicles; if data was available this could easily be included into our model. The same is also true for starting and stopping emissions.

3. COMPUTATIONAL EXPERIMENTS

The introduced DSS is developed with AnyLogic and coded in Java. In our experiments the mix of loading infrastructure, number of staff helping with unloading and available equipment both at the store and in the truck which lead to the best results for lead time and emissions for different situations is investigated. For the parameter variation/experiments in AnyLogic we varied the:

- Layout defined as the patterns of loading zones and loading bays within the street. Thus, we varied the number and positions of loading bays and loading zones to see how this affects lead time and emissions
- the number of staff helping with unloading at a shop, this was the same for each store with the same loading infrastructure i.e., each store with a loading zone had five staff members helping in one experiment
- The number and capacity of the equipment at the store, again this was the same for all stores with the same loading infrastructure, as it was assumed that other equipment can be used when a loading bay is used.
- The capacity of the equipment the driver uses
-

3.1. Test settings

To investigate the introduced problem setting and to derive policy and managerial implications, the test settings were built based on a busy retail street in Vienna with about 1200 businesses in the street itself and 1150 businesses in its close range according to Verkehrsplanung Käfer GmbH (2011). Although this study also looked at places to stop for unloading there was no differentiation made between loading bays and loading zones but mainly between loading zones close or further away from vehicle destinations. Within our test setting, each store was assigned the minimum and maximum number of boxes it receives during one delivery. The exact numbers were assigned randomly and stay constant within our test settings. The number of vehicles per day is set to 130. This is in line with findings in Verkehrsplanung Käfer GmbH (2011) and Cherrett et al. (2012) regarding the number of deliveries per receiver per week.

4. PRELIMINARY RESULTS

Results of first test runs indicate that lead time as well as emissions can be reduced by improving unloading operations. In case only loading zones are available within the retail street results suggest that providing only one additional staff member for helping with unloading can decrease the maximum of the mean lead time of vehicles by over 90 % given that the staff member is equipped with unloading equipment with a capacity of 5 (standard boxes) and the vehicles driver has a capacity of one unit. In this scenario maximum mean CO2 emission decrease by more than 40 %.

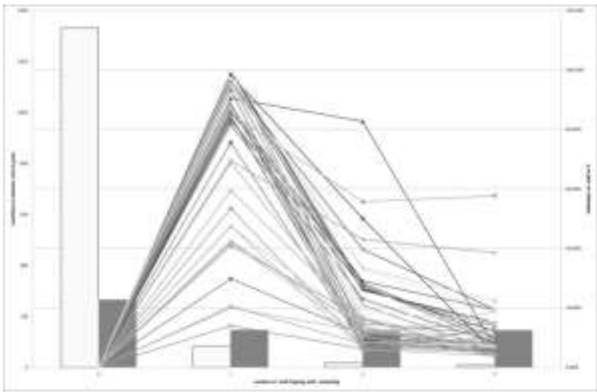

Figure 3: Changes in maximum mean lead time (white bar) and CO2 emission (grey bar) when adding additional staff to loading zones and maximum mean utilization of staff in at different stores (grey lines).

While on average, the maximum utilization for unloading lies between 30 and 100 %, this can be considerably reduced to 4 to 60 % when providing three staff members to help with unloading, additionally even further decreasing the vehicles lead time and CO2 emissions as shown in Figure 3. Lead times and CO2 emissions can also be reduced by increasing the drivers capacity to carry boxes. First results indicate that an increase in capacity from one to three boxes can decrease overall lead time of the vehicle by around 20 % in case no additional staff member helps with unloading and by around 15 % when one staff member (capacity 5) helps with unloading. Maximum CO2 emissions are reduced by around 15 % without a staff member helping with unloading and decrease with increasing driver capacity when there are three staff members helping with unloading in loading zones.

Similarly to CO2 emissions, other emissions can be reduced by adding additional staff to stores with loading zones as shown in Figure 4. For example, maximum mean NOx emissions can be reduced by around 40 % when one staff member helps with unloading. Using two or three staff members does, however, only have a small additional effect on NOx emissions. HC as well as CO emissions can be reduced by almost 50 % using one additional staff member. Fine dust (PM) can according to preliminary results be reduced considerably by more than 96 % when adding one and by over 98 % when adding two or three staff members to help with unloading.

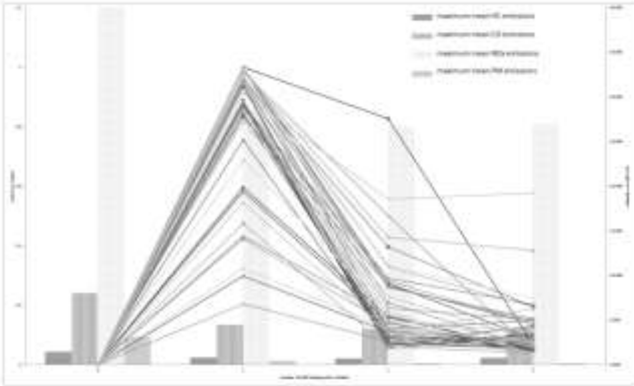

Figure 4: Changes in maximum mean emissions (bars) and maximum mean utilization of staff at different stores (grey lines) when adding additional staff

5. CONCLUSIONS

The preliminary results show that improving unloading operations in retail streets can have positive impacts on both economic and ecologic aspects. Total lead time of vehicles and, thus, drivers working time can be substantially reduced when providing the driver with additional help during unloading and equipping the vehicle with unloading equipment to increase the capacity of the driver. Depending on the cost of the driver/helper carriers might be able to provide financial advantages to stores helping with unloading their own goods. Additionally, all considered emissions to air could be reduced when unloading operations are improved. These first results imply that city representatives should provide incentives to stores in order for them to improve unloading operations by providing staff to help unloading. Future work will consider different number of staff and capacities of drivers and additionally different loading infrastructures as well as combinations thereof.

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REFERENCES

Alho A. R., de Abreu e Silva J., de Sousa J. P., Blanco E., 2016. Decreasing Congestion by Optimizing the Number, Location, and Usage of Loading/Unloading Bays for Urban Freight. Paper presented at the Transportation Research Board 95th Annual Meeting, Washington DC, United States.

Allen J., Anderson S., Browne M., Jones P., 2000. A framework for considering policies to encourage sustainable urban freight traffic and goods/service flows - Summary Report: University of Westminster.
Allen J., Browne M., Cherrett T., McLeod, F., 2008. Review of UK Urban Freight Studies: University of Westminster and University of Southampton.
Cherrett T., Allen J., McLeod F., Maynard S., Hickford, A., Browne M., 2012. Understanding urban freight activity – key issues for freight planning. Journal of Transport Geography 24:22-32.
de Abreu e Silva J., Alho A.R., 2016. Using Structural Equations Modeling to explore perceived urban freight deliveries parking issues. Transportation Research Part A: Policy and Practice 102:18-32.
Gatta V., Marcucci E., Le Pira M., 2017. Smart urban freight planning process: integrating desk, living lab and modelling approaches in decision-making. European Transport Research Review 9:32.
Grote M., Williams I., Preston J., Kemp S., 2016. Including congestion effects in urban road traffic CO2 emissions modelling: Do Local Government Authorities have the right options?. Transportation Research Part D: Transport and Environment 43:95-106.
IPCC, 2014. Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change[Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Geneva, Switzerland.
Marcucci E., Gatta V., Scaccia L., 2015. Urban freight, parking and pricing policies: An evaluation from a transport providers' perspective. Transportation Research Part A: Policy and Practice 74:239-249.
Martin H., 2014. Transport- und Lagerlogistik: Planung, Struktur, Steuerung und Kosten von Systemen der Intralogistik. Wiesbaden: Springer Fachmedien Wiesbaden.
Verkehrsplanung Käfer GmbH, 2011. Mariahilfer Strasse: Strukturerhebung Lieferverkehr: Wirtschaftskammer Wien, Abteilung Stadtplanung und Verkehrspolitik.

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CALABRIA REGION AS COMPETITIVE EUROPEAN TERMINAL PORT FOR THE SILK MARITIME ROAD. SCENARIO SIMULATION

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ABSTRACT
The markets globalization and the sustained world growth of trade in the last decades pushed many States toward new challenges; consistent investments are envisaged to build new great infrastructures.
After an overview of some development Scenarios of world freight transport, the attention is focused on the Chinese project of Silk Roads. A comparative analysis based on Scenario simulations is proposed, in order to valuate different intermodal alternative routes between China and Central Europe. The set of alternative solutions includes a route across Calabria Region, taken as strategic multi-function terminal for the Maritime Silk Road, with a connection to the center of Europe by railway along the Adriatic-Ionian coast. A methodological approach is firstly described, based on transport supply model, some potential alternatives routes are identified and simulated, and finally the main results are illustrated and commented. The analyses are proposed from the perspective of a multimodal transport operator (MTO), but also considering the relationship between investment costs and potential benefits for a Euro-Chinese partnership.

Keywords: silk road, simulation, intermodality, transport costs

1. INTRODUCTION

The distribution of commercial traffic on the planet is changing very rapidly. The economic development of some important areas in Asia, India, Africa and South America has generated significant levels of consumer goods demand and a further boost to the growth of transport supply in terms of infrastructures and services. Logistics chains are being modified and commit many States to sustain substantial investments. Some large infrastructural works have been completed, others are nearing completion, and others are still at the planning stage. Just think of the Suez and Panama canals, the development of transcontinental rail networks, the rapid growth of some big ports in the Far East, the intense revival of air traffic. Feasibility studies and hypotheses of new transport routes, such as the Silk Road or the Arctic Road, are on the international scene with increasing insistence. Europe and Asia, especially China and India, are characterized by increasing volumes of freight exchange; growing maritime traffics result in possible phenomena of saturation for some ports or in the need of larger and better organised ones (Ordabayev, 2015). China is strongly committed to the construction of two commercial corridors, one maritime and the other by rail (Silk Roads; "One Belt, one Road" - OBOR) in order to reach the freight at lower costs on the Europe (Fig.1). To achieve this great project, the Chinese government has planned significant investments; the construction and management of a new commercial port in Venice capable of hosting large container ships (18-24.000 TEUs), with a commitment of the order of 2 billion euros, is envisaged. The railway route starts from Xian through rural China, touches Teheran in Iran, arrives in Turkey, passing through Bosphorus Strait (Istanbul), and has the city of Duisburg in Germany the terminal in Europe. However, the railway arm of the new Silk Road is already a reality: some European freight forwarders offer today the opportunity to move freight along this route.

Figure 1: Silk Maritime and Railway Roads

A general overview of main international transport investments and projects is proposed firstly in the paper, and some development Scenarios of global freight traffic are illustrated (Suez Canal, Panama Canal, Arctic Freight Road, Silk Maritime Road, Trans-Asiatic Railway). The attention focus on the Chinese Silk Road (strategies on Mediterranean context, last segment of maritime silk).

The design of Maritime Silk Road seems to pass through Adriatic Sea, ending in Venice, where the freights should be moved on trains towards Central Europe. But this road solution maybe underestimates a series of problematics; so an alternative solution, more profitable and feasible, is proposed and described: the European continental terminal could be Calabria Region (with an interesting port system, based on two big terminal container as Gioia Tauro and Corigliano); with a possible integrated expansion of the port system along the ionic corridor towards Puglia (Taranto port) and towards Sicily (Augusta and Catania ports). The advantages should be seen from a comparative perspective: greater Euro-Mediterranean geographical centrality, less maritime distances, ports of considerable capacity already operational. This solution bring to lower and reasonable investments, addressed to improve slightly the rail transport; it permits to avoid heavy impacts resulting from the construction of a new great port in the Venetian lagoon on the environment and the existent tourism industry and to hook, from the South, the whole and attractive Italian region.
A comparative analysis based on Scenario simulations is proposed, which includes among the Scenarios also an option where Calabria Region is considered as a strategic multi-function terminal for the Maritime Silk Road, connected by railway along the Ionic-Adriatic coast, to Venice and the upper Adriatic ports. The methodological approach is firstly described, based on network model and quantitative transport supply attributes, so the potential alternative South-North Mediterranean routes are identified, and finally simulations are illustrated and results commented. The analyses are proposed from the perspective of a multimodal transport operator (MTO), but also considering the relationship between investment costs and potential benefits for a Euro-Chinese partnership.

2. GLOBAL DEVELOPMENT SCENARIOS

China, USA and India are likely to become by far the three largest economies in the World.
China, India, Brazil and other emerging markets are set to become not just low cost production locations but also increasingly large consumer markets.
The Triple-E class is synonymous with Economy of scale, Energy Efficiency and Environmental improvement. Their dimensions are 400 m length, 59 m beam and more than 70 m height. Access, mooring and operation of these mega-ships pose a new challenge for ports and terminals, demanding quays with 17 m draught and capacity to accommodate 1,800 MT cranes, with a maximum reach of more than 72 m. The Emma Maersk, CMA-CGM Marco Polo and Triple-E Class of Maersk Line are milestones within a process of gigantism that seems unlimited. In fact, marine engineering has already dreamt up bigger ships: the Malacca-Max-type (MalMax class) whose dimensions could be similar to those of Triple-E, except for a bigger draught. In this way, MalMax's dimensions might be as follows: 400 m length, 60 m beam and 21 m draught, with an equivalent capacity of 24.500 TEUs. This means double capacity of the New Panamax (12.500 TEUs). But, there are announcement of order vessels even of bigger capacity: 18.400 TEUs.
Another important pattern to take into account is that the container industry evolution is characterized by a continuous process of growth and concentration. So the top-3 container shipping lines (Grand Alliance, CKHY Alliance, New World Alliance) control almost 40 % of the total world fleet capacity. The Top-10 control 75 %. The resulting lower numbers of big operators – or port customers – means that the "big boys" have the control. As for the terminal operators, the situation is almost the same: the top-5 concentrate 67 % of the container business.
In the design of future Scenarios it is important to consider also significant investments aimed at improving transport infrastructures and services which will then affect international traffic framework. Among other, there are projects to facilitate the transit of ships in particular points (Canals of Suez, Panama, Malacca); or new routes such as the Trans-Asian Railway and the Arctic Road.

2.1. Suez Canal

The Suez Canal allows direct navigation from the Mediterranean to the Indian Ocean, avoiding the circumnavigation of Africa. The opening of the canal dates back to 1869; it measured 164 km, was 8 m deep and 53 m wide and allowed the transit of ships with a maximum draft of 7 m. Following the enlargement works, which began in 2010, the canal has taken the following measures: 193,30 km in length; 24 m depth; 205/225 m wide, and allows the transit of ships with a maximum draft of 20 m. The canal consists of three trunks: a 22 km north access, a 162,3 km canal body, a 9 km south access. In August 2015, the doubling of a part of the canal was inaugurated. A second 35 km long navigation lane was built alongside the existing canal, allowing ships to travel in opposite directions. A further enlargement was carried out and the depth reached 37 m.
Today the transit capacity is 97 ships compared to the previous 49 and it is possible the passage of ships without tonnage limits, with a capacity exceeding 21.000 TEUs. The canal operates a lock-free transit system with passage by convoy, one southbound and one northbound daily, with an average transit times di circa 12 hours.
In 2017, Suez scored 17.550 ships in transit and 1,04 billion tons of goods. The container segment is the leader, accounting for 45,4% of the total cargo. Tankers is the second market segment (18,0%).
The average cost of the transit through the Suez Canal is about 450 thousand dollars, with a saving of about 230 thousand dollars compared to the route around Africa.
The Canal is owned and maintained by the Suez Canal Authority (SCA), controlled by Egypt Government.

Figure 2: Suez Canal

2.2. Panama Canal

The Panama Canal is an artificial 77 km waterway that connects the Atlantic Ocean with the Pacific Ocean. The canal cuts across the Isthmus of Panama and is a conduit for maritime trade. Canal locks are at each end to lift ships up to Gatun Lake, an artificial lake created to reduce the amount of excavation work required for the canal, 26 m above sea level, and then lower the ships at the other end. The original locks are 34 m wide. A third, wider lane of locks was constructed between 2007 and 2016. The canal consists of artificial lakes, several improved and artificial channels, and three sets of locks. The layout of the canal as seen by a ship passing from the Atlantic to the Pacific is:

- an entrance runs 8.4 km. It provides a deep water port (Cristóbal), with facilities like multimodal cargo exchange (to and from train) and the Colón Free Trade Zone (a free port).
- a main central canal 55,4 km long.
- a 13.2 km exit channel passing under the Bridge of the Americas.

The expanded canal began commercial operation on June 2016. The new locks allow transit of larger, post-Panamax and new Panamax ships, capable of handling more cargo.

Figure 3: Panama Canal

This has far-reaching implications for the structure of world and European container trades, including the introduction of high-volume pendulum and round-the-world services through Panama and potential relay transhipment of North European cargoes at South Europe/Mediterranean hubs.
Emerging markets, such as West Africa, traditionally served by the Asia – Europe routes via transhipment, are now also being attended by direct services, with the help of important port developments which are in project in the West coast. The new locks will allow the transit of ships up to 49 m beam and 365 m length, with a maximum draught of 15 m. It is today possible, the passage of higher tonnage ships called “Post Panamax”, with a capacity of up to 15.000 TEUs. The traffic capacity is 7 ships/day.
The average transit times is 10 hours, but with waiting time, ships may require about 25 hours to negotiate the canal.
In 2017 the waterway scored 13.548 ships for a total of 241 million tons of freight. The container segment continued to serve as the leading market segment of tonnage through the Canal, accounting for 35.4 % of the total cargo received. Tankers represented the following market segment (26,0%). The next leading segments included bulk carriers (19,5%) and vehicle carriers (11,6%).
The toll depends on the ships size. The largest container ships pay between 800 thousand and 1 million dollars.
The Panama Canal Authority (ACP) is the agency of the Panama Government responsible for the operation and management of the Panama Canal.

2.3. Strait of Malacca

The Strait of Malacca is a narrow 890 km stretch of water between the Malaysia Peninsula and the Indonesian island of Sumatra and connects the Pacific Ocean with the Indian Ocean. From an economic and strategic perspective, the Strait of Malacca is one of the most important shipping lanes in the world. Nearly 100.000 vessels pass through it each year making it the busiest strait in the world, carrying about 25% of the world's traded goods. In addition, it is also one of the world's most congested shipping choke points because it narrows to only 2.8 km wide at the Phillips Channel (close to the south of Singapore). The maximum size (specifically draught) of a vessel that can pass through the Strait is referred to as Malaccamax, that is, for some of the world's largest ships (mostly oil tankers), the Strait's minimum depth (25 m) is not deep enough. The next closest passageway (the Sunda Strait between Sumatra and Java) is even more shallow and narrow. Therefore, ships exceeding the Malaccamax must detour a few thousand nautical miles and use the Lombok Strait, Makassar Strait, Sibutu Passage, or Mindoro Strait instead.
Several projects have been proposed aimed at creating a channel at the Gulf of Thailand that have not been successful.
The possibility of the Kra Canal becoming a reality has been greatly increased by China’s Maritime Silk Road initiative and the Thai Canal Association (TCA).
The new Thai Canal project includes two portions. The first portion is seen as a counter to the “Malacca Dilemma”. The canal will link the South China Sea to the Andaman Sea, drastically diminishing transit time across the busiest maritime shipping route. Chinese companies are extremely interested in speeding up the

project. The second portion is the establishment of a Special Economic Zone (SEZ). The new zone includes the addition of cities and artificial islands, which will enhance new industries and infrastructure in the region. This would make Thailand into a “logistic hub” and link Thailand to countries from all over the world.

Figure 4: Strait of Malacca

2.4. Arctic Route

In relation to climate change, an Arctic Route has been also hypothesized for the transit of ships from the Asian Far East to Europe (Jong-Ho et al, 2013). It would have the advantage of being shorter than the current routes (about 10 days less in comparison to Suez route), but currently has several limitations. In the first place, it is not always practicable. The navigability of arctic sea routes depends primarily on the expanse of the floe, since it prevents naval traffic for a part of the year. The fluctuation of the area covered by sea ice determines the time windows during which ships can pass through.

Figure 5: Arctic route and traditional maritime route between China and Europe (www.businessinsider.com)

Some projections indicate that the ice floe will greatly diminish in the future, and might even disappear by the end of the century. On average over a year, the ice floe has diminished by 4.3% every ten years. However, the reduction is not uniform over the year. It is maximum in September (- 10.7%) over ten years, and minimum in March (-2.8%). Projection models of the evolution of the arctic ice floe are based on the last 30 years. As a consequence of the reduction of the ice floe, the temporal window of navigability is increasing, and routes, once inaccessible to regular vessels, may open up. Some projections indicate that in 2030 the route will be open for a whole summer month and in 2060 from August to October.

2.5. Transcontinental railway

In the last decades an increasing Chinese attention was addressed to the continental railway, looking towards the European market.
First actions have been carried out to improve the connections through Russia. The freight traffics between Russia and China have recorded a sustained growth, especially as regards containerized goods. In 2006 China and Russia have signed an agreement that fixes the terms of a program of mutual exchange of freights, including a series of technical provisions concerning transport and the details of its operations and daily services. Regular railway services between Beijing and Moscow were envisaged, as well as programs aimed at a rapid widening of the network (Korovyakovsky and Szoltysek, 2006).
In 2008 China and Germany inaugurated a long-distance freight container train service (Figure 6). Travelling a total of 10.000 km, the train uses the China Railways and the Trans-Mongolian line to travel from Xiangtan to Ulaanbaatar, where it reach Irkutsk and then continues north to the Trans-Siberian. After reaching the end of the Trans-Siberian at Moscow the train continues through Belarus and Poland, until Hamburg. Total transit time was 15 days, as compared with the 30 days average it would take for the freight to make the same journey by ship. The first train of 50 containers, carrying a mixed load of clothes, ceramics and electronics, travelled on tracks operated by six different railway companies.

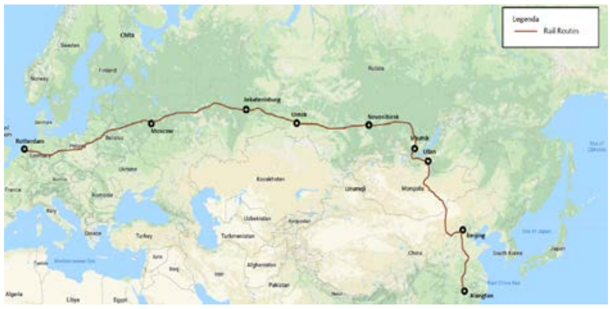
Figure 6: Railway Line from Xiangtang to Hamburg

Another test run, from Chongqing to Duisburg via Alashankou crossing Kazakhstan, Russia, Belarus and Poland, took place in spring 2011, covering 10.300 km in 16 days. As of March 2014, the Chonqing-Duisburg route makes three weekly services carrying up to 100 TEUs.

In April 2017 a first freight train started from UK (Stanford-le-Hope) to China (Yiwu), travelling for 12.000 km, through 7 States (France, Belgium, Germany, Poland, Belarus, Russia and Kazakhstan). Travel time was 3 weeks, about half of the maritime time.
By 2016, the freight rail service between a number of container terminals in China and in Europe has become fairly regular. Between some city pairs, there is one train per week.

2.5.1. A framework about main Euro-Asian railway network

The Euro-Asian transport Scenario results particularly complex. The sources often appear puzzled and incomplete; moreover, analysts find a large amount of proposals and plans of development. Therefore, it is suitable to consider UN guidelines, specifically those of the Economic and Social Commission for Asia and the Pacific which has elaborated a series of documents.
The Euro-Asian railway network is quite heterogeneous; its main components and features are here referred (Figure 7).

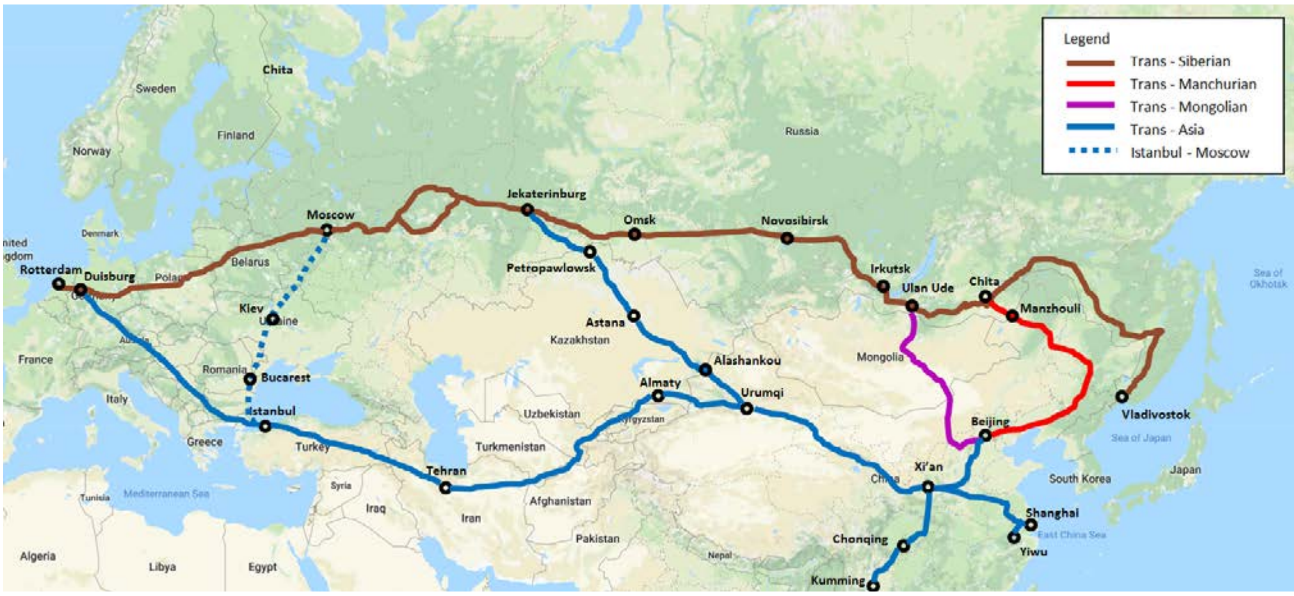

Figure 7: Main Euro-Asian railways network

The Trans-Siberian railway extends from Moscow to Vladivostok. Completely situated in the Russian territory, the railway presents a gauge value of 1.520 mm. The commercial speed is 58 km/h. Trans-Asia Railway has endpoints in Kunming and Shanghai (China) and in Istanbul (Turkey). The commercial speed is 36 km/h. Considerable technical times correspond to the changes of gauge (breaking gauge) and range from 4 to 5 hours depending on the convoy length and on many other factors. The rail gauge is equal to the standard (1.435 mm). From Almaty, a recent built line, opened in February 2016, reaches Iran through the territories of Kazakhstan, Uzbekistan and Turkmenistan. The central Asian route did not extend all the way into Europe until October 2013 when the rail link across the Bosphorus though the Marmaray link was opened. An important branch of the Trans-Asia Railway detaches from Urumqi in China, crosses Kazakhstan and joins the Trans-Siberian to Jekaterinburg. The Trans-Mongolia plays an important role on China-Russia connection, running along a vast desert area. The gauge ranges from 1.435 mm in China to 1.520 mm in Russia and Mongolia. The Trans-Manchuria is a branch of the Trans-Siberia departing from the station of Chita in Russia, reaching Beijing with a linear track mostly located in the Chinese territory. The rail gauge presents the standard value in China and the Russian value; the change of gauge takes place in Manzhouli. The commercial speed is about 38 km/h.

2.5.2. Technical gaps and critical aspects

Even if a progressive evolution and integration of the overall network is taking place, there are still many critical aspects in the Euro-Asian railway system, especially due to the variety of managing authorities. It is possible to distinguish technical gaps from those related to the service; although there is a strong dependence between the two aspects, the service depends on the structural constraints (Van der Putten et al., 2016). Physical integration makes a system more competitive only if the network is homogenous and compatible with the intermodal transport.
The integration of the Trans-Siberia, Trans-Mongolia and Trans-Manchuria seems easier, while the Trans-Asia is characterized by great difficulties because of the variety of nations involved; in fact the railway crosses seven national borders.

Concerning service problems, the operational characteristics of the network are based on 5 significant factors:

- compatibility and interoperability of rolling stock;
- agreements for block trains composition;
- adjustment of the various sections of the network;
- removal of break of gauge points;
- adjustment of the capacity of infrastructures.

About the first factor, Table 1 shows the main characteristics of the network.

Table 1: Trans Asian Railway interoperability

	Rail gauge (mm)	Floor height (mm)	Max. axle load (tons)	Max. speed (km/h)
China	1.435	1.149	n.a.	100
India	1.676	1.009	20,50	100
Iran	1.435	1.240	20,00	80
Mongolia	1.520	1.088	18,95	120
Pakistan	1.676	1.105	11,25	80
Turkey	1.435	1.240	20,00	100
Russia	1.520	1.016	20,00	120

As for the second factor, the power of the locomotive, supplied by the line voltage, and the maximum axle load play a crucial role; the tensions are homogeneous all over the Euro-Asian network and the maximum axle load allows the double stacking.
The capacity of the line is defined as the number of trains that can transit on a section during a 24 hours period; it depends on the technical characteristics of the railway.
The problem of the break of gauge is the main difficulty for integration; there are many sites where this problem leads to a significant time loss. The unification of the rail gauge in the different States leads to higher expenses since it would be necessary to modify whole national systems with relevant costs.
As for the height of the wagons, there is no considerable limitation; in fact, considering the loading diagram of a flat car with a (2,44 m) ISO container, limitations are not found for the circulation; flat cars with containers higher than the standard ISO are also allowed to circulate. There exists no problem up to containers (2,90 m) high cube of height, except in Turkey and Iran.
The integration of the railway network in Asia is not only hindered by technical factors, but also by the different national guidelines in terms of rules, customs and safety measures.

3. SILK ROADS

The OBOR is a strategic initiative launched in 2013 by the Chinese government which is aimed at creating two corridors, one terrestrial (One Belt) through Central Asia and one maritime (One Road) across the Indian Ocean and Mediterranean Sea, to join China and Europe (Figure 8). In addition to strengthening connections through substantial investments in infrastructure, the aim is to create an area of political and economic cooperation with China as a protagonist (Vainovskis, 2016).
The OBOR project includes 900 new infrastructure projects, almost 1000 billion $ of investments, 780 billion $ generated by exchanges with 65 countries involved, 200.000 new jobs.

Figure 8: New Silk Roads (www.sundayobserver.lk)

3.1. Maritime freight transport between Asia and Europe

The maritime route consists of two commercial routes that start both from the main Chinese ports: the first arrives in Africa and then in the Mediterranean Sea, through the Suez Canal and should see in Venice its final destination, the second covers the whole South East Asia unreachable by land, through the South China Sea.

3.2. Railway freight transport between Asia and Europe

The terrestrial routes branches off into three commercial corridors: the first will connect the regions of Southern China with the European consumer markets by rail, through continental Asia and Russia, the latter will reach the Middle East, passing through Central Asia and the third path is across South East Asia and India.

3.3. Railway versus maritime road

Some studies (Group of Experts on Euro-Asian Transport Links, 2017) predicted that over the next 10 years, the railways will be able to transport around one million containers per year in the Euro-Asian region more quickly than the maritime roads. However, the latter will still be dominant both commercially, as they are already capable to move over 20 times the container share expected from freight trains for 2030, and both at the environmental level, as emissions are 30 times lower than the land transport and 42 times lower than air transport.
The railway line connecting China to Europe and ending in Duisburg, Hamburg and Rotterdam, takes about 14 days of travel, almost half the time spent by sea. Despite this, the trains coming from China to Europe often come back empty. Along the northern route (Trans-Siberian), in the winter months the

temperature can reach very low levels to compromise the integrity of the load (e.g. electrical and electronic freights), with negative repercussions on the transport cost. Although the travel time by train is much shorter (2-3 weeks) than the maritime one, the cost is more than twice. Railway transport can be interesting for some types of freights having a higher value, like cars. However, the maritime freight transport remains dominant; the new trains can potentially move only 300-500 thousand containers/year, compared to 20 million moved by ships.

4. MEDITERRANEAN AND ITALIAN SILK ROAD

The Mediterranean remains one of the main world trade routes, involving around one-third of the World´s commercial exchanges: incoming from the Suez Canal and the Straits of Gibraltar, and outgoing to the Atlantic Indian Oceans.

It evolved from an "inland sea", where exchanges were held between coastal Countries, to a major intercontinental area of trade. Spain, France and Italy hold the 11th, 12th and 14th positions in the UNCTAD index of the top 20 world economies according to their maritime connectivity.

As the crossroads of the European, Asian and African continents, the Med and its ports are destined to carry on a strategic role on the commercial flows between the main production and consumption hubs (Landaluce, 2013). The Mediterranean Sea represents the western arrival point of the New Silk Road and through the upgrading works in the Suez Canal has already recorded a 20% growth in the number of container ships in the last 5 years.

The Chinese expansion strategy is under way in the Mediterranean basin and special attention is addressed to Southern Europe. In Greece, the port of Piraeus in 2016 was mostly privatized and sold to the giant Chinese Cosco maritime operator. The agreement provides for the strengthening of the operational capacity of the port and a new railway line that will connect the Greek port to the German market, through the Balkans (in this strategy ranks the building of the new Belgrade-Budapest railway). Before the entrance of the Cosco, the Athenian port moved about 500 thousand containers/year; today the threshold of 3.1 million has been exceeded, and prospects of doubling are assumed in few years. Recently also the port of Thessaloniki, following the logic of privatization, has passed under the control of a Chinese-German Consortium. Chinese banks have also allocated large loans to Greek shipowners to produce their new ships in China. Other collaborations encourage naval research and development programs between the two countries.

The strategy of the Chinese government seems to aim at the conquest of Europe and the Mediterranean basin, with important investments in maritime and logistic works. Major investments are under way in Turkey (Mersin), Israel (Haifa), Italy (Vado Ligure), Algeria and Spain.

Italy could play a strategic role, as it represents the final destination of the Silk sea route; it could therefore assume the role of primary gateway to Europe from the South. The hypothesis of a sea-land interchange node in the Northern Adriatic has pushed the ports of Venice, Trieste, Ravenna, Rijeka and Koper, to tighten an alliance (North Adriatic Ports Association) to intercept the new potential cargo ship trades and has outlined the hypothesis of an offshore port for large container ships; the Italian government has already allocated 350 million € and project costs are estimated at 2.2 billion €.

In reality, all Italian peninsula, with its main ports, starting from the large southern container hubs, and with its primary railway axes, could play an important and competitive role. However, an extraordinary planning and programming effort is required, as well as a commitment also in terms of Italian-Chinese relations, to prevent Italy and its companies from being cut off from the Silk Road and from new interesting commercial opportunities.

In a national strategic vision, considering the large volumes of expected traffic, it might be appropriate a choral participation of the Adriatic-Ionian ports to the challenge, starting from the important hub container port of Gioia Tauro.

In reality, not only Gioia Tauro, but the whole Calabrian port system could play the role of an European continental terminal on the Silk Maritime route; with a possible integrated expansion of the port system along the Ionian corridor (Crotone, Corigliano) towards Puglia (Taranto). The advantages should be seen from a comparative perspective: greater Euro-Mediterranean geographical centrality, less maritime distances, ports of considerable capacity already operational, much lower and reasonable investments (better organization of rail transport, avoiding the heavy impacts resulting from the construction of a new great port in the Venetian lagoon on the environment and the existent tourism industry), hooking from the South the whole and attractive Italian economic region.

5. SCENARIO SIMULATION

The Euro-Asian system presents a singular modal split situation in terms of freight flows; the World Bank (www.worldbank.com) states that, considering the total amount of goods transported by land, 14.45% are transported by road and 85.55% by rail; this situation, which is exactly the opposite of that of western countries, is still essentially due to an underdeveloped road sector and to the extension of the Asian regions, as well as to the fact that, generally, the most convenient vector for the transport of materials, bulk liquids and natural resources is the railway.

The total values of the freight traffic between the poles of interest, that is, between Europe (EU of 27 members) and the East (Russia, China, Japan, Korean Peninsula, Taiwan, Asia) are particularly relevant; it emerges that maritime traffics prevail over the terrestrial (road, rail) ones for containerized cargos. Such remarks clearly show a lead of the maritime vector in the containerized

traffic that is mainly imputable to the qualitative deficit of the terrestrial modes of transport.
It is suitable to use a set of models in order to compare sea and railway modes of transport; the idea is to calculate the times and costs of transport of 1 container between Asia and Europe by means of purposely specified and calibrated models and of a structured database. An aggregate comparative analysis has been carried out on the basis of the available data for specific Euro-Asian O/D pairs.

5.1. Modelling approach

Estimation of transport costs can be made using specific cost models (aggregated or disaggregated, generalized or not) suitable for the evaluation of the costs to carry out a shipment between a specific origin/destination pair with a given chain of basic modes (Cascetta, 2009). The approach used in the research is aggregated and provides for the separate analysis of non-homogeneous cost components (time and monetary cost). The costs are assessed, following an approach of a Multimodal Transport Operator (MTO), differentiating between the costs related to the routes and the costs at the interchange nodes as ports and railway terminals (Gattuso et al., 2008).
Generally, this type of analysis makes possible to obtain valid information to support decisions regarding the choice among different transport alternatives. It is possible to consider explicitly the cost components and to see the incidence of each individual factor; on the other hand, the separate valuation of the temporal cost and the monetary one facilitates the interpretation of the phenomena above all from the operators of the sector (Gattuso and Cassone, 2013).
The costs (time and money) associated with the maritime journeys depend on many factors. The travel time depends on the type of route (R), the ship (S), the intermediate stops (N_p), the travelled distance (L), the cruising speed during navigation in sea (v_c):

$$T_s=f(R;\ S;\ N_p;\ L;\ v_c)\ ) \qquad (1)$$

The evaluation of travel times along the routes was made by taking reference to the navigation times of some of the major shipping companies. Table 2 shows the current transit times for the connection of the concerned ports.

The cost of transport by sea (C_s) is essentially identified with the freight that is a function of many variables such as distance (L), kind of container used (T_c), kind of transport (T_t), value of the freights (V_f) and freights type (T_f):

$$C_s=f(L;T_c;\ T_t;\ V_f;\ T_f) \qquad (2)$$

Table 3 shows the freight rates considered for the transport of 1 TEU containing freight for a value of 2,000 $ under the FLC (Full Container Load) regime.

Table 2: Maritime transit times

O/D	Navigation companies	Stops	T_s (days)
Shanghai - Piraeus	CMA-CGM	4	25
Piraeus - Venice	Ever Green	0	4
Piraeus - Gioia T.	MSC	0	1
Piraeus - Rotterdam	Evergreen	1	11
Piraeus - Thessaloniki	COSCO	0	1
Shanghai-Gioia T.	Maersk	5	23
Shanghai-Venice	MSC	n.a.	32
Shanghai-Rotterdam	MSC	n.a.	28
Shanghai - Thessaloniki	CMA-CGM	1	30

Table 3: Freight maritime rates of transport

O/D	Rate (€)
Shanghai - Piraeus	1.799
Piraeus - Venice	562
Piraeus - Gioia Tauro	737
Piraeus - Rotterdam	1.049
Piraeus - Thessaloniki	572
Shanghai - Gioia Tauro	1.195
Shanghai - Thessaloniki	1.799
Shanghai - Rotterdam	1.426
Shanghai - Venice	1.781

For railway transport the time (T_r) and monetary cost (C_r) are estimated using the following models:

$$T_r=L/v \qquad (3)$$

$$C_r=\alpha\cdot L\cdot Q \qquad (4)$$

where:

- L is the distance (km);
- v is the commercial speed for freight trains (km/h);
- α is a unit cost parameter (€/t·km);
- Q is the quantity of freight moved (t).

The commercial speeds and the α parameter vary according to the geographical area of reference (Tables 4-5). For Scenario analysis (Scenarios 1 and 2), some hypotheses have been considered.

At present (Scenario 0), the commercial speeds in East Europe are very low; the trains to northern Europe have to cross many countries with often different characteristics of the railway network. This situation generates high downtimes at the border stations which can even reach 48 hours. For Scenarios 1 and 2 it was assumed an improvement and strengthening of the Italian railway system (commercial speeds comparable to those of Northern-Central Europe) and that of Eastern Europe (doubling of commercial speeds).

Table 4: Railway commercial speed

Geographic area	v (km/h)	
	Scen.0	Scen. 1-2
Italy	50	60
Central / Northern Europe	60	60
Eastern Europe	15	30

Table 5: α parameter values

Geographic area	α [€/t·km]	
	Scen.0	Scen. 1-2
Italy to Germany (Bank of Italy 2011)	0,05	0,04
In Germany (Bundesnetzagentur, 2016)	0,06	
Eastern Europe (our processing on EIA data)	0,04	

Concerning the railway monetary costs in the Scenario 1 and 2, it has also been assumed a reduction of the costs of 30% on railway journeys from Italy to the North Europe.
The evaluation of the times and of the monetary costs at interchange nodes, and in particular at the ports, is not easy: costs and times depend on many different factors. It is useful to take into account the operation of the node, its equipment to serve the ships and move containers, and to consider the loyalty relationships between operators and terminals.
Table 6 shows the values of transit times through the ports taken in the research.

Table 6: Transit times of freight through the ports

Port	Interchange	Node crossing time (days)	
		Scen.0	Scen. 1-2
Gioia Tauro	Sea - Rail	7	2
Rotterdam	Sea - Rail	1	1
Venice	Sea - Rail	4	
Piraeus	Sea - Sea	2	
Piraeus	Sea - Rail	7	
Thessaloniki	Sea - Rail	7	3
Shanghai	Road-Sea	2	2
Venice OF	Sea – Sea*		7

*Reaching Inland port Sea-Rail

In general, the costs to cross the port node (C_{port}) consist of the Terminal Handling Charges (C_{THC}), the Storage Charges (C_{SC}) and the Container Handling Rates (C_{CHR}):

$$C_{port} = C_{THC} + C_{SC} + C_{CHR} \quad (5)$$

The C_{THC} represents the cost related to the loading/ unloading of the container on/from the ship and is charged to the shipping company by the terminal operator. THC are not considered a surcharge, but ancillary charge, similar to documentation fees. Generally they vary according to the reference trade route. Table 7 shows the values assumed for the C_{THC} with reference to a 20' container.
The C_{SC} represents storage cost for port usage or terminal depot or inland container yard facilities. This charge is levied by the port or the terminal to the shipping line. It depends on the direction of the commercial flow (import/export), the type of contract between company and terminal operator, the type of container stored (20', 40', dry, reefer, etc.) and it is proportional to the holding time of the container at the node. Generally for the first week it is zero and increases after, week by week.

Table 7: Terminal Handling Charges C_{THC} (€)

Port	Euro-Med	Nord Atlantic	Far East-Europe	Europe-Mid.East
Rotterdam	120	156	138	136
Piraeus	220	150	150	150
Gioia Tauro	165	154	132	
Shanghai			147	
Venice	173	173	173	173
Thessaloniki	105	105	105	105

Finally, the C_{CHR} is the cost to move the container between the different areas of the terminal towards road/railway and vice versa. This cost depends on the number of movements. The values assumed for the C_{CHR} are 40 and 24 €/movement, respectively for sea-railway and sea-road interchange.
The transit cost through the Off Shore (OS) platform in Venice has been estimated in 440 euro.

6. RESULTS AND DISCUSSION

The analysis of the possible articulations of the Silk Road in the Euro-Mediterranean context has been dealt assuming a *Scenario Zero*, corresponding to a realistic situation of reference. The port of Piraeus represents the starting logistics hub (Figure 9), and the following travel alternatives have been considered:

1. Piraeus -Venice - Duisburg;
2. Piraeus - Gioia Tauro - Duisburg;
3. Piraeus - Rotterdam - Duisburg;
4. Piraeus - Thessaloniki (sea) - Duisburg;
5. Piraeus - Thessaloniki (railway) - Duisburg.

In Italy the solution through Gioia Tauro port includes Adriatic railway, free from tunnel gauge constraints (able to move high cube containers).

Table 8 shows a summary of the results from the cost analysis associated with the shipment of a 20' container from China (Shanghai) to Germany (Duisburg) with reference to some possible paths alternatives of the new Silk Road assuming the Greek port of Piraeus as hub for traffic coming from China. It is assumed a moved container having a value of 2.000 $ and weight of 15 t.

Figure 9: Scenario 0. Alternative transport paths between Piraeus and Duisburg

Table 8: Scenario 0. Transport costs from Shanghai to Duisburg

Alternative paths through	Distance (km)	Time (days)	Cost (€)
Piraeus - Venice	16.917	34,67	3.464
Piraeus - Gioia Tauro	17.265	36,50	4.439
Piraeus - Rotterdam	19.959	39,12	3.394
Piraeus-Thessaloniki (Sea)	16.994	40,00	4.115
Piraeus-Thessaloniki (Rail)	16.997	38,35	3.916

Figures 10 and 11, respectively, show the trend of time and monetary cost as a function of the distance travelled for each of the alternatives. Being the first route (Shanghai - Piraeus) invariant for all the alternatives, in the figures this cost component was not considered.

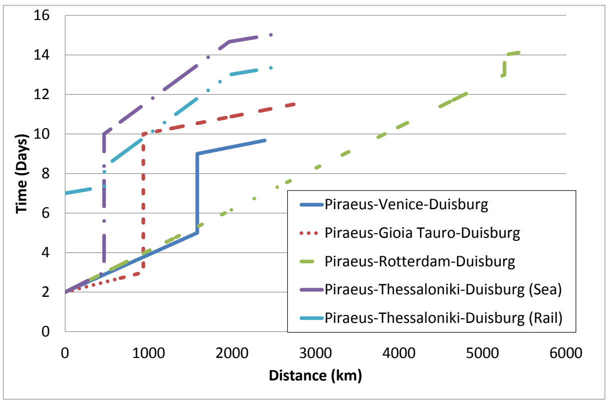

Figure 10: Scenario 0. Transport times from Shanghai to Duisburg

The most convenient alternative from the time point of view appears the path reaching the final destination (Duisburg) via Venice in 35 days: two days less than Gioia Tauro, where crossing time is higher (7 days against the 4 of Venice), four days less than Rotterdam (longer maritime route), five days less than Thessaloniki where bottlenecks characterize the railway system of the Balkan area.

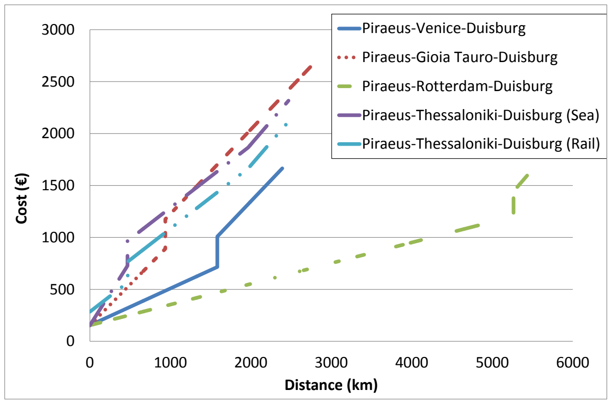

Figure 11: Scenario 0. Transport costs from Shanghai to Duisburg

Concerning monetary cost, the most convenient alternative is the maritime path (Mediterranean - Atlantic) to Duisburg from Piraeus through Rotterdam. The cost of this alternative (excluding the Shanghai-Piraeus section) is around 1.500 euro with a saving of 2.1% compared to the alternative via Venice, about 18% compared to the option via Thessaloniki and 24% compared to the alternative via Gioia Tauro. Such savings are mainly due to the reduced railway distance, in fact Duisburg can be considered as a back-port area of Rotterdam: the two cities are only 170 km away.

Some future Scenarios have been considered and the impacts in term of costs simulated. The Scenario 1 (Figure 12) includes the following characteristics:

1. Shanghai - Venice (Off Shore) - Duisburg. The building of an offshore platform off the Venetian lagoon is planned; it allows large ships to reach Venice without intermediate stops in other Mediterranean ports. In the offshore platform there is the unloading from the mother ships and the loading on the feeder ship to the land port where the interchange takes place with the railway mode (see Venice zoom in Figure 12);
2. Shanghai-Gioia Tauro - Duisburg. An improvement in the operating conditions of the Calabrian port (sea-railway interchange in two days) and the strengthening of the Ionian-Adriatic railway line (commercial speed of 60 km/h) are envisaged;
3. Shanghai - Rotterdam - Duisburg;
4. Shanghai - Thessaloniki - Duisburg. The port of Thessaloniki assumes the role of primary hub with transit time of three days; an improvement of rail services is also considered, in particular for the route from Thessaloniki to Belgrade - Budapest.

Table 9 shows the results relative to the analysis of monetary and temporal costs in the hypothesis that Piraeus is not considered a preferential node for the forwarding of freights coming from China to Central/ Northern Europe, thus assuming that this role can be played by the hubs of Venice (with a new Off Shore port able to receive and handle the greatest ships), Gioia Tauro (with upgrading of railway connections, port services, decreasing rail costs by 30%), Thessaloniki (with strengthening of the Balkan railway network and the port productivity) and Rotterdam.

Figure 12: Scenario 1. Alternative transport paths between Shanghai and Duisburg

Table 9: Scenario 1. Transport costs from Shanghai to Duisburg

Alternative paths through	Distance (km)	Time (days)	Cost (€)
Venice OS	16.664	41,56	2.900
Gioia Tauro	17.006	28,25	2.691
Rotterdam	19.661	31,12	2.055
Thessaloniki	16.792	33,45	3.483

Figures 12 and 13 show the trend of times and costs as a function of distance. In order better to read the results, figures refer the trends starting from km 13.267 (Suez Canal to Duisburg).

The most convenient alternative in term of time sees Gioia Tauro as first hub for freights coming from China. Indeed, the transit time is 28 days. In particular, there are 13 days less than alternative via Venice where longer sea times and downtime at the Off Shore platform have a strong impact, where a double load break is required for the transfer to railway. There is also a time advantage of 5 days compared to the route via Thessaloniki, which pays for the lack of Balkan rail system not very competitive. In monetary terms Rotterdam is still more competitive: -29%, -23.6% and -41% compared to the alternatives respectively via Venice, via Gioia Tauro and via Thessaloniki. This situation depends above all on the minimum railway distance to reach Duisburg from Rotterdam (only 170 km compared to about 1.800 km of the alternative via Gioia Tauro).

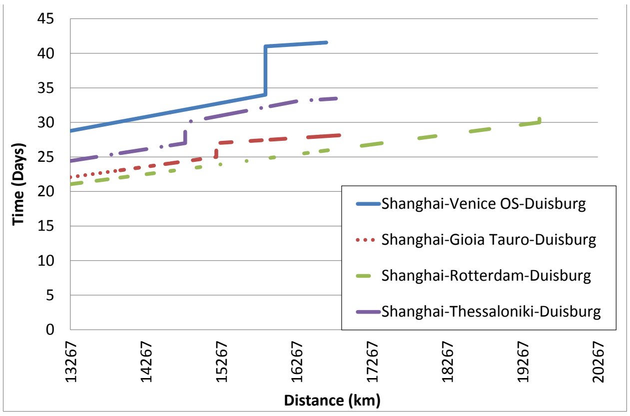

Figure 12: Scenario 1. Transport times from Shanghai to Duisburg

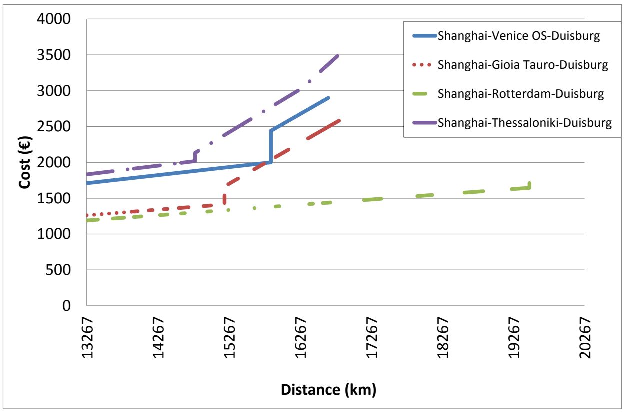

Figure 13: Scenario 1. Transport costs from Shanghai to Duisburg

Assuming as final destination in Munich, in the geographical heart of the European continent (Scenario 2, Figure 14), the results change in a significant way (Table 10, Figures 15-16) because there is a rebalancing of the railway distances.

Figure 14: Scenario 2. Alternative transport paths between Suez and Munich.

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Table 10: Scenario 2. Transport costs from Shanghai to Munich

Alternative paths through	Distance (km)	Time (days)	Cost (€)
Venice OS	16.163	41,21	2.615
Gioia Tauro	16.505	27,90	2.406
Rotterdam	20.162	31,47	2.506
Thessaloniki	16.291	33,10	3.032

In this case, the alternative via Gioia Tauro port appears the most convenient both from time and monetary cost; in this latter point of view this solution give -8% compared to the alternative via Venice, -4% compared to the Rotterdam alternative, -21% respect to the Thessaloniki alternative.

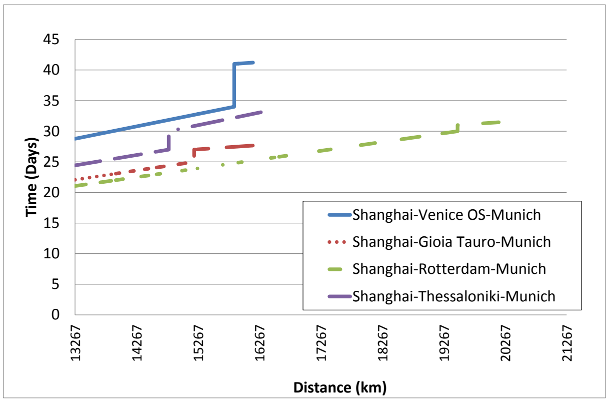

Figure 15: Scenario 2. Transport times from Shanghai to Munich

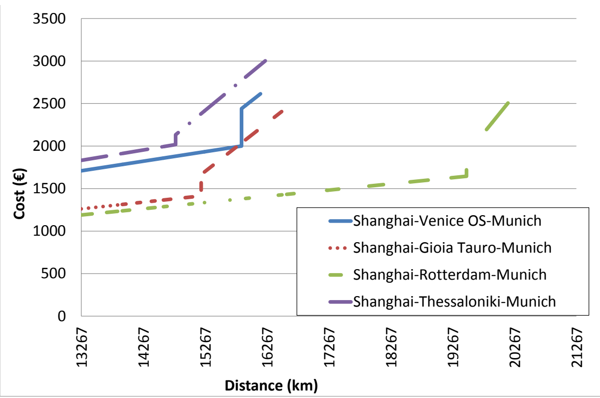

Figure 16: Scenario 2. Transport costs from Shanghai to Munich

7. CONCLUSION

Following the constant growth of the markets and of trade among the different countries of the Euro-Asian context, the world of transports is continuously evolving; although several projects to improve the transport system are being carried out, there are still many problems and critical aspects to solve. The increase in freight volumes asks multiple organizational and infrastructural adjustments.

An overview about geo-politics development Scenarios concerning freight network and logistic, has been proposed in order to frame the specific subject of simulation analysis. The attention has been addressed to the Chinese project of Silk Roads.

A comparative analysis based on scenario transport simulations is therefore proposed, in order to valuate different intermodal alternative routes between China and Central Europe. Among the alternatives, a route passing through Calabria Region has been considered; the Southern Italian region can represent a large and strategic multi-function terminal for the Maritime Silk Road, and the connection to the center of Europe could be operated by railway along the Adriatic-Ionian coast.

A methodological approach has been proposed for simulations, based on network model and quantitative transport supply attributes, some potential alternative routes have been identified in a perspective of a multimodal transport operator. Simulations have been illustrated and results commented with graphical support.

The development of models able to compare alternative multimodal transport solutions on a transcontinental scale is not easy, either in terms of specification of the functional form or in terms of calibration (it is hard to build a database because of the number of involved variables in transcontinental trade). It is suitable to develop further insights; this could be possible under a research project recently approved and financed by European Commission (ADRION-Interreg program).

8. BIBLIOGRAPHY

Banca d'Italia, 2012. Indagine campionaria sui trasporti internazionali dell'Italia. Benchmark 2011. Rapporto finale. https://www.bancaditalia.it/statistiche/tematiche/rapporti-estero/trasporti-internazionali/sintesi-indagini/indagine-trasporti11.pdf [July, 2018]

Bundesnetzagentur, 2016. Market Analysis Railway https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/Rail/Downloads/MarketAnalysisRailway2016.pdf?__blob=publicationFile&v=3 [July, 2018]

Cascetta E., 2009. Transportation System Analysis. Models and application. New York. Springer.

Group of Experts on Euro-Asian Transport Links, 2017. Scientific and Research Institute of Motor Transport (NIIAT). Draft report of the phase III of the Euro-Asian Transport Links project. Economic Commission for Europe. Inland Transport Committee. Working Party on Transport Trends and Economics. Yerevan.

EIA, 2010. Intermodal freight transport and logistics best practice. European Intermodal Association. Brussels:

Gattuso D., 2008. Agri-food logistics in the Mediterranean area. Milano. Franco Angeli.

Gattuso D., Cassone G.C., 2013. I nodi della logistica nella Supply Chain. Milano. Franco Angeli.

Jong-Ho N., Inha P., Ho Jin L., Mi Ok K., Kyungsik C., Young-Kyo S., 2013. Simulation of optimal arctic routes using a numerical sea ice model based on an ice-coupled ocean circulation method. International Journal of Naval Architecture and Ocean Engineering. Volume 5, Issue 2: 210-226.

Korovyakovsky E., Szoltysek J., 2006. Creating international supply chains in Europe and Russia. The main principles. Contemporary research issues in international railway logistics. Olli-Pekka Hilmola (editor). Lappeenranta University of technology. Research Report 171.

Landaluce G., 2013. Logistics and transport flows in the Mediterranean sea: consequences for ports. 3rd Mediterranean Days of Coastal & Port Engineering (PIANC). Marseille.

Ordabayev A., 2015. Geopolitics of Transport Corridors in Central Asia. The Institute of World Economics and Politics (IWEP). Kazakhstan.

Vainovskis D., 2016. Cargo shipment options Asia – Europe. Proceedings LIAA seminars eksportētājiem, Riga.

Van der Putten P.F., Seaman J., Huotari M., Ekman A., Otero-Iglesias M., 2016. Europe and China's. New Silk Roads. A Report by the European Think-tank Network on China (ETNC).

www.maersk.com

www.businessinsider.com

www.sundayobserver.lk

www.worldbank.com

PREDICTION OF TIMES AND DELAYS FOR SHIP HANDLING PROCESS BASED ON A TRANSITION SYSTEM

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ABSTRACT

For a long time, the issue of port processes optimization (by means of process management, not through the improvement of port infrastructure) and more accurate predictions for ship scheduling remain relevant. The work addresses primarily the building of a transition system for ship handling at the oil terminal. The main aim of this paper is to find delays and make predictions based on obtained transition system. At the beginning of the article, basic concepts of transition systems and object of study are defined. Furthermore, we describe steps of building of transition system for ship handling process. Next, we're comparing transition systems to statistical prediction methods and are pointing its advantages and disadvantages. The paper also presents some further perspectives regarding future developments of transition system.

Keywords: ship scheduling, transition system, process models, time prediction, ship handling, oil terminal

1. INTRODUCTION

There is an increasing interest in freight transport modelling research, and new directions for modeling are developing quickly. A key challenge is to populate the freight modelling frameworks with the descriptive models of logistics decision making behavior, where the models are usually normative in nature (De Jong 2016). In addition, low level of attention to ship scheduling should involve a great potential for significant improvements by introducing optimization and forecasting based on process maps for the planners. The reasons for widespread interest in solving these issues could include the following: reducing the idle time of ship handling, increasing of port KPI's, maximizing the utilization of port resources. All these factors, in turn, may lead to reduction value added for clients and, thereby, improve the competitiveness of given transport channel.

To elaborate, there is considerable potential in the use of Machine Learning and Process Mining techniques to transform historical data and real-time data into actionable advice in daily operations, also denoted short-term process optimization and predictions. Advanced methods and algorithms offer new and more effective options to deal with above mentioned issues. As a rule, key predictions are derived from port technological maps and results of statistical methods, which are applied to collected historical data. In practice, dispatcher's knowledge and experience also play a significant role. In turn, process remains unknown black-box and has no influence on predictions.

Prior studies (Fagerholt 2000, Christiansen 2004) have noted the importance of solving the ship scheduling issue and specific solutions are provided in [Saharidis 2009, Richta 2017] as well.

In this article, we consider very different approach to this issue from another perspective – process perspective. Through the transitional system, delays in the whole ship handling process will be found and times (elapsed, sojourn and remaining) for various ship handling operations at the oil terminal will be defined. It gives an opportunity to examine all process including separate operations and to make predictions based on the real process model (van der Aalst, 2011). Such approach provides a complete picture of the difficult workflow and basis for establishment of process maps, recommendation and decision support systems. It is also important to note that methods of transition systems are universal and depend on input data. They can be applied to other kind of terminals.

Today there are a huge number of ways to model the processes. For example, one of them is described in the work (Richta 2017) and based on Reference Petri nets. Study (Douma 2008) considers the barge handling process and developing of Multi-Agent system. However, the findings of the previous research don't consider a real descriptive process model and build models according to ideas about how should the process model work. Until now, there has been no attempt to represent interconnected port processes in some validated descriptive settings. A possible reason for this is the difficulty of obtaining real data from the port. Getting such data is costly and it can also be commercially sensitive (though the sensitivity should decrease with the age of data). Also, available data in transport remains relatively poor and low-quality.

Accordingly, the different approach for building models based on raw data and corresponding to reality was proposed in the article (Rudnitckaia 2017). The approach presented in this paper is another way to build the model and make more accurate predictions. The study produces results that could be used for improving our understanding of the chain of nautical handling processes directed at maritime ships around seaports, from arrival to departure.

2. TRANSITION SYSTEMS (TS)

This part describes the basis for our prediction approach – annotated transition system, that represents an abstraction of the process with annotations.

2.1. Event log

To explain the basic principle of TS construction, we first consider event log. An event log is simply a set of events, where each event is linked to particular trace and globally unique. A trace in the event log represents a particular process instance also referred to as case. Moreover, time should be non-decreased within each trace in the log. Event log must obtain four important elements: case id, activities and timestamps (start and finish time for the activity). For further analysis, an event log can be enriched with an information about process attributes such as costs, operators, ship sizes, weather conditions and so forth. In our case, an event log (Table 1) was created based on an information from port documents – timesheets/statements (i.e. a detailed chronological description of the activities of the vessel during the stay in a port). For ship-handling process, every ship case at the terminal is case, operations are activities, and timestamps are start and end times. Process mining techniques, including TS, simulates process maps, extracting necessary information from event logs.

Table 1: Fragment of event log for ship-handling process

Case id/ Ship Case	Events id	Activity/Operations	Start time	End time
9997	1	Arrival	02/01/2012 00:00	02/01/2012 08:30
9997	2	NOR tendered	05/01/2012 00:00	05/01/2012 00:01
9997	3	Piloting for mooring	06/01/2012 18:35	06/01/2012 19:15
9997	4	Mooering maneuvers	06/01/2012 19:15	06/01/2012 19:50
....	n	....	....	....
9997	n+1	Pilotage for leaving	07/01/2012 23:20	07/01/2012 23:50
10000	n+2	Arrival	03/01/2012 00:00	03/01/2012 06:30

2.2. Basic concepts of TS

A *transition system* is a triplet (*S, E, T*), where *S* is the state space (i.e. possible states of the process), *E* is the set of events labels (i.e. transition labels), and $T \subseteq S \times E \times S$ is the transition relation describing how the system can move from one state to another. A transition $(s_1, e, s_2) \in T$ describes that the process can move from state s_1 *to* s_2 by an event labeled *e.* A transition has some initial state and set of final states. The set of behaviors possible according to a transition system is given by all traces from the initial state to some final states. The naïve algorithm for constructing a TS is straightforward: for every trace σ we create a new state if it doesn't exist yet. The algorithm can be studied in more detailed in the paper (van der Aalst, 2011).

For this study, set of activities abstraction was chosen as the most suitable. It means that mechanism optionally removes the order or frequency from the resulting trace. Only the fact that it occurs makes sense.

In order to use TS for making predictions, it is necessary to annotate it first. System learns from the information collected for earlier process instances that visited the same state. This way states are annotated with set of measurements that are used as a basis for predictions. The set contains *remaining time* (the average time in a current state until completion of case), *elapsed time* (the average time to reach a particular state from initial state), and *sojourn time* (the average duration of a current state) (Figure1). It is important to note that in the event log we usually see activities and now states, therefore, state information is deduced from the activities executed before and after a given state.

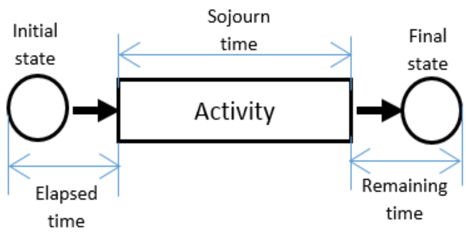

Figure 1: Time measurements for TS

These measurements can be used for calculating additional time parameters for every state: average time, standard deviation, minimum and maximum remaining time until completion.

2.3. Quality of predictions

To measure the quality of prediction we take the log, derive the annotated TS and predictions and then compare the predicted values with the real values. The term Mean Squared Error (MSE) is used to quantify the difference between the predicted and real values. Also, we take the Root Mean Squared Error (RMSE), by taking the square root of MSE.

3. CASE PREDICTION

In this section, we demonstrate our case and the construction of annotated TS based on an obtained event log. Also, some insights into the process and its delays are provided.

3.1. Problem description

Ship handling process at the terminal is supposed to be clear and straight. However, it remains a black box for analysts. There are many simulation and normative to understand what the ship-handling process is, but none of them reflects real/descriptive model. Using algorithms of Process Mining and data from timesheets, descriptive process model was constructed in previous studies (Rudnitckaia 2017). To provide insights into the process structure, process model is presented in Appendix A. It is important to note that in obtained process model infrequent activities have been removed and only the main flows are shown. In this work, we try to enrich this model with additional information to make predictions about one of the main performance parameter – ship handling duration. The multiplicity, dynamism and interdependence of the factors influencing this parameter, does not allow the forecast to be created by traditional methods with a sufficient degree of reliability. The ship case handling can be divided into cargo and auxiliary operations. And if there is no problem with forecasting of cargo operations duration, then the auxiliary operations cause a number of difficulties.

3.1.1. Filtering data

The analyzed data (see Table 1) were obtained from timesheets documents that comprise necessary information about full ship handling process at an oil terminal for subsequent financial settlement between ship and a port. According to results of the previous studies, the data was pre-processed in the following way: ship cases with start activity “Ship arrival” and end activity “Pilotage for leaving” were defined as a process with a normal behavior; all ship cases that do not belong to confident interval {the median value ± standard deviation} were referred to data noise and outliers. In this way, incompleteness and partially noise problems were solved. Despite the data preprocessing, the results should be received with some caution, as there bound to be noise in the data. Raw data was obtained from an old database and don’t have a unified standard. For instance, two similar operations «Weather conditions» and «Weather conditions (Other)» (or «NOR tendering-berth» and «NOR tendering-road») have two different identifications. This problem could be tackled by aggregation of operations according to experts’ knowledge or based on international standard. Another issue of equal importance is uncertainty in data. There are duplicates with different timestamps within a case, which may affect results of algorithms.

3.1.2. Delays detection.

Process mining techniques are able not only to discover process model but use it for delays detection. Moreover, process owner can identify reasons, find patterns or dependencies in data caused delays in all process based on process map. It is important issue for optimization, because delays at one operation causes the appearance of a number of operations that significantly increase the total handling time and affect the operations of other berths.

Figure 2 demonstrates graphic (on the left) showing distribution of ship-handling duration time within a few years. Every dot is a single ship case. There is a clear pattern – the longest cases occur in January. One of the most apparent explanation for these deviations is weather condition. However, if we consider the process model (on the right) extensively, we can find out that there are some different reasons for delays. On the process model, discovered by Fuzzy Miner algorithm for the period 2012-January, every rectangle presents operation and arcs are transitions between them.

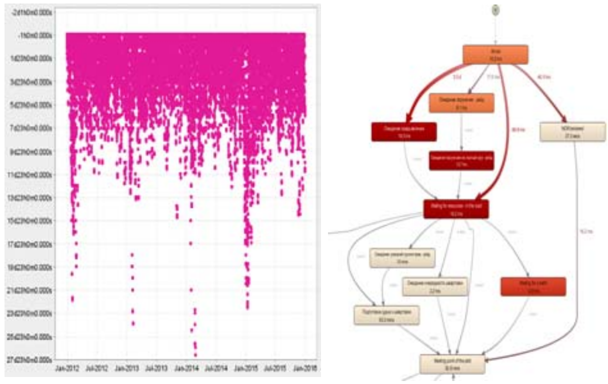

Figure 2: Delays detection

Performance analysis showed that weather condition in this period didn’t play central role. Nevertheless, operations Waiting for documents, Waiting for resources and, consequently, Waiting for a berth take most part of the time, thereby, impacting the qualitative and quantitative parameters of the process.

3.2. Experiments

We used two data sets for construction and evaluation of the transition system. The training data set L_1 contains all ship cases that were handled at oil terminal within first half of 2012 year. L_1 holds 303 cases, 12480 events and 68 different operations/activities. The test data set L_2 has 236 cases and 76 operations/activities, occurred within first half of 2013 year. The main operations for ship handling process are common for both data sets, but each has its own operations relevant to ship cases specific. Eventually, the transition system was obtained using the set abstraction based on all activities. With the plugin FSM analyzer the TS was also reinforced with an information about times for every operation. The goal is to predict, at any point of time, remaining handling time of a case. The transition system and the annotated TS extracted from event log L_1 are not intended to be readable (also with ignoring unnecessary details). For this reason, result is presented with certain parts of process – initial and finish states (Figure3).

For the initial state [[]], the predicted remaining time until completion 4,82 days. The first activity is always «Arrival» and the second activity is «NOR tendered». After these two steps, the process is less structured (see Appendix A). On average almost 1 day is spent in the state between these two activities.

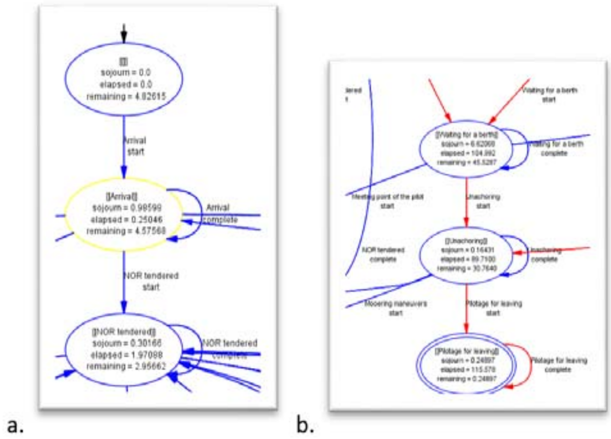

Figure 3: Annotated transition system for two states (a.initial state, b.final state)

3.3. Evaluation of results

To evaluate the quality of the predictions we use data set L_2 and FSM Evaluator. Resulting table is presented below.

Table 2: Fragment of prediction results (in days) for each state

state	MAE	RMSE	MAPE	Freq
[[]]	2.08835	2.71099	244.742	284
[[Arrival]]	1.94176	2.63705	49.6053	501
[[NOR tendered]]	1.15991	1.93890	33.2289	502
[[Meteo-before docking (1 turn)]]	1.41004	2.54888	42.9369	76
[[Meeting point of the pilot]]	0.47991	0.94939	23.2901	491
[[Piloting for mooring]]	0.46212	0.93999	22.9048	488
[[Mooering maneuvers]]	0.74323	1.04185	1448.30	990
[[Docking with port's forces]]	0.45898	0.93096	23.3453	493
[[Arriving examination]]	0.44978	0.75828	24.8651	394
[[COTs acceptance]]	0.51271	1.10823	24.7437	488
overall(mean)	0.68894	1.03677	101.270	40
overall(aggregated mean)	0.57261	0.94588	183.387	10680

In comparison with the results of statistical prediction models (SARIMA, ARIMA), describing in (Rudnitckaia 2018), annotated transition system shows better results. It not only relies on change of a predicted parameter in time, but also takes into account process model, which itself is a more high-level prediction mechanism. In contrast to statistical methods, TS is able to indicate deviations and causes for delays, as well as support multicriteria analysis for process instances. It is also significant, that results described in Table 2 can be improved substantially with increasing of input data quality and using other abstractions of TS (sequence, multisets).

However, the TS prediction method has some disadvantages. The main problem is heightened sensitivity to input data. Duplicates, noise and incompleteness, uncertainty in the event log can lead to meaningless results. Before applying of algorithm, event log should be preprocessed to avoid potential mistakes. Furthermore, the final representation of the TS has problems with complex control-flow constructs. In order to tackle this problem, a two-step approach (combination TS method with other Process Mining techniques) (van der Aalst 2016). In the next section, some further directions for research will be offered.

4. DISCUSSION

The method as described before can be applied to different terminals, including tank terminals. Results of this approach outperform results derived from statistical prediction models. It is also more flexible and resistant to changes. Transition systems is descent framework for further researches. It makes possible to predict not only times, but also next operations with percentage probability of occurrences. Adding to a process model process attributes makes possible to examine the behavior of system and identify decision rules and hidden dependencies in process. In terms of seaport, using this method can play important role for constructing recommendation and decision-support systems. Moreover, the process model and annotated transition system provide feasible solutions concerning outstanding issues in terms of maritime transport:

- Enhancement of ship-scheduling accuracy
- Optimization of ship-handling process by delays detection and causes of them
- Improving our understanding of nautical process by examination of descriptive process model
- Using a descriptive process model to strengthen existing MAS (multi agent systems) and operation management.

CONCLUSIONS

This article showed that we can use effectively annotated transition system to predict ship-case duration time. Transition system can provide information about remaining time in every state and, at the same time, help with understanding of control-flow, delays detection and reasons for them. Thus, the terminal operator will be aware of exactly how every operation affects all process and will be able to make arrangements.

Such analysis can lead to the creation of decision-making rules, determination of measures to improve the quantitative and qualitative dimensions of the process (in our case this is the ship handling duration).

The results presented could be relevant and useful for shipping companies, port and tank terminal managers and policy makers both on port foreland development, for example nautical access, hinterland connections, and for researchers within the field of ship handling and port economics

ACKNOWLEDGMENTS

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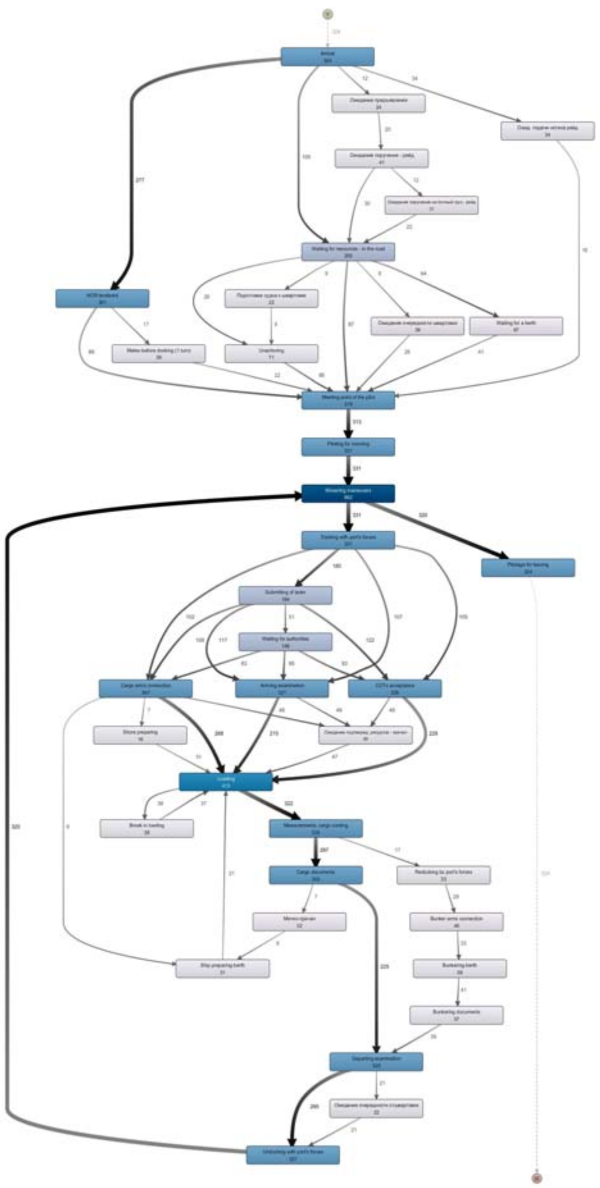
APPENDIX

A. Process model of ship-handling process (including only frequent activities and the main flows)



REFERENCES

Fagerholt K., Christiansen M., 2000. A combined ship scheduling and allocation problem. Journal of the operational research society, 51, pp.834-842

Christiansen M., Fagerholt K., Ronen D.,2004. Ship routing and scheduling: status and perspectives. Transportation science, Vol. 38, No.1, pp.1-18

Saharidis G.K.D., Minoux M., Dallery Y., 2009. Scheduling of loading and unloading of crude oil in a refinery using event-based discrete time formulation. Computers and chemicals engineering, 33, pp.1413-1426

Richta T., Wang H., Osen O., Styve A., Janousek, 2017. Data-Driven Maritime Processes Management Using Executable Models. Computer Aided Systems Theory – EUROCAST 2017, pp.134-141

van der Aalst W.M.P., Schonenberg M., Song M.,2011. Time prediction based on process mining. Information systems, 36.2, pp.450-475

van der Aalst W.M.P., Rubin V., van Dongen B.F., Kinfler E., Gunther C. W., 2006. Process Mining: A two-step approach using transition systems and regions. BPM Center Report BPM-06-30, BPM Center

Rudnitckaia, J., 2017. Study of descriptive process model of ship handling at an oil terminal based on timesheets. Vestnik of Astrakhan State Technical University, 1, pp. 7-15

Rudnitckaia, J., Hruska T., 2018. Time Series Analysis and Prediction Statistical Models for the Duration of the Ship Handling at an Oil Terminal. Lecture Notes in Networks and Systems, Springer, 127-137

Senderovich A., Weidlich M., Gal A., & Mandelbaum A., 2014. Queue mining–predicting delays in service processes. In International Conference on Advanced Information Systems Engineering, Springer, pp.42-57

Douma A.M., 2008. Aligning the operations of barges and terminals through distributed planning. Thesis (PhD). University of Twenty, Enschede, Netherlands.

De Jong G., Tavasszy L., Bates J., et al., 2016. The issues in modelling freight transport at the national level. Case Studies on Transport Policy, 4(1), pp. 13-21.

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SIMULATIVE ANALYSIS FOR PERFORMANCE MEASUREMENT OF RFID IMPLEMENTATION IN CARGO HANDLER LOGISTICS

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ABSTRACT

The research focuses on the Air Cargo Handler logistic activities that take place in warehouses. The performances of these activities are highly influenced by human errors. Radio-Frequency IDentification (RFID) implementation in warehouses allows to promptly detect human errors and to implement mitigation actions in order to reduce human error consequences. Consequences are analyzed in the paper in terms of delay in transit times.

The paper proposes a methodology for evaluating RFID implementations in air cargo handler's warehouses. Different set-ups of RFID implementation in cargo handler logistics define different scenarios and the proposed methodology allows to compare the performances of these scenarios.

Keywords: RFID, Logistic, freight transport

1. INTRODUCTION

The context is *air transportation* that enables fast transit times, which have had an effect on global distribution. The speed of air transportation combined with the frequency of scheduled flights has reduced some global transit times from a month to only 1-2 days (Coyle et al. 2009). This method of transportation is suggested to be more suited to high value, perishable, or urgently needed commodities that can bear the higher cost of air freight.

The research refers to truck-air intermodal transport where in the segment of the journey where flight is inaccessible, goods are transported by trucks. As part of an intermodal transport, a truck allows better accessibility with regard to the origin and the final destination of the shipment, where airports may not ultimately be reached. If the final destination is situated in urban areas, freight coming by trucks from airports could be reorganized in Urban Distribution Centers and delivered to the final receivers (retailers and consumers) through smaller vehicles in order to reduce the well-known last mile distribution problems (Cepolina 2016, Cepolina and Farina 2013).

With any intermodal transportation method, the advantages and disadvantages of each method are experienced. It does however require coordination between different actors and that can add costs because of the additional handling when transferring the freight from one transportation mode to another (Molfino et al. 2015, Cepolina and Farina 2015; Rushton et al. 2010).

Air Cargo Handler is an actor involved in truck-air intermodal transport for the safe and timely movement of cargo.

The paper focuses on logistic processes carried out by the air cargo handler, which include: freight receipt, freight security control, consolidation activities and freight storage, that take place in a warehouse, and transport by truck to the boarding airport. The performances of these processes depend on human performances which are affected by contextual factors, which include personal factors and environmental factors. Human errors may lead to freight impairment, which is a crucial aspect for high value and perishable goods and to delay in transit times that degrades the level of service provided by air cargo handler and therefore customer satisfaction.

The consequences of these errors may be limited by introducing RFID technologies in the logistic processes. RFID is a technology similar in theory to bar codes. However, the RFID tag does not have to be scanned directly, nor does it require line-of-sight to a reader. The RFID tag must be within the range of an RFID reader, which ranges from 0.9 to 91.5 meters, in order to be read. RFID technology allows quickly scan several items and enables fast identification of each particular product, even when surrounded by several other items. For these characteristics, RFID technology could be very useful in logistics. RFID implementation consists in RFID tags and readers' selection.

Tags could be active or passive: passive tags have a lower price than active tags. Active RFID systems have three essential parts – a reader or interrogator, an antenna, and a tag. Active RFID tags possess their own power source. Passive tags have no internal power source and are powered by the electromagnetic energy transmitted from an RFID reader, instead.
Passive RFID tags are used for applications such as access control, file tracking, race timing, supply chain management, smart labels, and more. For our goal, passive tags have been selected.
Not all passive RFID tags operate at the same frequency. There are three main frequencies within which passive RFID tags operate: Low Frequency (LF), High Frequency (HF) and Ultra High Frequency (UHF). The frequency range, along with other factors, strongly determines the read range (LF: 1 – 10 centimeters; HF: 1 centimeter up to 1 meter; UHF: about 5 – 6 meters, but up to 30+ meters could be achieved).
An *RFID Reader* is a radio frequency transmitter and receiver. RFID Readers can read and write information to an RFID tag. RFID Readers can be fixed or portable. **Portable RFID Readers** (Handheld RFID Scanner Readers, tablet RFID readers, wearable RFID readers) can be installed or carried almost anywhere. **Fixed RFID Readers**, like portals or gateways, have a fixed location and allow reading pallets moving throughout portals.
Different RFID implementation set-ups in the air cargo handler's warehouse are possible, depending on the aggregation level of the freight to which tags are attached and on the location and type (fixed vs portable) of tag readers.
In this study, we designed a methodology for assessing performances of different RFID implementation set-ups in the Air Cargo Handler logistic processes. The method adopts the Probabilistic Risk Assessment (PRA) to identify and quantify delay in transfer time of freight units through: the forecast of human errors that can occur during the working activities in the air cargo handler's warehouse, the error detection and the application of mitigation measures. Delay values are assessed by an event-based simulator and their occurrence probability by Monte Carlo method. In this paper, we show the preliminary performance evaluation results.
The remainder of this paper consists of the following. Section 2 defines the problem in detail. Section 3 explains related work from the viewpoints of methods that are used to measure RFID performance in logistics. Section 4 describes our approach. Section 5 shows the simulation results. Lastly, Section 6 illustrates the conclusions of the paper.

2. PROBLEM DESCRIPTION

Activities and problems incurred by air cargo handlers have been analyzed with the support of ALHA (Alha 2018) and are reported in the following.

Goods arrive to air cargo handler's warehouse usually by truck. Usually other actors are in charge of this activity.
The incoming freight is unloaded from trucks; the possible formats at the entrance (IN format) are: bulk goods or pallets or ULDs (Unit Load Device). Freight units leave the warehouse in one of the following formats (OUT format): pallets or in ULDs, as shown in figure 1. ULDs and pallets are characterized by the assigned flight number and the related boarding and destination airports.

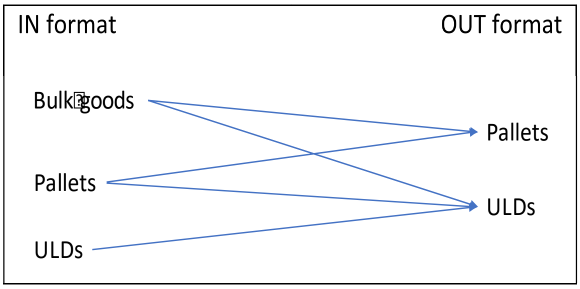

Figure 1: Possible formats of freight at the entrance (IN format) and exit (OUT format) of the warehouse.

Usually in air cargo handler's warehouse, freight units are subject to:

1. Check-in: according to visual checks on package status, goods are accepted, tentatively accepted or rejected by the handler at the receiving dock. Freight units are then moved inside the warehouse. The storage is typically composed by multi-level racks holding pallets and can be organized in order to reduce wasted of space (Cepolina and Cepolina 2014). In this phase, shipping information and priorities for each freight unit are acquired and freight units are tagged with labels reporting this information.
2. Security checks: the freight is made secured following IATA protocol.
3. Pallet consolidation: freight units are consolidated in pallets, according to shipping information.
4. ULD consolidation: pallets are consolidated in ULDs. If a pallet doesn't fit in the ULD because the spare space in the ULD is too small, the pallet could be split in two parts. As described in phase 5, the first part will be put in the current ULD, the second one will wait for the next ULD, assigned to the same flight number.
5. Pallet re-assembly: the pallet is deconsolidated and the freight units in it are split in two groups and consolidated in two new pallets of smaller dimensions. This activity allows to exploit the ULD capacity.
6. Truck consolidation: ULDs characterized by the same boarding airport are loaded on the respective truck.

Air cargo handlers are also often in charge of:

7. Freight transport to the boarding airport by truck

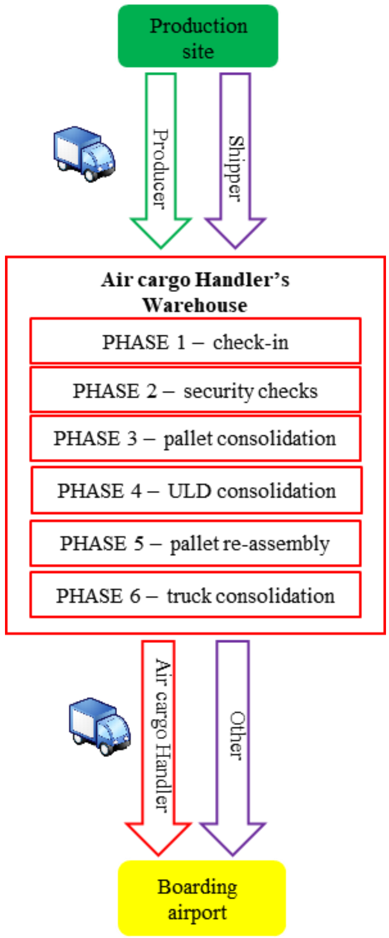

Figure 2: Air Cargo Handler logistic processes

The main problems incurred in these activities and reported by air cargo companies, could be categorized in three main classes:

- **Class A, check errors**: the air cargo handler accepts goods that have been damaged by a previous actor;
- **Class B, preservation errors**: errors in handling and storage tasks that lead to a degradation of the freight units' quality; for instance, wrong temperature good storage, which is a main issue for perishable goods, or shocks in handling operations, which is a main issue for high value goods;
- **Class C, consolidation errors**: that lead to delays, which are a critical issue for urgently needed commodities; for instance, freight units are wrongly tagged at the warehouse entrance or pallets are consolidated in wrong ULDs and therefore loaded on wrong flights.

The consequences of these problems could be partially reduced by introducing RFID technology. RFID allows to detect human errors and to adopt corrective actions that aim to limit error consequences. Each RFID set-up determines the amplitude of the interval of time that elapses between the moment in which an error occurs and the instant in which it is detected. If the time interval is small, corrective measures will be promptly implemented and the error consequences will be mitigated.

Scenarios refer to different set-ups for RFID introduction in cargo handler activities. Different scenarios may be defined combining the following elements:

- in relation to the aggregation level of the freight to which tags are attached: tags may be attached to each freight unit, to pallets (where many freight units have been aggregated) and/or to ULDs containing many pallets, and/or to tracks that move several ULDs;
- in relation to the position of the tag readers in the warehouse;
- in relation to the typology (fixed or portable) of tag readers.

Each scenario leads to specific performances. The research target is to set up a method for evaluating different scenarios.

3. RELATED WORKS

In general, the Internet of Things (IoT) usage can affect financial and non-financial performance characteristics of business processes via three bottom-up and non-exclusive effects (Mooney et al. 1996). Following (Tellkamp 2006), these can be categorized as:

- *automation* of information acquisition process that formerly was manual: for example, RFID gates at a company's goods receipt area can eliminate the need for employees to capture data of incoming pallets manually by applying mobile barcode scanners;
- *informatisation* related to an increased information quality: for example, automated real-time comparisons of to-be-picked and actually picked positions can improve manual picking processes, enabling better decisions, such as, in the case of detected picking errors, the beginning of rework and mitigation measures, in order to reduce the severity of mistake consequences;
- *transformation* related to new or re-engineered business processes: for instance, the provision of new services and products (e.g., tracking and tracing services) is possible.

Gille and Strucker (2008) present an extensive review of performance measurement methods in the RFID field: they present the first empirical evaluation of RFID performance measurement conducted among 146 German companies. All the performance measurement approaches used for evaluating the success of RFID adoption, offer advantages as well as disadvantages. Traditional and mainly financially oriented control mechanisms have increasingly been criticized for,

among others, neglecting strategic objectives, short-termism and a lack of consideration of non-financial performance dimensions (Neely 1999).
Non-financial performance dimensions include KPI (Key Performance Indicators) which have been considered in the proposed approach. KPI have been designed, in the proposed research, for the monitoring of benefits related to *informatisation,* that allows automated real-time comparisons of to-be-status and actual status of freight units and the beginning of rework and mitigation measures. Consequences have been considered in terms of freight preservation conditions and delay in relation to the expected arrival time at the destination airport.
Forecasting non-financial performance, mainly due to informatisation and transformation, constitutes the largest problem regarding RFID performance measurement (Strassner 2005). This problem has been faced with risk analysis. Risk assessment is here intended as a systematic process for assessing the impact and the outcome of RFID implementations in warehouses involving human activities with hazardous characteristics.

4. APPROACH TO ASSESS THE SCENARIO PERFORMANCE

The system refers to the supply system (air cargo handler's warehouse) and the freight demand that is processed there.

The system is defined by:

- the reference time period
- the freight demand, specified in terms of: number of freight units that arrive in the warehouse within the reference time period, the freight unit flow in time, their IN format (bulk, pallet or ULD), their OUT format (pallet or ULD), their typology (perishable, high value or normal), their flight number, boarding airport and destination airport.
- logistic activities through which each freight unit is processed. The logistic activities that take place in the warehouse are the ones described in figure 2. Each freight unit is processed through a standard sequence of phases that not necessary includes all the 6 phases. Freight unit standard sequence depends, for instance, on the IN/OUT formats.
- a human error matrix ***e***:

$$\begin{bmatrix} e^{phase1}_{class\,A} & e^{phase1}_{class\,B} & e^{phase1}_{class\,C} \\ e^{phaseJ}_{class\,A} & e^{phaseJ}_{class\,B} & e^{phaseJ}_{class\,C} \\ e^{phase5}_{class\,A} & e^{phase5}_{class\,B} & e^{phase5}_{class\,C} \end{bmatrix}$$

The generic component e^j_k refers to the human error of class k that can occur in a given phase j. Each component gives the human error probability (HEP): $e^j_k = 0$ means that the error class k cannot occur in phase j.

For the given system, several scenarios can be defined. Each scenario will lead to a different performance that will be assessed by simulation.

The level of application of tags and the location and type of tags readers determine the amplitude of the interval of time that elapses between the moment in which an error occurs and the instant in which it is detected. If the time interval is small, corrective measures will be implemented soon and the error consequences will be mitigated.
All the scenarios are characterized by the same matrix ***e*** since the performance shaping factors (PSF), in terms of personal factors and environmental factors, are assumed to be the same in all the scenarios. The influence of every PSF level considered, both in singular way and combining with the other factors, could be quantified through numerous simulations in SHERPA (Di Pasquale et al. 2015).

The performance of each scenario is evaluated in terms of risk assessment. R^S is the risk value for the scenario S and it has been assumed as a measure of the scenario performance: a low value of risk means a high-performance scenario.
In a given scenario *S*, R^S is assessed by summing the product of each damage class D_{dc} and its related occurrence probability H_{dc}.

$$R^S = \sum_{dc} D_{dc} * H_{D_{dc}} \quad (1)$$

The classes of damage are 5: negligible, minor, moderate, significant and severe.
The steps for calculating D_{dc} are:

1. assessing the damage level D_i experienced by each freight unit *i* in the scenario S, in the reference time period. This is done performing a run of a discrete event simulation, as described in paragraph 4.1.

2. in each run of discrete event simulation, assessing the total damage level as: $D = \sum_{i=1}^{FUN} D_i$, extended to the overall number *FUN* of freight units handled in the reference time period. The resulting total damage level *D* is reported to the related class D_{dc}.

H_{dc} is the probability that, in the reference time period, the scenario is affected by the total damage level that belongs to class *dc*. This probability is assessed by Monte Carlo technique, as reported in paragraph 4.2.

4.1. Assessment of the damage level for freight unit i Di - Discrete event simulation

For each freight unit *i*, damage level D_i is assessed by the product of vulnerability and exposition.
Exposition E_i is the monetary value of freight unit *i*.

Vulnerability, V_i is a function that links the error matrix ***e*** and the related damage level for the freight unit *i*. It is therefore a function of the specific scenario as it depends on the level of application of the RFID tags and the location and type of the tag readers.
In order to assess vulnerability of freight unit *i* in the given scenario *S*, a run of the discrete event simulator is performed.
As shown in figure 3, during the discrete event simulation: human errors are generated at their own respective phases, the freight unit is processed through all the phases of its standard sequence plus the phases for eventual mitigation actions, then the freight unit is delivered to the boarding airport by truck (phase 7) and, finally, arrives to the destination airport by flight (phase 8). In the simulation we assume that trucks leave the warehouse as soon as they have been consolidated with a given number of freight units and that cargo flights leave the boarding airports as soon as they have been loaded with a given number of freight units. Otherwise possible delays generated within the warehouse can be hidden by the waiting time for boarding at the departure airport.

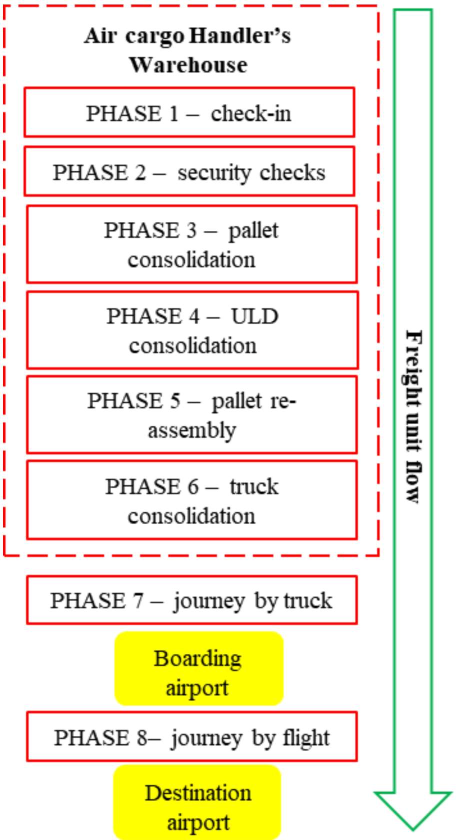

Figure 3: Simulated freight units' flow.

For each freight unit *i*, the related error consequences are evaluated in terms of freight unit delay as:

$$delay_i = time_{real\ i} - time_{ideal\ i} \qquad (2)$$

where:

$time_{real\ i}$ is the actual delivery time of freight unit *i* at the right destination airport. It is a consequence of the possible occurance of human errors, of the error detection time and of the application of mitigating actions. It is assessed by simulation.

$time_{ideal}$ is the delivery time of freight unit *i* at the right destination airport in case of no error occurrence. It is assessed by simulation.

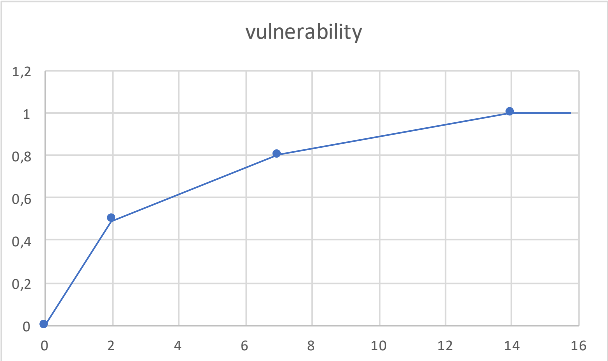

Figure 4: Vulnerability as a function of freight unit delay (days)

The delay value determines the freight unit vulnerability, according to the function shown in figure 4, which has been qualitatively assessed discussing with experts from an air cargo handler company.
Vulnerability $V_i \in [0,1]$:

- zero delay corresponds to vulnerability equal to 0 (no damage)
- when the delay is higher than 14 days, vulnerability equals 1 (i.e. total loss of the freight unit).

Knowing the freight unit Exposition and Vulnerability, the freight unit damage level could be calculated.
In table 1 the row refers to the run of the discrete event simulator. For each freight unit, its delay, vulnerability and damage level are calculated. At the end of the discrete event simulation, the total damage level *D* and the related class of damage D_{dc} can be assessed.

Table 1: Outputs of the discrete event simulator

SCENARIO S – RUN #1			
	Delay	Vulnerability	Damage level
Freight unit #1	$delay_1$	V_1	D_1
Freight unit #2	$delay_2$	V_2	D_2
…	…	…	…
Freight unit #FUN	$delay_{FUN}$	V_{FUN}	D_{FUN}
TOTAL DAMAGE LEVEL *D*			ΣD_i

4.2. Assessment of the likelihood H_{dc} of the class k of damage level - Monte Carlo method

By Monte Carlo method, the occurrence number of each class of damage level D_{dc}, in the given scenario, is assessed.

Monte Carlo method is an iterative process.

At the generic iteration *n*, a run of the discrete-event simulator is performed, as described in paragraph 4.1. The damage level of each freight unit is assessed and then the total damage level and the related class.

At the end of n^{th} iteration, the following operations are performed:

1. the occurrence number # is increased by 1 unit for the identified class of damage: $\#D_{dc} = \#D_{dc} + 1$ whilst the occurrence numbers of the other damage classes are not updated;
2. the likelihood of each damage category D_{dc} is updated according to the following formula:

$$H_{dc_n} = \frac{\#D_{dc}}{n} \quad (3)$$

   where *n* is the number of performed iterations.
3. Check on the stopping rule: the maximum, extended to each damage category D_{dc}, of the absolute values of the relative difference of $\widehat{y_{dc}}$ in 2 successive iterations is lower than a threshold ε.

$$\max_{dc=1,2\ldots5} \left| \frac{H_{dc_n} - H_{dc_{n-1}}}{H_{dc_{n-1}}} \right| < \varepsilon \quad (4)$$

At the end of the Monte Carlo method, the H_{dc} values, for each damage category D_{dc}, are reported to the related class. The classes for likelihood are: very unlikely (0-0,2), unlikely (0,21-0,4), possible (0,41-0,6), likely (0,61-0,8) and very likely (0,81-1).

At the end of the process the results are stored in a risk matrix that refers to the given scenario *S*. The risk matrix, shown in table 2, displays the classes for the likelihood H_{dc} against the classes for damage levels D_{dc}.

Table 2: The Risk Matrix

		H_{dc}				
		Very Unlikely	Unlikely	Possible	Likely	Very likely
D_{dc}	Negligible					
	Minor					
	Moderate					
	Significant					
	Severe					

Given the risk matrix, R^S is assessed according to:

$$R^S = \sum_{dc} D_{dc} * H_{D_{dc}} \quad (5)$$

5. SIMULATION RESULTS

5.1. System characterization

In the following the data input for the discrete event simulator are reported.

Freight unit typology: high value and normal (no perishable).

Freight unit Exposition: a 100 euro value has been assumed for all the freight units.

Freight unit boarding airport: 50% is directed to MPX (Malpensa airport) and 50% to FCO (Fiumicino airport). The freight unit destination airports have not been defined because we assume all the destination airports could be reached in 24h. Freight unit flight numbers have not been defined because we assume that the flight leaves the boarding airport as soon as the first two ULDs arrives in the airport.

Freight unit IN/OUT format: bulk/ULD.

We assume that: 1 pallet contains 12 freight units (bulk); 1 ULD contains 48 freight units; 1 truck contains 96 freight units.

The reference time period has been assumed the typical 8 hours working day.

The average number of freight units processed in the reference time period is 576. The freight arrivals have been assumed deterministic with a uniform rate.

Processing times through the eight phases are characterized by a triangular distribution, with vertices corresponding to the mean +-40%. The mean values have been reported in table 3. The reported times refer to the movement unit in the respective phase, as reported in the table.

The estimated matrix *e* for the case of study is reported in table 4. The number of rows in the matrix is 6 since the phases that take place in the warehouse are 6, as shown in figure 1. The number of columns in the matrix is 3, since we consider three classes of errors: A, B and C.

We assumed a Bernoulli distribution for HEP with mean values reported in figure 8.

We assumed the following classes of damage in euro:

- Negligible: if total damage level < 500
- Minor: if 501< total damage level < 1000
- Moderate: if 1001< total damage level < 3000
- Significant: if 3001< total damage level < 5000
- Severe: if 5001< total damage level

Table 3: Process times

Mean processing times			
Phase 1	Freight unit	17,5s	
Phase 2	Freight unit	50s	
Phase 3	pallet	180s	
Phase 4	ULD	7200s	
Phase 5	Freight unit	360s	
Phase 6	truck	600s	
Phase 7	truck	36000s (10h-MPX)	28800s (8h-FCO)
Phase 8	flight	86400s (24h)	

Table 4: The error matrix for the warehouse

Error matrix ***e***	classA	classB	Class C
Phase 1 check in	0,02	0,012	0,017
Phase 2 security checks	0	0,012	0
Phase 3 pallet consolidation	0	0,012	0,02
Phase 4 ULD consolidation	0	0,012	0,017
Phase 5 pallet re-assembly	0	0,012	0,012
Phase 6 truck consolidation	0	0,012	0,05

5.2. Current scenario

No RFID implementation.
The performed number of iterations in the Monte Carlo method is 75, even if the stopping criterion with ε=0,02 has been verified after 40 iterations.

Table 5:The Risk Matrix for the current scenario

		H_{dc}				
		Very Unlikely	Unlikely	Possible	Likely	Very likely
D_{dc}	Negligible	X				
	Minor	X				
	Moderate	X				
	Significant			X		
	Severe			X		

The resulting likelihood associated to each damage class is assessed by Monte Carlo method and reported in the risk matrix in table 5.
The total risk is: 7300 euro/day.

5.3. RFID implementation: 1st scenario

The scenario refers to a RFID set-up where the RFID tags are applied during the freight check-in at the warehouse entrance (phase 1) and a fixed RFID reader (portal) is located where the truck consolidation takes place (phase 6).
The performed number of iterations in the Monte Carlo method is 75, even if the stopping criterion with ε=0,02 has been verified after 67 iterations.
The resulting likelihood associated to each damage class is assessed by Monte Carlo method and reported in the risk matrix in table 6.

Table 6: The Risk Matrix for the 1st scenario.

		H_{dc}				
		Very Unlikely	Unlikely	Possible	Likely	Very likely
D_{dc}	Negligible	X				
	Minor	X				
	Moderate		X			
	Significant			X		
	Severe		X			

The total risk is: 5000 euro/day.

5.4. RFID implementation: 2nd scenario

The scenario refers to a RFID set-up where the freight units arrive in the warehoused already with correct RFID tags and a fixed RFID reader is located where the truck consolidation takes place (phase 6). In this scenario, HEP for errors of class C in phase 1 is 0.
The performed number of iterations in the Monte Carlo method is 75, since the stopping criterion with ε=0,02 has been verified after 75 iterations.
The resulting likelihood associated to each damage class is assessed by Monte Carlo method and reported in the risk matrix in table 7.

Table 7: The Risk Matrix for the 2nd scenario.

		H_{dc}				
		Very Unlikely	Unlikely	Possible	Likely	Very likely
D_{dc}	Negligible	X				
	Minor	X				
	Moderate					X
	Significant	X				
	Severe	X				

The total risk is: 3500 euro/day.

6. DISCUSSION AND CONCLUSIONS

The target of this research is to evaluate the performances of different RFID implementations in air cargo handler warehouses. To do that, a simulator has been calibrated and validated with the support of expert operators in air cargo handler logistics (Alha 2018). The paper presents preliminary results of the research project.

The proposed approach seems suitable for the research target: it is able to assess the performance of different scenarios in terms of benefits related to the *informatisation* (the initiation of rework and mitigation measures, in the case of detected errors, in order to reduce the severity of mistake consequences).

Moreover, the Probabilistic Risk Assessment allows to solve the forecasting problem related to human activities with hazardous characteristics.

In the future, the approach will be improved in order to include in the RFID performance assessment benefits related to *automation*. Actually, RFID allows the automation of information acquisition, which has the additional advantage of process times' reduction.

Finally, to obtain a realistic and complete comparison between different scenarios, implementation costs will be included in the analysis.

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REFERENCES

ALHA S.p.A. 2018, private communications.

Cepolina, E. M., 2016. The packages clustering optimization in the logistics of the last mile freight distribution. International Journal of Simulation and Process Modelling: 11 (6), pp. 468-478.

Cepolina, E. M., Farina, A., 2013. An optimization methodology for the consolidation of urban freight boxes, Proceedings of 15th Int. Conference on Harbor, Maritime and Multimodal Logistics Modeling and Simulation, HMS 2013, Held at the International Multidisciplinary Modeling and Simulation Multiconference, I3M 2013, pp. 46-52.

Cepolina, E.M., Farina, A., 2015. A new urban freight distribution scheme and an optimization methodology for reducing its overall cost, European Transport Research Review, 7 (1): 14 p.

Cepolina, F., Cepolina, E.M., 2014. Space optimization in warehouses logistics, Proceeding of 16th International Conference on Harbor, Maritime and Multimodal Logistics Modelling and Simulation, HMS 2014, pp. 140-145.

Coyle J. J., Novack R. A., Gibson B., Bardi E. J., 2009. Transportation: A Supply Chain Perspective. South-Western Cengage Learning.

Di Pasquale V., Miranda S., Iannone R., Riemma S., 2015. A Simulator for Human Error Probability Analysis (SHERPA), Reliability Engineering & System Safety, Volume 139, July 2015, Pages 17-32.

Gille D. and Struker J., 2008. Into the unknown – measuring the business performance of RFID applications. In W. Golden, T. Acton, H. van der Heijden, &V. Tuunainen (Eds.), Proceedings of 16th European Conference on Information Systems (ECIS 2008), CD-ROM. Galway.

Molfino, R., Zoppi, M., Muscolo, G.G., Cepolina, E.M., Farina, A., Nashashibi, F., Pollard, E., Dominguez, J.A., 2015. An electro-mobility system for freight service in urban areas, International Journal of Electric and Hybrid Vehicles, 7 (1), pp. 1-21.

Mooney, J. G., Gurbaxani, V. et Kraemer, K. L., 1995. A process oriented framework for assessing the business value of information technology, In Actes du Sixteenth International Conference on Information Systems, Amsterdam, December 10-13.17-27.

Neely, A. 1999, The performance measurement revolution: why now and what next?, International Journal of Operations & Production Management, 19, 2, 205-228.

Rushton, A., Croucher, P., & Baker, P., 2010. The Handbook of Logistics & Distribution Management (4th ed.). London, UK: Kogan Page Limited.

Tellkamp, C., 2006. The impact of Auto-ID technology on process performance—RFID in the FMCG supply chain. Ph.D. Thesis, The University of St. Gallen.

SPATIO-TEMPORAL EVOLUTION OF ECOSYSTEM SERVICE VALUES IN PORT AREAS

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ABSTRACT

The continuous development of maritime industry has brought a marked increase in the construction land of port areas. The ecological problems of ports in China have received more and more attention. Frequent human activities had caused dramatic changes of land use pattern in port areas in the past decades, which brought a significant impact on local environment. Together with the RS, GIS technologies, we relied on land use pattern analysis and ecosystem service value evaluation methods to analyze the ecosystem service value changes of study area. The authors found that from 1995 to 2015, the area of ecological lands reduced significantly in the study area. The total ecosystem service value of the study area was 3.84×10^7 Yuan in 1995 and 2.25×10^7 Yuan in 2015, with a reduction of 1.59×10^7 Yuan from 1995 to 2015. This study aims to provide references for the ecological environment protection in port areas.

Keywords: port area; land use change; ecosystem service value; Dalian

1. INTRODUCTION

Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life (Daily 1997), ecosystem service assessment can benefit human well-being and achieve sustainable economic development (Millennium Ecosystem Assessment 2005). Frequent human activities had caused dramatic land use changes in port areas: the expansion of construction land occupied large amounts of ecological lands and changed the structure and service functions of local ecosystem. Quantitative study on the relationship between the change of ecosystem service value and the land use conversion is conducive to the scientific planning and utilization of land use in port areas. Analysis of the relationship between ecological environment and the port development is of great significance to the sustainable development of ports.

Thirteen scientists had classified and evaluated the global ecosystem comprehensively in 1997 (Costanza, d'Arge, De Groot, Farber, Grasso, Hannon, Limburg, Naeem, Oneill, Paruelo, Raskin, Sutton, and van den Belt 1997), which had led to many researches worldwide and ecosystem service value evaluation included. China's ecosystem service functions contained organic matter production, O_2 release, the fixation of CO_2, etc., and their indirect economic values were estimated by ecological function analysis (Ouyang, Wang, and Miao 1999). In conjunction with ecological questionnaire surveys on Chinese professionals, researchers proposed the value coefficient of Chinese terrestrial ecosystem (Xie, Lu, Leng, Zheng, and Li 2003). Port ecosystem can be seen as the sub-ecosystem of the urban ecosystem and the value coefficient of Chinese terrestrial ecosystem should be revised before ecosystem service value assessment in port areas (Wang 2015).

A significant body of literature has put emphasis on the changes of land use pattern and the corresponding ecosystem service value evaluation in a certain area (Mendoza-González, Martínez, Lithgow, Pérez-Maqueo, and Simonin 2012; Estoque and Murayama 2013; Ninan and Inoue 2013), analyzing the response of ecosystem value changes to land use pattern changes (Lin, Xue, Shi, and Gao 2013; Zeng, Li, and Yao 2014; Liu, Zhang, and Zhang 2014). Most of the studies focused on natural ecosystems (such as oceans, forests, lakes, basins) or a compound ecosystem containing urban areas (Wang, Zhang and Zhang 2004; Xiao, Xiao, Ouyang, Xu, Xiang and Li 2014; Chen, Lu, Ling, Wan, Luo, and Huang 2015). To date there is little research on port ecosystem and ecosystem service value evaluation in port areas is rather limited. In this paper, we reconstructed the 20-year evolution process of port areas of Dalian by combining remote sensing images with historical data of Dalian city. Based on the land use classification results, an evaluation on ecosystem service value of port area was conducted to study the impact of port area sprawl on port ecosystem. We aimed at analyzing the ecosystem service value changes and providing information and guidelines to facilitate decision-making in relation to land use planning in port areas.

2. METHODS

2.1. Study Area

Dalian is a coastal city in northern China, located at the front of the peninsula of Liaodong. Since its establishment in 1984 as one of the 14 open coastal cities in China, Dalian has experienced massive changes in land use pattern in response to the rapid economic growth, especially in port areas. We chose the port areas of Dalian as the case study to measure the effects of land use change on ecosystem. So far, there are 18 berths and 3240m shorelines in the study area which is located in the southwest of Dalian (China Ports Yearbook 2016). This study took the urban construction area border as the boundary line on the land side and the coastline as the boundary line on the sea side.

2.2. Data Collection and Processing

We used high resolution satellite images (Landsat TM/OLI_TRIS) obtained from the United States Geological Survey (USGS) of the same area from different time periods (1995, 2000, 2005, 2010 and 2015) to assess the land use changes that had occurred from 1995 to 2015.

In this study, considering the features in port ecosystem, the land use types are classified into four categories, including woodland, grassland, waterbody and construction land, the first three of them are ecological lands which provide numbers of ecosystem services.

2.3. Land Use Dynamic Degree

We calculated the dynamic degree of the single land use type (K) as:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \tag{1}$$

Where U_a is the area for a certain land use type at the initial stage, U_b is the area for a certain land use type at the end stage, T is the length of the research period. When T is year(s), K is the annual changing rate of area for a certain land use type.

We calculated the integrated dynamic degree of land use (LC) as:

$$LC = \left[\frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2\sum_{i=1}^{n} LU_i} \right] \times \frac{1}{T} \times 100\% \tag{2}$$

In this equation, $\Delta LU_{i\text{-}j}$ is the absolute value of the changing area from land use type i to other land use types, LU_i is the area for land use type i at the initial stage, T is the duration of the study, when T is year(s), LC is the annual integrated changing rate of area for all land use types.

2.4. Ecosystem Service Value Evaluation

This study employed the table (Equivalent values per unit area of ecosystem services in China) to calculate the ecosystem service value (*ESV*) (Xie, Lu, Leng, Zheng, and Li 2003). We assumed that the *ESV* of construction land was zero and revised the table taking into account the differences in port areas (Wang 2015). The *ESV* of study area can be calculated by Eq. (3):

$$ESV = \sum (A_k \times VC_k) \tag{3}$$

In this formula, A_k is the area of land use type k, VC_k is the ecosystem services value coefficient (Yuan/ha.) of land use type k.

The contribution rate of ecosystem service value (ESV_c) can be used to measure the proportion of the *ESV* change of a certain land use type in the total *ESV* change and offer us insights into the influence degree of the change of a certain land use type on the total *ESV* change.

$$ESV_c = \frac{ESV_{ib} - ESV_{ia}}{ESV_b - ESV_a} \times 100\% \tag{4}$$

In this equation, ESV_{ib} and ESV_{ia} are the *ESV* of land use type i at the end and beginning moment of the research, respectively. ESV_b and ESV_a are the total *ESV* of study area at the end and beginning moment of the research, respectively. If $ESV_c<0$, the changing trend of *ESV* of land use type i is opposite to the changing trend of total *ESV* of study area. If $ESV_c>0$, the changing trend of *ESV* of land use type i is the same as that of total *ESV* of study area.

3. RESULTS

3.1. Analysis of Land Use Pattern

Fig.1 illustrates different types of land use changes in study area from 1995 to 2015. The land use distribution in 1995, 2000, 2005, 2010 and 2015 in study area are shown in Fig.2.

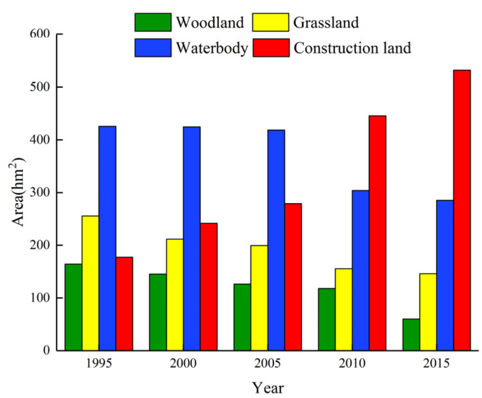

Figure 1: The Area Changes of Different Land Use Types

From 1995 to 2015, the area of construction land nearly doubled in size, while the area of grassland, woodland and waterbody reduced 43%, 63.6%, and 33%, respectively. With the continuous development of social economy, the transportation of goods had put forward higher requirements on the handling capacity of ports, which resulted in the increase of construction land. The port area eroded ecological lands by coastal reclamation on the sea side and occupying grassland and woodland on the land side. Table 1 shows that the land use dynamic degree during 2005 to 2015 is more than that from 1995 to 2005, indicating a larger land use change intensity.

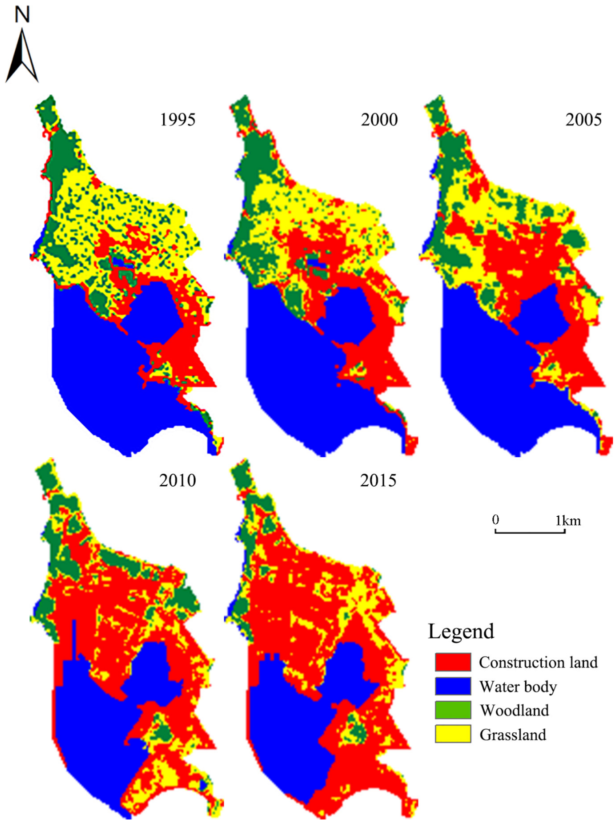

Figure 2: The Land Use Distribution in Study Area for Years of 1995, 2000, 2005, 2010 and 2015

3.2. Changes of Ecosystem Service Values

According to the data from *Dalian Statistical Yearbook 2016* (Dalian Municipal Bureau of Statistics 2016), we calculated the port ecosystem service value per unit area, as shown in Table 2.

Based on the ecosystem service value per unit area in Table 2 and the land use classification results, we used Eq. (3) to calculate the *ESV* of study area. Table 3 and Table 4 show the *ESV* of different service functions and the *ESV* of different land use types, respectively.

The *ESV* of various service functions decreased by the year, the value from water reservation had the greatest decrease of 5.14×10^6 Yuan, followed by the waste disposal (5.04×10^6 Yuan) and climate regulation (2.26×10^6 Yuan), the changing rate of *ESV* of various service functions differed slightly (Table 3).

From 1995 to 2015, the total *ESV* decreased year by year in the port areas, the *ESVs* of various ecological lands (woodland, grassland and waterbody) were also decreasing, the greatest changing rate occurred in the value of woodland (63.61%), followed by grassland (43.03%) and waterbody (33.04%), the total *ESV* had reduced 41.53% during the past 20 years (Table 4).

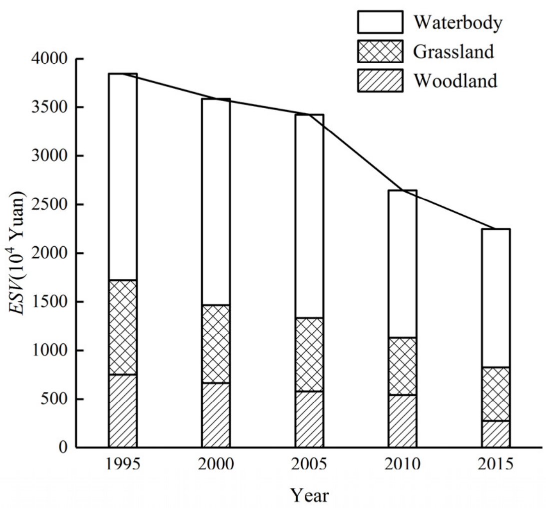

Figure 3: The Ecosystem Service Value Changes in Study Area

The contribution rates of *ESV* for various ecological lands were positive, which illustrated that the *ESVs* of ecological lands were consistent with the trend of total *ESV*, indicating their contributions of *ESV* were negative to total *ESV* change, i.e., the decrease in *ESV* of these land use types led to the reduction in the total ecosystem service value. The largest contribution rate occurred in the value of waterbody, which was mainly caused by the higher *ESV* coefficient of waterbody.

Table 1: Land Use Changes of Study Area from 1995 to 2015

Land use type	Single dynamic degree/%		Integrated dynamic degree/%	
	1995~2005	2005~2015	1995~2005	2005~2015
Woodland	-2.31	-5.27	0.99	2.48
Grassland	-2.19	-2.71		
Waterbody	-0.17	-3.19		
Construction land	5.69	9.11		

Table 2: Port Ecosystem Service Value per Unit Area (yuan/hm^2)

Service type	Woodland	Grassland	Waterbody	Construction land
Gas regulation	2874.817	1410.287	0.000	
Climate regulation	10739.882	9763.529	499.025	
Water reservation	10143.222	8841.418	22108.968	
Formation and protection of soil	3042.966	1985.251	10.848	
Waste disposal	10571.732	10571.732	19722.328	0.000
Biodiversity conservation	3124.329	1947.282	2701.243	
Food production	216.967	325.451	108.484	
Raw materials	1448.257	65.090	10.848	
Entertainment and culture	3704.717	3032.118	4708.191	

Table 3: Ecosystem Service Value of Different Service Functions (10 thousand yuan)

Service type	1995	2015	Changes	Changing rate
Gas regulation	83.05	37.63	-45.42	-54.69%
Climate regulation	446.20	220.13	-226.06	-50.66%
Water reservation	1333.42	819.51	-513.91	-38.54%
Formation and protection of soil	100.93	47.30	-53.64	-53.14%
Waste disposal	1282.92	779.15	-503.77	-39.27%
Biodiversity conservation	215.90	123.96	-91.94	-42.58%
Food production	16.48	9.12	-7.36	-44.67%
Raw materials	25.83	9.88	-15.95	-61.74%
Entertainment and culture	338.57	200.43	-138.14	-40.80%

Table 4: Ecosystem Service Value of Different Land Use Types from 1995 to 2015 (10 thousand yuan)

Year	Woodland	Grassland	Waterbody	Construction land	Total
1995	750.89	968.09	2124.31	0.000	3843.29
2000	663.79	802.82	2118.47	0.000	3585.08
2005	577.51	756.38	2087.51	0.000	3421.39
2010	541.60	588.71	1516.15	0.000	2646.45
2015	273.27	551.49	1422.34	0.000	2247.10
Changes	-477.61	-416.60	-701.97	0.000	-1596.19
Changing rate	-63.61%	-43.03%	-33.04%		-41.53%
Contribution rate	29.92%	26.10%	43.98%		

4. CONCLUSIONS

By analyzing and discussing the changes of land use pattern and *ESV* based on land use classification in one of the port areas of Dalian from 1995 to 2015, this study finally came to the conclusions as follows:

(1) The area of construction land increased significantly in study area during 1995 to 2015, while the areas of woodland, grassland and waterbody decreased gradually. Compared with 1995, the area of construction land showed an increase of 200% in 2015, while the area of woodland showed a reduction of 63.6%, followed by grassland (43%) and waterbody (33%).

(2) The total *ESV* of study area decreased the amount of 41.53%, the *ESVs* of various service functions decreased without exception, the value from water reservation had the greatest decrease, followed by the waste disposal and climate regulation.

(3) For various ecological lands (woodland, grassland and waterbody), their contribution rates were all positive, indicating the trend of *ESV* changes of ecological lands were consistent with the total *ESV* in study area, i.e., the decline in total *ESV* of study area was caused by the decrease of *ESVs* of woodland, grassland and waterbody.

(4) The ecosystem service value and functions tend to decline under current land use patterns, future land use planning should pay more attention to the environmental protection.

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REFERENCES

Costanza R., d'Arge R., De Groot R., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., Oneill R.V., Paruelo J., Raskin R.G., Sutton P., van den Belt M., 1997. The value of the world's ecosystem services and natural capital. Nature, 387 (6630), 253–260.

Chen M., Lu Y., Ling L., Wan Y., Luo Z., Huang H., 2015. Drivers of changes in ecosystem service

values in Ganjiang upstream watershed. Land Use Policy, 47, 247–252.
China Ports Yearbook Editorial Department, 2016. China Ports Yearbook. Shanghai: China Ports Magazine.
Daily G. C., 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Washington D. C.: Island Press.
Dalian Municipal Bureau of Statistics, 2016. Dalian Statistical Yearbook. Beijing: China Statistics Press.
Estoque R. C., Murayama Y., 2013. Landscape pattern and ecosystem service value changes: Implications for environmental sustainability planning for the rapidly urbanizing summer capital of the Philippines. Landscape & Urban Planning, 116 (4), 60–72.
Lin T., Xue X., Shi L., Gao L., 2013. Urban spatial expansion and its impacts on island ecosystem services and landscape pattern: A case study of the island city of Xiamen, Southeast China. Ocean & Coastal Management, 81 (9), 90–96.
Liu G., Zhang L., Zhang Q., 2014. Spatial and temporal dynamics of land use and its influence on ecosystem service value in Yangtze River Delta. Acta Ecologica Sinica, 34 (12), 3311–3319.
Mendoza-González G., Martínez M. L., Lithgow D., Pérez-Maqueoc O., Simonin P., 2012. Land use change and its effects on the value of ecosystem services along the coast of the Gulf of Mexico. Ecological Economics, 82 (20), 23–32.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human well-being: biodiversity synthesis. World Resources Institute, 42 (1), 77–101.
Ninan K. N., Inoue M., 2013. Valuing forest ecosystem services: What we know and what we don't. Ecological Economics, 2013, 93 (3), 137–149.
Ouyang Z., Wang X., Miao H., 1999. A primary study on Chinese terrestrial ecosystem services and their ecological-economic values. Acta Ecologica Sinica, 19 (5), 607–613.
Wang H., 2015. Research of the Calculation Method and Impact of the Port Ecosystem Service Value. Thesis (Master). Dalian University of Technology.
Wang Z., Zhang B., Zhang S., 2004. Study on the effects of land use change on ecosystem service values of Jilin Province. Journal of Natural Resources, 19 (1), 55–61.
Xiao Q., Xiao Y., Ouyang Z., Xu W., Xiang X., Li Y., 2014. Value assessment of the function of the forest ecosystem services in Chongqing. Acta Ecologica Sinica, 34 (1), 216–223.
Xie G., Lu C., Leng Y., Zheng D., Li S., 2003. Ecological assets valuation of the Tibetan Plateau. Journal of Natural Resources, 18 (2), 189–196.
Zeng J., Li J., Yao X., 2014. Spatio-temporal dynamics of ecosystem service value in Wuhan Urban Agglomeration. Chinese Journal of Applied Ecology, 25 (3), 883–891.

DISTANCE ESTIMATE FOR ORDER PICKING SYSTEMS IN MANUAL WAREHOUSES

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ABSTRACT

Given the importance of warehouse processes, this paper proposes an estimate of the order picking distance in a warehouse as a function of the number of items in the picking list, the warehouse shape factor and the number of cross-aisles. Two routing policies, i.e. S-Shape and combined, are taken into account in the evaluation. A model developed in Excel™ is first used to identify the warehouse configuration that generates the best (shortest) distance for each of the policies analysed. Then, an estimate of the picking distance is obtained through a linear regression model. For validation purpose, the results provided by the simulation model for the SS policy are compared with those resulting from the application of an analytic model available in literature.

In terms of picking distance, results generally indicate that the S-Shape policy performs better in the absence of cross-aisles and with a warehouse shape factor high for a few order lines, while the COMB policy reaches the best results with an odd number of cross aisles, that decreases as the number of order lines increases; the optimal shape factor instead increases with the number of order lines.

Keywords: order picking, picking distance, simulation, linear regression

1. INTRODUCTION

A warehousing system is one of the most important resources affecting the capability of firms to compete in the current environment and plays an important role in companies' supply chains (De Koster, Le-Duc, & Zaerpour, 2012; Choy, et al., 2014). Warehouse activities like receiving, storage, order picking and shipping are critical to each supply chain (van Gils, Ramaekers, Caris, & de Koster, 2018). Among these operations, order picking is one of the most time and cost intensive processes (Calzavara, Glock, Grosse, Persona, & Sgarbossa, 2017; Petersen & Aase, 2004; Hsieh & Tsai, 2006), and is considered by many researchers and practitioners as the most critical warehousing activity (Roodbergen, Vis, & Taylor Jr, 2015). Order picking as a warehouse function arises because goods are received in large volumes and customers order small volumes of different products. Each customer order is composed of one or more order lines, with every order line representing a single stock keeping unit (SKU). In order to manage order picking operations, warehouse managers are confronted with four order picking planning problems, in particular storage location assignment, order batching, zone picking and routing (De Koster, Le-Duc, & Roodbergen, 2007) (van Gils, Ramaekers, Braekers, Depaire, & A., 2018).

The literature on manual order picking has mainly focused on economic performance measures, such as the minimization of travel time/distance or the reduction of order throughput times (Calzavara, Glock, Grosse, Persona, & Sgarbossa, 2017). The purpose of routing planning is to reduce the unnecessary picking distance that in turn results in the shortest and the most efficient picking (Hsieh & Tsai, 2006).

In line with these considerations, this study provides an estimate of the distance covered by an order picker in a manual warehouse, as a function of the warehouse shape factor, the number of items in the picking list and the number of cross-aisles. The analysis takes into account two routing policies, i.e. the S-Shape (SS) and the combined (COMB) policy. The former policy implies that any aisle containing at least one picking item is traversed entirely (except, potentially, the last visited aisle), while aisle without picks are not entered. From the last visited aisle, the order picker returns to the depot (Bahrami, Aghezzaf, & Limere, 2017). Instead, the combined routing policy is basically an SS routing enriched with aspects of the largest gap heuristic (Roodbergen, Vis, & Taylor Jr., 2015).

A simulation model developed in Microsoft Excel™ and described in a previous publication (Bottani, Montanari, & Rinaldi, in press) is used to generate the warehouse settings and the picking data. The same model determines which warehouse configuration provide the optimal (minimum) picking distance for each of the policies analysed. For the particular case of the SS policy, the model was also validated by comparing its results with those obtained by applying an analytic approach available in literature (Roodbergen & Vis, 2006). Grounding on the simulated data, an estimate of the picking distance is obtained through different linear regression models, for both policies. The results provided by the regression model are finally compared with those resulting from the simulation model, to evaluate the capability of the regression model to estimate the picking distance.

The paper proceeds as follows. The next section provides some information about the warehouse under examination and describes the simulation strategy adopted to estimate the picking distance. Section 3 discusses the main results and Section 4 concludes by highlighting the main limitations of this work and suggesting future research directions.

2. METHODOLOGY

2.1. Warehouse settings

The assumptions for the picking environment considered in this paper are:

- rectangular warehouse;
- manual picker-to-parts order picking system;
- random storage of items in the warehouse;
- depot located at the bottom left corner of the warehouse;
- the picking area uses double-side shelves with a total storage capacity of 1200 SKUs;
- each SKUs is 1.25x1.00 meter in width and depth, respectively;
- aisle width is 3 meters.

2.2. Simulation model

The model used in this study was developed by Bottani et al. (in press) to help design picker-to-parts order picking systems and simultaneously evaluate the effect and interactions of various design and operating factors on the process performance. This software allows the geometry of any rectangular warehouse to be reproduced as a function of its main parameters, such as the number of aisles and cross-aisles, shape factor and total storage capacity. Moreover, four routing policies can be applied to identify the picking route and compute the resulting travel distance.
In this study, the model is used to evaluate the warehouse design problems with a variable number of cross aisles (0-10, step 1), length of the order picking list (10-50, step 10) and shape factor (from 0.118 to 4.889) for two policies, such as SS and COMB. For each policy, 121 simulations are carried out. Simulation is used as a powerful tool to simultaneously consider all possible warehousing design combinations (Altarazi & Ammouri, in press).

2.3. Model validation

According to Kleijnen (1995), "validating" a simulation model means checking whether the model is able to provide an accurate representation of the system under study. This can be done in several ways: one of them is to compare the model results with available data (Kleijnen, 1995). In line with this suggestion, the simulation model of the SS policy was validated by comparing the outcomes provided with those available in the study developed by Roodbergen & Vis (2006), as both studies grounds on the same warehouse description and assumptions. The aim is to check whether the model outcome (i.e. the travel distance) the same obtained in the previous study found in literature. This should confirm the correctness of the model. Conversely, differences in would indicate that changes were made also to the basic structure of the model, probably with errors. Unfortunately, the same validation cannot be made for the COMB policy, because an analytic model for this policy is not available in literature.

2.4. Linear regression

Linear regression was used to gather the results obtained by the simulation model and to estimate the distance covered by the picker as a function of the warehouse characteristics. To this end, two linear regression models were used to estimate the picking distance for each of the policies. For the first (two-parameter) model, the key parameters considered are the number of cross-aisles and the warehouse shape factor; for the second (three-parameter) model, besides the parameters of the first model, the number of items in the picking list is added.
Therefore, the first linear regression model that estimate the travel distance d (dependent variable) has the following general form:

$$d = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 \quad (1)$$

In eq.1, x_1 denotes the number of cross-aisles and x_2 warehouse shape factor, while α_i $(i = 0, 1, 2)$ are the linear regression coefficients.
The equation for the three-parameter linear regression model is given below:

$$d = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 \quad (2)$$

In eq.2, x_1 denotes the number of items in the picking list, x_2 the number of cross-aisles and x_3 the warehouse shape factor.

3. RESULTS

3.1. Simulation outcomes

The optimal warehouse layout, i.e. the layout that returns the minimum travel distance for an order picker, is shown in Tables 1 and 2 for the two policies studied.

Table 1: Minimum travel distance for SS policy

LENGTH OF THE ORDER PICKING LIST	CROSS AISLES	SHAPE FACTOR	DISTANCE [m]
10	0	3.0555	468.839
20	0	3.0555	641.814
30	0	0.1410	669.923
40	0	0.1410	677.596
50	0	0.1410	685.150

Table 2: Minimum travel distance for COMB policy

LENGTH OF THE ORDER PICKING LIST	CROSS AISLES	SHAPE FACTOR	DISTANCE [m]
10	5	0.4583	319.099
20	3	0.7333	444.119
30	1	2.8205	535.911
40	1	2.8205	608.776
50	1	2.8205	670.734

As can be seen in Table 1, the set of parameters that returns the minimum travel distance in the SS policy always excludes cross-aisles in the warehouse. It is interesting to note that the optimal shape factor changes depending on the number of order lines: with 10 or 20 order lines, the shape factor is high (3.055), while with 30, 40 or 50 order lines, the optimal shape factor is very low and close to its lower bound (0.118).
For the COMB policy (Table 2), the increase in the number of items in the picking list involves a decrease in the number of cross-aisles and an increase in the warehouse shape factor. Nonetheless, it is interesting to note that, with 30, 40 or 50 order lines, the optimal warehouse configuration does not change (i.e. 1 cross aisle and 2.8205 shape factor).

3.2. Model validation

As mentioned before, the validation of the results of the SS policy was made by comparing the travel distances obtained with those resulting from the application of the analytic model developed by Roodbergen & Vis (2006). To this end, 50 comparisons were carried out overall, with 10 simulation results per size of the order picking list. For sake of brevity, Table 3 reports only the average values of the travel distance across the 10 simulations. The same table also provides the results of the validation by comparing the simulated outcomes with the analytic ones and computing the percentage difference between them.

Table 3: Model validation for the SS policy

ORDER LINE	SHAPE FACTOR	SIMULATED DISTANCE	ANALYTIC DISTANCE	PERCENTAGE DIFFERENCE
10	1.6916	531.459	524.233	-1.4%
20	1.6916	667.551	655.206	-2.1%
30	1.6916	731.488	712.346	-2.6%
40	1.6916	768.223	741.289	-3.7%
50	1.6916	792.282	757.595	-4.4%

As shown in Table 3, the distances returned by the analytic model and by the simulation are very similar. The average deviation for the 50 instances analysed was -2.84%, while the highest error found was -4.4%. In particular, the analytic model always provides slightly shorter distances than the simulation, which, therefore, slightly overestimates the travel distance. Furthermore, errors tend to increase if increasing the number of items in the picking list.

3.3. Linear regression

The best linear regression models for the picking distance as a function of the number of items in the picking list are shown in Table 4.

Table 4: Linear regression with two parameters for both policies

POLICY	ORDER LINE	α_0	α_1	α_2
COMB	10	325.0316	4.3802	42.9841
COMB	20	393.3030	14.5330	78.9619
COMB	30	422.6685	25.4976	104.0906
COMB	40	441.3953	34.4401	121.9617
COMB	50	454.1493	2.8205	135.8940
SS	10	547.0409	20.9158	-11.9267
SS	20	613.2042	32.6937	29.5294
SS	30	603.9494	40.8520	72.9303
SS	40	584.2678	46.5046	106.1016
SS	50	567.5775	50.4549	129.8099

The best regression model obtained with three parameters is instead shown in Table 5.

Table 5: Linear regression with three parameters for both policies

POLICY	α_0	α_1	α_2	α_3
COMB	64.870	11.4146	24.127	96.778
SS	304.081	9.3042	38.282	65.289

As can be seen from the tables above, for the two-parameter regression, five regression models per policy were built (each one resulting from 121 observations), while for the three-parameter regression only one regression model per policy was built (resulting from 121*5=605 observations).
It can also be noted that the COMB policy is not so well represented by a linear trend, while for the SS policy the travel distance tends to be closer to a linear trend.
Tables 6 and 7 report the values of the coefficient of determination (R^2) and the average and maximum deviation obtained as absolute values of the difference between simulation and two-parameter regression distance for both policies analysed.

Table 6: Comparison of the results obtained for SS policy for two-parameter regression

ORDER LINE	R^2	PERCENTAGE DIFFERENCE	MAXIMUM DIFFERENCE
10	0.7514	5%	16%
20	0.8308	5%	21%
30	0.8156	7%	29%
40	0.8211	8%	33%
50	0.8262	9%	35%

Table 7: Comparison of the results obtained for COMB policy for two-parameter regression

ORDER LINE	R^2	PERCENTAGE DIFFERENCE	MAXIMUM DIFFERENCE
10	0.4570	12%	39%
20	0.5558	13%	57%
30	0.6050	14%	60%
40	0.6375	15%	58%
50	0.6641	14%	56%

Table 6 shows that, for SS policy, the linear model describes the picking distance trend with a good approximation. Nevertheless, the regression model shows some deviations with high values of the number of items in the picking list (i.e. 30, 40 and 50 order lines).
On the contrary, as Table 7 shows, even if R^2 improves with the increase in the number of items in the picking list, overall the R^2 values are lower than those observed with the previous policy. In particular, the average deviation is never lower than 10%, while the maximum deviation, in four cases out of five, is higher than 50%.
To sum up, we can conclude that the linear model cannot describe the picking distance trend of the COMB policy with a good approximation. This is probably due to the fact that, when the COMB policy is adopted, the

picker does not follow a predefined route (as for the SS or return policies); hence, the picking distance is more complex to model.
As in the case of the two-parameter linear regression, we report the average values of the coefficient of determination (R^2), the average and maximum deviation obtained as absolute values of the difference between simulation and three-parameter regression distance for both policies analysed.

Table 8: Comparison of the results obtained for three-parameter regression

POLICY	R^2	PERCENTAGE DIFFERENCE	MAXIMUM DIFFERENCE
COMB	0.7071	15.6%	64%
SS	0.7422	11%	44%

The detailed analysis of the results obtained for both policies as a function of the number of items in the picking list is shown in Table 9:

Table 9: Comparison of the results obtained for three-parameter regression as a function of the number of items in the picking list

POLICY	NUMBER OF ITEMS IN THE PICKING LIST	PERCENTAGE DIFFERENCE	MAXIMUM DIFFERENCE
COMB	10	23%	64%
COMB	20	14%	54%
COMB	30	13%	51%
COMB	40	13%	52%
COMB	50	15%	56%
SS	10	18%	42%
SS	20	9%	31%
SS	30	8%	23%
SS	40	8%	34%
SS	50	12%	44%

As can be seen from Table 9, for both policies the deviation increase by increasing the number of order lines. Indeed, these linear regressions return the best results for 30 and 40 order lines. It can also be noted that with the introduction of the third parameter, both policies are getting worse. Indeed, the model with three parameters is too imprecise.

4. DISCUSSION AND CONCLUSION

This paper has proposed an estimate of the picking distance in a manual warehouse as a function of the shape factor, number of items in the picking list and number of cross-aisles, for two routing policies, i.e. the SS and COMB policy. In particular, we described the application of a simulation model, developed in Excel™ to evaluate the distance of the order picking systems. The simulation model for the SS policy was validated by comparing its outcomes with those of an analytic model available in literature. The estimate of the travel distance was then obtained through a linear regression model. Finally, the results provided by the simulation model are compared with those resulting from the analytical model.
In general terms, the SS policy performs better in the absence of cross-aisles; the optimal shape factor is high if the number of items in the picking list is low, while it is lower if the number of items in the picking list increases. The COMB policy instead reaches its best results with an odd number of cross-aisles, that decreases as the number of order lines increases. Concerning the model validation, the comparison between the simulation outcomes and the analytic ones, obtained using the model developed by Roodbergen & Vis (2006), shows the good accuracy of the simulation. In particular, the average error found was 3.00%, while the maximum error was 6.00%. This result further validates the simulation outcomes. Moreover, the SS policy, in a two-parameter linear regression, returns a picking distance trend similar to the original, while the COMB policy shows a quite different behaviour and, therefore, cannot be described using a linear model. The regression model with 3 parameters, which is more general than the previous one, returns results that are too approximate and often too high compared to the outcomes of the simulation.
Estimating the travel distance as a function of the warehouse settings and the length of the picking list has interesting practical applications. In fact, although an analytic model exists for the SS policy, carrying out the analytic computation is not trivial. On the contrary, the use of a regression model is easier from a computational point of view. On the other hand, compared to the analytic approach, the regression model introduces some approximations, which has been highlighted by computing the percentage difference between the results provided by the linear regression and the simulated results.
From a technical perspective, some limitations of the analysis should also be mentioned. Specifically, the analysis carried out in this paper does not take into account other traditional routing policies which are often adopted in manual order picking systems, e.g. return and aisle by aisle. Further, more elaborated, routing policies have also been proposed recently in literature (see Bottani et al., in press, or De Santis et al., 2018). Adding these policies could be an adjustment to be made to the model, in the attempt to estimate the picking distance also in different configurations. Moreover, starting from this work, several future research directions could be undertaken. For instance, the study developed could be used to analyse different picking environments, with the purpose of evaluating whether the travel distance may vary depending on the characteristics of the warehouse. The choice of the parameters used in the regression model could be modified, including further factors in the evaluation.

REFERENCES

Altarazi, S., & Ammouri, M. (in press). Concurrent manual-order-picking warehouse design: a simulation-based design of experiments approach. *International Journal of Production Research*. DOI: 10.1080/00207543.2017.1421780

Bahrami, B., Aghezzaf, E.-H., & Limere, V. (2017). Using simulation to analyze picker blocking in manual order picking systems. *Proceedings of the 27th International Conference on Flexible*

Automation and Intelligent Manufacturing, FAIM2017, (p. 1798-1808). Modena (Italy)

Bottani, E., Montanari, R., & Rinaldi, M. (in press). Development and testing of software tool for warehouse design and picking optimisation. *International Journal of Management and Decision Making*. DOI: 10.1504/IJMDM.2018.10013618

Calzavara, M., Glock, C., Grosse, E., Persona, A., & Sgarbossa, F. (2017). Analysis of economic and ergonomic performance measures of different rack layouts in an order picking warehouse. *Computers & Industrial Engineering*, 111, 527-536. DOI: 10.1016/j.cie.2016.07.001

Choy, K., Sheng, N., Lam, H., Lai, I., Chow, K., & Ho, G. (2014). Assess the effects of different operations policies on warehousing reliability. *International Journal of Production Research*, 52(3), 662-678. DOI: 10.1080/00207543.2013.827807

De Koster, R., Le-Duc, T., & Roodbergen, K. (2007). Design and control of warehouse order picking: a literature review. *European Journal of Operational Research*, 182(2), 481-501. DOI: 10.1016/j.ejor.2006.07.009

De Koster, R., Le-Duc, T., & Zaerpour, N. (2012). Determining the number of zones in pick-and-sort order picking system. *International Journal of Production Research*, 50(3), 757-771. DOI: 10.1080/00207543.2010.543941

De Santis, R., Montanari, R., Vignali, G., Bottani, E., 2018. An adapted ant colony optimization algorithm for the minimization of the travel distance of pickers in manual warehouses. *European Journal of Operational Research*, 267, 120-137. DOI: 10.1016/j.ejor.2017.11.017

Hsieh, L.-F., & Tsai, L. (2006). The optimum design of a warehouse system on order picking efficiency. *International Journal of Advanced Manufacturing Technology*, 28, 626-637. DOI: 10.1007/s00170-004-2404-0

Kleijnen, J. (1995). Verification and validation of simulation models. *European Journal of Operational Research*, 82(1), 145-162. DOI: 10.1016/0377-2217(94)00016-6

Petersen, C., & Aase, G. (2004). A comparison of picking, storage, and routing policies in manual order picking. *International Journal of Production Economics*, 92, 11-19. DOI: 10.1016/j.ijpe.2003.09.006

Roodbergen, K., & Vis, I. (2006). A model for warehouse layout. *IIE Transactions*, 38, p. 799-811. DOI: 10.1080/07408170500494566

Roodbergen, K., Vis, I., & Taylor Jr., D. (2015). Simultaneous determination of warehouse layout and control policies. *International Journal of Production Research*, 53(11), 3306-3326. DOI: 10.1080/00207543.2014.978029

van Gils, T., Ramaekers, K., Braekers, K., Depaire, B., & Caris, A. (2018). Increasing order picking efficiency by integrating storage, batching, zone picking, and routing policy decisions. *International Journal of Production Economics*, 197, 243-261. DOI: 10.1016/j.ijpe.2017.11.021

van Gils, T., Ramaekers, K., Caris, A., & de Koster, R. (2018). Designing efficient order picking systems by combining planning problems: state-of-the-art classification and review. *European Journal od Operational Research*, 267, 1-15. DOI: 10.1016/j.ejor.2017.09.002

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THE BLOCK RELOCATION PROBLEM UNDER A REALISTIC MODEL OF CRANE TRAJECTORIES

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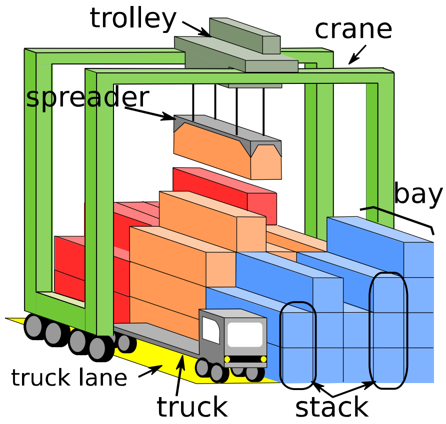
ABSTRACT
This paper addresses the block (container) relocation problem whose objective is to minimize total crane operation time necessary for retrieving all blocks (containers) stacked in tiers according to a specified order. We already proposed a branch-and-bound algorithm for this problem, but it simplified the crane trajectories so that an unnecessarily large margin between the placed containers and the spreader of the crane was considered. In this study we propose a more realistic model of crane trajectories and construct a branch-and-bound algorithm for the problem based on it. Then, we compare the two models by numerical experiment.

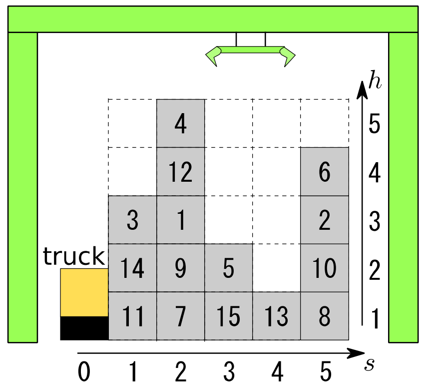
Keywords: container terminal, block relocation problem, crane trajectory model

1. INTRODUCTION

Container terminals interconnect multimodal logistics networks by providing temporary storage space for containers. Containers transported to a seaport by vessels or trucks are stacked in tiers in a container yards of a container terminal as Fig.1(a). These containers are retrieved from the yard in the order determined by their destinations, weights, contents, and so on. Since this order is not always known in advance, we sometimes have to retrieve a container in a low tier, which requires relocation of the containers placed above it. This relocation leads to further relocation if they are placed on the container to be retrieved next. Reduction of delays in container handling caused by such relocation is important for improving the throughput of not only the container terminal but also the overall logistics networks. The container relocation problem, which is also known as the block relocation problem, aims to minimize the delays in retrieving containers according to a specified order. Throughout this paper, we refer to this problem as the block relocation problem (BRP), and a container as a block accordingly. In order to simplify the problem, most of the previous studies on the BRP considered minimization of the total number of relocations. Indeed, there are several studies for this type of BRP, regarding heuristics (eg. Kim and Hong (2006), Wu and Ting (2015), Jovanovic and Voß (2014), Jin et al. (2015)), IP formulations (eg. Caserta et al. (2012), Zehendner et al.



(a) Container Yard



(b) Example of Bay

Figure 1: Container terminal

(2015), Galle et al. (2017)), exact algorithms (eg. Kim and Hong (2006), Zhu and Qin (2012), Tanaka and Takii (2016), Tanaka and Mizuno (2018)), and so on.

It is true that the total number of relocations provides an index of handling efficiency in container terminals, but it is more desirable to reduce the total crane operation time directly. Nevertheless, studies in this direction are still limited. Lee and Lee (2010), Ünlüyurt and Aydın (2012) and Lin et al. (2015), proposed heuristics for BRP in which the horizontal crane travel time is considered. Schwarze and Voß (2016) improved the formulation proposed by Caserta and Voß (2012) to the one considering the crane travel time in the horizontal and vertical directions. In our previous study (Inaoka and Tanaka (2017)), we proposed a branch-and-bound algorithm for the BRP to minimize the total crane operation time, and examined its effectiveness under different settings of the crane operation time. However, these studies, including ours, calculated the crane operation time using a simplified model of crane trajectories. In this study we introduce a more realistic model of crane trajectories and improve the branch-and-bound algorithm to solve the BRP under this model. Then, we examine the effect of the models on the total crane operation time by numerical experiment.

2. PROBLEM SETTING

Suppose that blocks of the same size are stored in a container yard as illustrated in Fig.1(a). A set of blocks piled up vertically is called a stack and a single row of stacks is called a bay. We consider retrieving all N blocks in a bay composed of S stacks using a gantry crane (Fig.1(b)). The blocks are numbered from 1 to N according to their retrieval order. The blocks can only be moved within this bay, and the number of blocks that can be placed in each bay is limited to H. The slot in the hth tier of stack s is denoted by (s, h). To retrieve blocks, the following two types of crane operation are permitted:

- Relocation: A block on the top of a stack is moved to the top of another stack that does not reach the height limit,
- Retrieval: The block with the smallest number (target block) is moved to the bed of the truck at $(0, h_{\mathrm{out}})$ if it is on the top of a stack.

The objective is to find an optimal sequence of crane operations that minimize the total working time. In this study, the restricted BRP is considered where only the blocks above the target block can be relocated.

3. NEW MODEL OF CRANE TRAJECTORIES

In Inaoka and Tanaka (2017), as in the other studies that consider the vertical crane travel time, the spreader of the crane is assumed to be always hoisted up to the highest position h^{top} when the trolley is moved horizontally (Fig.2(a)). However, in practice, we only need to keep an enough margin between the spreader and the placed blocks. Specifically, the required height for the spreader in trolley moves is determined by the height of the stacks between the source and destination stacks. By denoting this height by $h_{\max}$ and the margin height by h_{margin}, the vertical position of the spreader in trolley moves from stack s^{s} to stack s^{d} of the configuration C is given by

$$h_{\mathrm{l}}(\mathsf{C}, s^{\mathrm{s}}, s^{\mathrm{d}}) = h_{\max} + h_{\mathrm{margin}} + 1 \qquad (1)$$

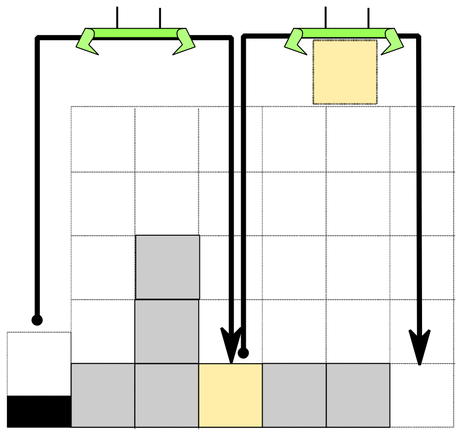
if a block is moved, and

$$h_{\mathrm{u}}(\mathsf{C}, s^{\mathrm{s}}, s^{\mathrm{d}}) = h_{\max} + h_{\mathrm{margin}} \qquad (2)$$

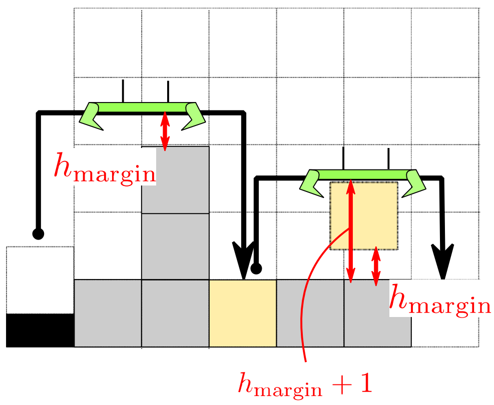
otherwise (Fig.2(b)). Based on this model, we will express the objective function in an explicit form.

Table 1: Crane Operation Time

t_{sg}[s]	The block grasp time
t_{sr}[s]	The block release time
t_{t} [s/stack]	The trolley speed for horizontal move
t_{hu} [s/tier]	The hoisting speed (unloaded)
t_{hl}[s/tier]	The hoisting speed (loaded)



(a) Previous Model



(b) New Model

Figure 2: Two Models of Crane Trajectories

Suppose that the position of the target block i is (s, h) and n_i blocks are stacked on it. Furthermore, the position of the spreader is assumed to be $(0, h^{\mathrm{out}})$. To retrieve the target block i, the n blocks above it at $(s, h + n_i)$, $(s, h + n_i - 1)$, …, $(s, h + 1)$ should be relocated to other stacks. If their destinations are denoted by $(s_1^{\mathrm{d}}, h_1^{\mathrm{d}})$, …, $(s_n^{\mathrm{d}}, h_n^{\mathrm{d}})$, respectively, and their current positions by $(s_1^{\mathrm{s}}, h_1^{\mathrm{s}})$, …, $(s_n^{\mathrm{s}}, h_n^{\mathrm{s}})$, respectively ($s_j^{\mathrm{s}} = s$, $h_j^{\mathrm{s}} = h + n_i - j + 1$), the crane operation is decomposed into: unloaded move from $(0, h^{\mathrm{out}})$ to $(s_1^{\mathrm{s}}, h_1^{\mathrm{s}})$, loaded move from $(s_1^{\mathrm{s}}, h_1^{\mathrm{s}})$ to $(s_1^{\mathrm{d}}, h_1^{\mathrm{d}})$, unloaded move from $(s_1^{\mathrm{d}}, h_1^{\mathrm{d}})$ to $(s_2^{\mathrm{s}}, h_2^{\mathrm{s}})$, …, unloaded move from $(s_n^{\mathrm{d}}, h_n^{\mathrm{d}})$ to (s, h), and loaded move from (s, h) to $(0, h^{\mathrm{out}})$. in the previous model where each crane trajectory is determined only by the source and destination positions, the crane operation time is expressed by:

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$$T_i^{\mathrm{P}} = t_{\mathrm{s}} + 2t_{\mathrm{t}}s + (t_{\mathrm{hl}} + t_{\mathrm{hu}})\{2h^{\mathrm{top}} - (h + h^{\mathrm{out}} + 1)\}$$
$$+ \sum_{j=1}^{n_i} \{t_{\mathrm{s}} + 2t_{\mathrm{t}}|s - s_j^{\mathrm{s}}| + (t_{\mathrm{hl}} + t_{\mathrm{hu}})(2h^{\mathrm{top}} - h_j^{\mathrm{s}} - h_j^{\mathrm{d}})\} \quad (3)$$

where, $t_{\mathrm{sg}}, t_{\mathrm{sr}}, t_{\mathrm{t}}, t_{\mathrm{hu}}$ and t_{hl} are as summarized in Table 1, and $t_{\mathrm{s}} = t_{\mathrm{sg}} + t_{\mathrm{sr}}$. On the other hand, in the new model, the crane operation time is calculated as:

$$T_i^{\mathrm{N}} = t_{\mathrm{s}} + 2t_{\mathrm{t}}s + t_{\mathrm{hl}}\{2h_{\mathrm{l}}(\mathrm{C}_{n_i}, s, 0) - (h + h^{\mathrm{out}} + 1)\}$$
$$+ t_{\mathrm{hu}}\{h_{\mathrm{u}}(\mathrm{C}_0, 0, s) + h_{\mathrm{u}}(\mathrm{C}_{n_i}, s_{n_i}^{\mathrm{d}}, s_{n_i}^{\mathrm{s}}) - (h + h^{\mathrm{out}} + 1)\}$$
$$+ \sum_{j=1}^{n_i} [t_{\mathrm{s}} + 2t_{\mathrm{t}}|s - s_j^{\mathrm{s}}| + t_{\mathrm{hl}}\{2h_{\mathrm{l}}(\mathrm{C}_{j-1}, s_j^{\mathrm{s}}, s_j^{\mathrm{d}}) - h_j^{\mathrm{s}} - h_j^{\mathrm{d}}\}$$
$$+ t_{\mathrm{hu}}\{h_{\mathrm{u}}(\mathrm{C}_{j-1}, s_{j-1}^{\mathrm{d}}, s_{j-1}^{\mathrm{s}}) + h_{\mathrm{u}}(\mathrm{C}_j, s_j^{\mathrm{d}}, s_j^{\mathrm{s}}) - h_j^{\mathrm{s}} - h_j^{\mathrm{d}}\}] \quad (4)$$

where C_0 is the bay configuration before the operation is executed, C_j $(j = 1 \dots n_{\mathrm{i}})$ is the bay configuration after jth block is relocated, and $s_0^{\mathrm{s}} = s, s_0^{\mathrm{d}} = 0$. As a result, the objective function is given by $\min \sum_{i=1}^{N} T_i^{\mathrm{N}}$.

4. BRANCH-AND-BOUND ALGORITHM

From (1) and (2), we see that the computation of the objective value becomes complicated and thus difficult, compared with that under the previous model. Nevertheless, we improve the branch-and-bound algorithm in Inaoka and Tanaka (2017) to solve the BRP under the new model. The algorithm for our problem is basically the same as the previous one. It searches for an optimal sequence of relocations in a depth-first manner. In the search tree, each node at depth k represents a bay configuration after first k relocations are performed and all retrievable blocks are retrieved (Fig.3). Child nodes are generated by enumerating all feasible $(k+1)$th relocations. Since our problem is the restricted BRP, the block relocated next is uniquely determined, so that we in practice enumerate its destination stacks. There are two differences from the previous branch-and-bound algorithm. In Inaoka and Tanaka (2017), we derived dominance properties to reduce unnecessary branches. However, it is difficult to extend them to our model, and no dominance properties are utilized in the algorithm in this study. The second difference is lower bounding. Obviously, we have to derive a lower bound of the new objective function. In the following, we explain how to compute the lower bound.

In the new model, the heights of stacks greatly affect the crane trajectories and thus the objective value. It follows that to obtain a good lower bound of the objective value, we need to take into consideration the bay configuration when each block is relocated or retrieved. Although it depends on how blocks are relocated before that block, we can figure out the invariant part of the bay configuration as follows. Recall that in our problem, we can relocate only blocks above the current target block. In other words, we cannot relocate blocks below the target block. For example, when block 13 is relocated to retrieve block 1 in the bay configuration in Fig.4(a), all

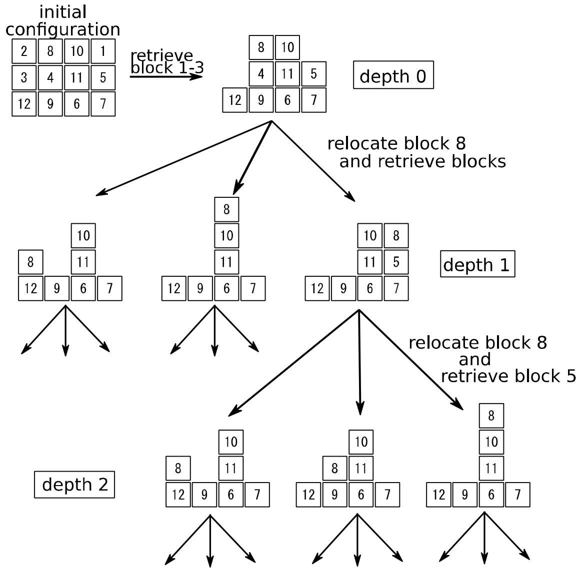
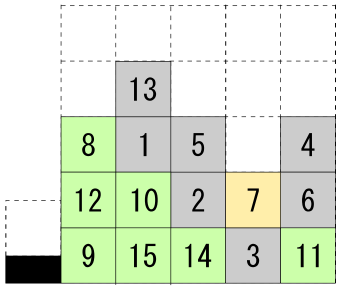
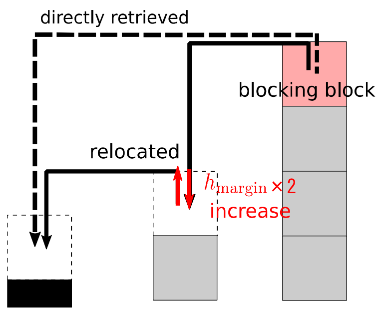
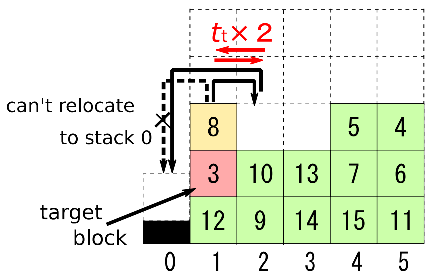


Figure 3: Part of the Search Tree


(a) Unmoved Blocks before Block 7



(b)Increase due to Relocations



(c)Increase due to blocking blocks in stack 1

Figure 4: Improvements on Lower Bound

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the other blocks stay unchanged. After block 1 is retrieved, block 2 becomes the target block and block 5 is relocated next. At this moment, all the blocks except blocks 1, 2, 5 and 13 stay unchanged. Formally speaking, block *i* is in its original position when block *t* is the target block if

(i) $i > t$,

(ii) no block j with $j < t$ is placed below it

are both satisfied.

Assuming that only these invariant blocks are placed, we compute a lower bound of the crane operation time required for retrieving block *t*. We also ignore relocations of blocks. It is true that block t is relocated before its retrieval if a block with a higher priority is placed below it. However, even in this case, the total crane operation time for block *t* is never shorter than that for retrieving it directly from its original position, which ensures this approximation validity as a lower bound. Let τ_t be the crane operation time for retrieving block t computed in this manner. Then, this lower bound is given by $\sum_{i=m}^{N} \tau_i$, where m is the minimum priority of the blocks in the current bay configuration.

We try to further improve it in two ways. First, we note that when a block should be relocated before its retrieval, the total crane operation time is at least $2h_{\text{margin}}$ longer than that of the direct retrieval as illustrated in Fig.4(b). Therefore, we can increase the lower bound by $2h_{\text{margin}} r_{\text{LB}}$ where r_{LB} is a lower bound of the total number of relocations. We use the lower bound by Kim and Hong (2006) as r_{LB} for simplicity. It is defined by the number of blocking blocks, where a blocking block is such a block below which a block with a higher priority is placed. Second, we note the blocking blocks in stack 1, the left most stack next to the truck lane (Fig.4(c)). Since they should be relocated to the stacks in the direction opposite to the truck lane, the increase in the crane operation time for each of such blocking blocks is at least $(2t_t + 2h_{\text{margin}})$. Hence, we further add $2t_t n_1^{\text{B}}$ to the lower bound, where n_s^{B} denotes the number of blocking blocks in stack s. In summary, we use

$$\sum_{i=m}^{N} \tau_i + 2h_{\text{margin}} r_{\text{LB}} + 2t_t n_1^{\text{B}} = \sum_{i=m}^{N} \tau_i + 2h_{\text{margin}} \sum_{s=1}^{S} n_s^{\text{B}} + 2t_t n_1^{\text{B}} \quad (5)$$

as the lower bound.

5. EXPERIMENT AND RESULTS

We solved the benchmark instances in Caserta et al. (2011) under the proposed crane trajectory model by the branch-and-bound algorithm. The instances are characterized by two parameters: the number of stacks *S* and the number of blocks in each stack *T*. Hence, the total number of blocks is *ST*. The dataset includes 40 randomly generated instances for each combination of *S* and *T*. Following Lin et al. (2015), we set the crane operation time as follows: the block grasp and release time are ignored ($t_s = 0$), the trolley speed for horizontal move $t_t = 1.2$[s/slot], the spreader hoisting speed $t_{\text{hl}} = 5.18$[s/slot] (loaded), and $t_{\text{hu}} = 2.59$[s/slot] (unloaded). In addition, we set $h_{\text{out}} = h_{\text{margin}} = 0.5$ and $H = T + 2$. The computation was conducted on a desktop computer with an Intel Core i7-2700K CPU (3.50GHz) and 32GB RAM. The computational results are summarized in Table 2. In the table, "opt" denotes the number of instances solved to optimally within 1800s, "operation time" the average objective value (total crane operation time), and "CPU" the average computation time in seconds over solved problems. For comparison, we present the results for the previous model (Inaoka and Tanaka, 2017) in "Previous model", and those for the new model in "New model". From Table 1, it can be seen that the total crane operation time is reduced by approximately 30% under the new model from the previous model, owing to the removal of unnecessarily large margins, although the computation time for solving instances becomes longer. It is partly because dominance properties are not employed in the proposed branch-and-bound algorithm. For previous model, we successfully derived some dominance properties among solutions, which enabled us to restrict the search space in the branch-and-bound algorithm. However, it is not direct to extend them to the new model, and thus no dominance properties are utilized in the proposed branch-and-bound algorithm, so that it should search a larger solution space. To improve its efficiency, it would be necessary to derive dominance properties for the new model.

Table 2: Computational Results for two models

T	S	Previous model			New model		
		opt	operation time[s]	CPU [s]	opt	operation time[s]	CPU [s]
3	3	40	589.3	0.00	40	361.8	0.00
	4	40	767.4	0.00	40	494.2	0.00
	5	40	936.3	0.00	40	632.4	0.01
	6	40	1129.0	0.34	40	814.3	0.39
	7	40	1309.2	1.13	40	958.2	2.46
	8	40	1523.5	21.26	40	1146.6	26.80
4	4	40	1244.4	0.01	40	837.2	0.02
	5	40	1569.9	1.29	40	1086.4	4.98
	6	40	1809.2	88.36	38	1304.8	58.52
	7	22	2056.5	402.28	28	1556.4	335.16
5	4	40	1865.3	0.51	40	1300.8	5.27
	5	31	2259.0	210.05	24	1555.4	128.39
	6	4	2442.3	515.74	6	1898.4	324.42

6. CONCLUSION

We considered the BRP under a realistic model of crane trajectories and proposed a branch-and-bound algorithm to solve it. The computational experiment confirmed that the new model can greatly decrease the total crane operational time. However, there is still room for improvement in the branch-and-bound algorithm. In future research, it is also worth investigating a more realistic crane model where acceleration and deceleration are taken into account.

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REFERENCES

Kim K. H. and Hong G.-P., 2006. A heuristic rule for relocating blocks. Computers & Operations Research, 33, 940-954.

Wu K. -H. and Ting C. -J., 2016. A constructive heuristic for the container relocation problem. International Journal of Industrial Engineering, 23(3), 195-206.

Jovanovic R. and Voß S., 2014. A chain heuristic for the Blocks Relocation Problem. Computers & Industrial Engineering, 75, 79-86.

Jin B., Zhu W. and Lim A., 2015. Solving the container relocation problem by an improved greedy look ahead heuristic. European Journal of Operational Research, 240, 837-847.

Zhu W., Qin H., Lim A. and Zhang H., 2012. Iterative deepening A* algorithms for the container relocation problem. IEEE Transactions on Automation Science and Engineering, 9, 710-722.

Tanaka S. and Takii K., 2016. A faster branch-and-bound algorithm for the block relocation problem. IEEE Transactions on Automaton Science and Engineering, 13, 415-422.

Tanaka S. and Mizuno F., 2018. An exact algorithm for the unrestricted block relocation problem Computers & Operations Research, 95, 12–31

Caserta M., Schwarze S. and Voß S., 2012 A mathematical formulation and complexity consideration for the block relocation problem. European Journal of Operational Research, 219, 96–104.

Zehendner E., Caserta M., Feillet D., Schwarze S. and Voß S., 2015. An improved mathematical formulation for the blocks relocation problem. European Journal of Operational Research, 245, 415-422.

Galle V., Barnhart C. and Jaillet P., 2018. A new binary formulation of the restricted Container Relocation Problem based on a binary encoding of configurations. European Journal of Operational Research, 267, 467-477.

Lee Y. and Lee Y. J., 2010. A heuristics for retrieving containers from a yard. Computers & Operations Research, 33, 940-954.

Ünlüyurt T. and Aydın C., 2012. Improved rehandling strategies for the container retrieval process. Journal of Advanced Transportation, 46, 378-393.

Lin D.-Y., Lee Y.-J. and Lee Y., 2015. The container retrieval problem with respect to relocation. Transportation Research Part C, 52, 132-143

Schwarze S. and Voß S., 2016. Analysis of alternative objectives for the blocks relocation problem, working paper.

Inaoka Y. and Tanaka S., 2017 A branch-and-bound algorithm for the block relocation problem to minimize total crane operation time. Proc HMS 2017, 98-104

Caserta M. and Voß S., 2011. Applying the corridor method to a blocks relocation problem. OR Spectrum, 33, 915-929.

ANALYSIS OF FLIGHT-EFFICIENT ECOSYSTEM SOLUTIONS IN A MULTI-AIRCRAFT CONFLICT ENVIRONMENT

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ABSTRACT
To accommodate future demands in air traffic management, this article qualitatively elaborates the multi-aircraft conflict resolution relying on the concept of an airborne ecosystem, as a set of autonomously operating aircraft whose trajectories are causally involved in a tactically detected conflict. The methodology provides two types of solutions: air traffic control-based resolution that is executed as a set of compulsory avoidance maneuvers at a certain time instance, and the multi-agent simulated resolution as a product of the aircraft negotiation interactions and agreement on the avoidance maneuvers for the conflict state removal. The article further analyses a flight efficiency of the ecosystem resolution, in both distance and time, by comparing the compulsory against the negotiated solutions. From the total amount of tested trajectories and identified conflict patterns, three ecosystem scenarios have been selected and analyzed. Finally, the results have shown the significant savings in favor of the multi-agent solution approach.

Keywords: compulsory resolution, ecosystem, flight efficiency, multi-agent solution

1. INTRODUCTION

The aerial ecosystem framework relies on the analysis of spatiotemporal interdependencies between aircraft located in the proximate airspace volume of a pairwise conflict that must consequently lead to a trajectory amendment. By checking the maneuverability impact of any aircraft that could be affected by a pairwise conflict resolution, it is possible to predict an operationally emergent behavior of the surrounding traffic, and identify a subset of the trajectory amendments that will not cause a negative domino effect with neighboring aircraft. At a technological level, the proposed ecosystem concept (Radanovic et al. 2017) is based on multi-agent technology (Premm and Kirn 2015; Ramasamy et al. 2014), in which agents represent a set of aircraft inside a computed airspace volume, with a decision-making capability, whose trajectories are causally involved in the safety event.

Based on this concept, this paper elaborates two conflict resolution methods, and further quantitatively analysis the efficiency effects of such decisions. The principal objective aims to, first, illuminate the methodology behind the generation of the ecosystem resolution for both the air traffic controller (ATC) and the multi-agent system (MAS) in the event of a violation of the separation minima between aircraft in the ASEAN en-route traffic, before illustrating a comparative analysis of the differences between Air Traffic Control (ATC)-based and MAS-based approach relative to flight efficiency metrics such as time, distance and fuel savings. This comparison is performed in a direct-route operational environment within a single functional airspace block formed from the union of the currently sectorized ASEAN airspaces.

The evidence of time and distance savings in this paper has been shown to be an economic impetus for the introduction of a decentralized, agent-based modelling approach for the design of a decision-support tool (DSTs) as a pivotal role in the mitigation of conflict between ecosystem aircraft. In addition to this introductory section, the paper comprises additional six sections. Section 2 provides a background on the conflict resolution methodology as a subject to complexity of the conflict scenarios. Section 3 defines the ecosystem concept from a mathematical point of view, while Section 4 describes the ecosystem resolution methods. Section 5 derives an analytical framework for the flight efficiency in applied resolution, and Section 6 discusses the simulation results. Concluding remarks and directions for the further research are given in Section 7.

2. BACKGROUND

The consequence of a continuous increase in air traffic density within ASEAN is a higher frequency of violation of the separation minima among any pair of aircraft. Yet, there exists continual downwards pressure on improvement of air traffic control technology to ensure satisfaction of key performance metric: safety, capacity, cost-efficiency (Gluchshenko and Foerster 2013; Cook, Belkoura, and Zanin 2017). Evidently, this call is led by The Single European Sky ATM Research (SESAR) and Next Generation Air Transportation System (NextGEN) joint initiatives (Enea and Porretta 2012; Brooker 2008), calling for a complete replacement of the centralized tactical ATC interventions with a more efficient decentralized separation-management (SM) operations relying on the advanced decision-support tools (DSTs). An area of research is the study of logic deficiency of the traffic alert and collision avoidance system (TCAS) under the circumstance of induced collisions from surrounding traffic (ST) scenarios (Murugan 2010). Furthering the logical deficiency of TCAS is the frequent inconsistency between standard ATC separation procedures, creating a lack of integration between the separation management (SM) on the tactical level, and, collision avoidance (CA) on the operational level (Bennett 2004). This outcome prompts new research in the direction of a collaborative and decentralized separation management (SM) layer with which better alignment between human performance and automation may be enabled.

From an ATC perspective, the compulsory directive exists as a function of ecosystem time, and is dependent only on the horizontal maneuverability with respect to parameters of different heading values and time delays. Ignoring Vertical maneuverability allows for coherence between ATC compulsory directives for a longer look-ahead time with TCAS advisory, that are triggered as vertical directives.

On the contrary, a multi-agent simulated solutions approach to conflict mitigation between aircrafts in an ecosystem is dependent on the trajectory preferences of airlines and the availability of conflict-free trajectories within some proximity in some forward time. The mathematical model and methodologies in the preceding section is approached deterministically but provides for a basic concept from which more complex exploration may entail for use in both tactical and operational level. As such, stochastic factors arising from navigation, positioning and weather are ignored. Following this, an analysis of flight efficiency in terms of time and distance is compared, in both ATC-based and MAS-based solutions in ASEAN en-route airspace, to determine savings in time and distance of maintained aircraft speed over resolution segments, in a direct-route operational environment.

The need for complexity analysis is driven by the need for a multi-agent frame capable of providing a conflict-free configuration of the system. The time-evolution of the conflict-free configuration of the system determines the number of acceptable solutions within the system. For complex configuration of conflicts, collaborations between agents involved in an ecosystem are required and within a shorter ecosystem time for a solution compared to a less complex conflict configuration which allows for a longer ecosystem time. The information regarding the complexity of the system is crucial (Lyons 2012; Prandini et al. 2011).

3. ECOSYSTEM CONCEPT AND DEFINITIONS

3.1. Mathematical Formalism and Identification of the Ecosystem Aircraft

An ecosystem is defined as a set of at least two aircraft detected in a conflict. For any aircraft, if there exists at least one maneuver that, can be performed during an ecosystem time interval, by either this aircraft or at least one other aircraft resulting in a conflict, then at least two of these aircrafts are part of a surrounding traffic. These two definitions enable a framework that takes into account the identification of ecosystem aircraft as aircraft part of a surrounding traffic.

Definition 1. An ecosystem is defined as a set of at least two aircraft detected in a conflict.

Definition 2. Any two aircraft A/C1 and A/C2 are defined to be in conflict if a way point of A/C1 exists in the cylindrical volume of space due to the separation minima of A/C2 at some time $t \in R_0^+$.

Definition 3. For any aircraft, if there exists at least one maneuver that, can be performed during an ecosystem time interval, by either this aircraft or at least one other aircraft resulting in a conflict, then at least two of these aircrafts are part of a surrounding traffic.

Note: A closed ball of radius R = 5 nautical miles centered on the location *p* of any aircraft represents the horizontal separation minima. The vertical separation minimum is H = 1000 feet, centered on the location *p* of any aircraft represents the vertical separation. This invites a construction of a cylinder space encasing any aircraft observing the separation minima.

Definition 4. $X = \prod_{i=1}^{n} X_\alpha$ of some space X_α indexed by some index α. The canonical projection corresponding to some α is the function $p_\alpha : X \Longrightarrow X_\alpha$ that maps every element of the product to α component. A cylinder set is a preimage of a canonical projection or finite intersection of such preimages.

Formally, it is a set of the form, $\cap_{i=1}^{n} p_{\alpha_i}^{-1}\left(A_{\alpha_i}\right)\{(x_\alpha \in X: x_{\alpha_i} \in A_{\alpha_1} \in A_{\alpha_1}, \dots, x_{\alpha_n} \in A_{\alpha_n}$ for any choice *n* and a finite set of index α_i and subset $A_{\alpha_i} \subseteq X_{\alpha_i}, \forall i \in [1, n]$.

Definition 5. A graph G is an ordered pair G = (V (G), E (G)) comprising a set V of vertices such that $V \neq \emptyset$, and a set E of edges such that $E \neq \emptyset \land E = \emptyset$.

Definition 6. A vertex V of a graph G is a set $V(G) = \{p_i : p_i \in R^n, n, i \in Z^+\}$ of a graph.

Definition 7. An edge E of a graph G is a set $E(G) = \{e_{p_i,p_{i+1}}, i \in Z_0^+\}$.

Definition 8. Let p_i be a node on the major axis of an ellipse at which an ecosystem aircraft performs a control action in its attempt to mitigate a conflict. Let $p_{tactical} = p_{i+1}$ be a vertex on the boundary $\partial_{ellipse}$ defined by an ellipse to which this aircraft maneuver to and let $p_{return} = p_{(i+1)+1}$ be a vertex on the major axis (representing the original flight path) symmetrical about the y-axis.

Then, $\exists i \in Z_0^+, \exists n \in Z^+$, a resolution candidate is a set $S = \{p_i \in V \subseteq R^n : e_{p_i,p_{i+1}} \cup e_{p_{i+1},p_{(i+1)+1}}$.

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3.2. Model Assumptions and Restrictions

The concept is built on three fundamental assumptions: Firstly, the airspace within which the aircraft trajectories live is discretized in both, three spatial, and one timely, Euclidean coordinates so that the deviation in aircraft trajectory from the original trajectory, considered as a reference business trajectory (RBT), is a function of a discrete time. Maximum aircraft angle deviation is assumed to be 30°. Secondly, the variance in the aircraft's horizontal and vertical spatial displacement as a function of time is assumed to be zero. Lastly, any maneuver performed by any agents within any ecosystem should be synchronous.

3.3. Greedy Algorithm for Solution Search in Discretized Space and Time

The search for a set of solutions to mitigation of conflict between any pairwise aircraft in a discretized space and time is underpinned by an algorithmically efficient mechanism that is, unfortunately, known as the greedy algorithm. In general, the greedy algorithm seeks to maximize or minimize an objective function $\mathcal{F}(x_1, \ldots, x_N)$.

Step 1: The search for a set of solutions in a discretized space and time Euclidean coordinate system works in a manner like this: Suppose for a moment that there exists a conflict between a pairwise aircraft indexed A/C1 and A/C 2. By *Definition 1*, A/C1 and A/C2 exists within an ecosystem. Suppose further that the burden to maneuver rests on A/C1 to mitigate the conflict with A/C2. By the assumptions in section 3.2, there exists a maneuver angle $\phi \in [-30°, +30°]$, to which A/C1 may subscribe to. This is, otherwise, also known as a perturbation to its initial trajectory.

Step 2: Assuming an approximately constant cruise velocity then, a range of tactical nodes $p_{tactical}$ is generated which forms a subset of nodes on the boundary $\partial_{ellipse}$ of an ellipse to which A/C1 travels to before traveling to the return node p_{return} on the original trajectory.

Step 2.1: If no further conflict is encountered in the time t between the time instant at which A/C1 performs a maneuver angle, $\phi_{i_1} \in [-30°, +30°]$, $\exists (i_1 < \infty) \in N$, to $p_{tactical}$, then to p_{return}, one solution is recorded. This process is iterated from time t using a maneuver angle $\phi_{i_j}: j \neq i_{j-1}, i_{j-2}, \ldots, i_1$. The solution is count for maneuvers that does not produce further conflict.

Step 2.2: If a conflict is encountered in the time t between the time instant at which A/C1 performs a maneuver angle, $\phi_{i_1} \in [-30°, +30°]$, $\exists (i_1 < \infty) \in N$, to $p_{tactical}$, before heading to p_{return}, a new maneuver is assign to the traffic aircraft involved in the new conflict. Any maneuver resulting in a conflict is rejected and does not count as a solution.

4. ECOSYSTEM RESOLUTIONS

4.1. Compulsory Resolutions

Compulsory resolutions describe the ATC-based approach as a solution to non-agreed negotiated interactions among aircrafts within an ecosystem. The generation of compulsory resolutions via control action δ to ensure the safety key performance indicator by an algorithm shares an inverse relationship with trajectory efficiency ξ. Indeed, any algorithm that aims at generating the compulsory resolutions must satisfy:

- zero net change in the complexity within the ecosystem, among ecosystem aircraft.
- ensuring a steady-state trajectory efficiency of the system; sum of the trajectory efficiency brought about by control actions within an ecosystem is approximately stable.

With complexity ζ and efficiency ξ being independent parameters of a cost function, $\mathcal{F}(\zeta, \xi)$, optimization of this cost function (Section 4.2) with subjected boundary conditions generates the optimal parameter $\mathcal{F}(\zeta, \xi) \in R^2$ to produce the best compulsory resolution for at least two aircraft in a conflict. (Verdonk Gallego and Sáez Nieto 2016) illustrates the implications of this idea on the design of the algorithm. The time evolution of an ecosystem complexity is described by an exponentially decay rate in the number density of member resolution trajectories in an ecosystem. Qualitatively, a resolution candidate trajectory is a set of tactical waypoints (TWPs), $p_{tactical}$ and return waypoints (RWPs), p_{return} to the RBT. The TWPs $p_{tactical}$ are located on the boundary $\partial_{ellipse}$ of any ellipse to which any aircraft, located at a node p_0 along a semi - major axis at some initial time t_0, must travel to before returning to any node located on the diametrical semi - major axis at some time t_{return}. The different length of the major and minor axis of the ellipse is dependent on different time delay introduced to the flight (Figure 1).

A pair of candidate trajectories is then evaluated against one another by computing the time evolution of the ecosystem complexity defined in (Verdonk Gallego and Sáez Nieto 2016). If the trajectories of any two ecosystem candidates have a complexity values greater than the values analogous to the traffic advisories of TCAS, the compulsory resolution is rejected. Further, the compulsory resolution is rejected if it results in a violation of the separation minima between any two aircraft members within an ecosystem.

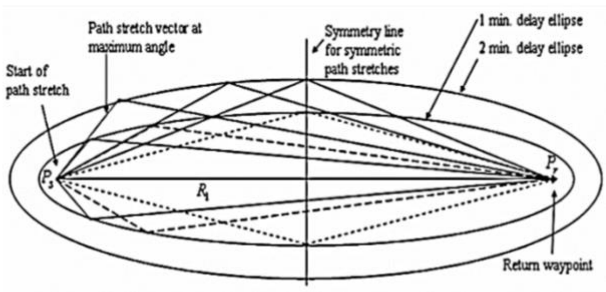

Figure 1: Locus of the tactical waypoints for introducing a given delay to a trajectory (Erzberger 2006)

Verdonk Gallego and Sáez Nieto (2016) provide the methodology for computing compulsory resolution trajectories. The algorithm includes the following steps:

1. *priority sort*: an input is fed into the algorithm to determines a list of aircraft within the ecosystem that generates the conflict - free trajectories from higher to lower priority (complexity minimization);
2. *resolution trajectories generation*: for each member aircraft in an ecosystem, a set of potential resolution trajectory is computed;
3. *complexity minimization*: the output from priority sort is used to compute the complexity at different phase of the resolution trajectories via minimization of a cost function. This includes the complexity and the delays introduced because of the resolution trajectory.

4.2. Negotiated Resolutions

The concept of multi - agent system (MAS) underpins the negotiated ecosystem resolution. MAS comprises of at least two intelligent agents interacting with each other within an ecosystem to mitigate the conflict - performing control actions within their degree of freedom without external intervention. Ljungberg and Lucas (1992) and Mao, Roos, and Salden (2009) illustrate some literatures demonstrating the use of MAS for problem solving of complex systems in the field of ATM. The caveat in the application of MAS to conflict resolution lies in the criticality of spatiotemporal interdependencies presented within any airspace configuration, resulting in different emergent dynamics, with each requiring certain resolution trajectories to avoid new conflicts in a look-ahead time (Bicchi and Pallottino 2000). Indeed, the consequence to modeling a conflict - resolution method is constraint by MAS verification. In more sophisticated models, success with a MAS air traffic conflict resolution framework necessitates the introduction of emergent dynamics together with uncertainties and perturbations on traffic behaviors. Figure 2 illustrates an ecosystem as being a self-governing and adaptive MAS. In this illustration, the ecosystem is composed of four agents, involved in a detected conflict, and enhanced with an advanced negotiation capability (ANC). They are actively interacting amongst themselves for a conflict resolution at a satisfactory level.

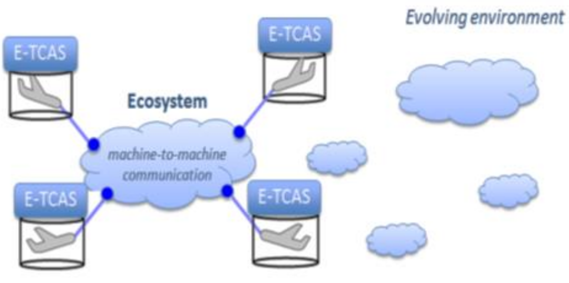

Figure 2: An ecosystem as a MAS system of four aircraft relying on the negotiation interactions for resolution

4.2.1. Satisficing as a Solution Concept

The concept of game theory argues an impossibility to provide a definition for a unique optimum for an ecosystem where any agents that exists within this system practices pareto-optimality. Under these constraints, a hybrid solution concept - satisficing - requires each agent to provide their minimal requirements. The degree of acceptability of a hybrid solution is defined by the aggregation of these minimal requirements. The advantages to satisficing as a solution is multifold, of which, only two will be mentioned. First, a satisficing solution forces conflicted agents within an ecosystem to engage in the decision - making process among themselves to enable a distribution of decision - making. Second, the decision - making process resembles a branching search for a solution where the process of finding a solution is equivalent to a search strategy. The search strategy branches into classification of exploratory and exploitative - the former branch principal on a broad search space and the latter, to find a solution in the shortest possible time (Simon 1956).

An exploitative-based search strategy converges to a solution at an exponential rate. It is clear, that the exponential convergence to a solution to resolve a multi-agent conflict within an ecosystem is the obvious solution.

4.2.2. MAS-Explored Solution Approach

The advantage to having a satisficing solution enables the quantization of the decision – making process into positive integer steps and a *divide and conquer* approach. The negotiation between A/C1 and A/C2 in Figure 3 illustrates a search for a specific conflict - free solution at time t_0, avoiding an induced conflict with A/C3.

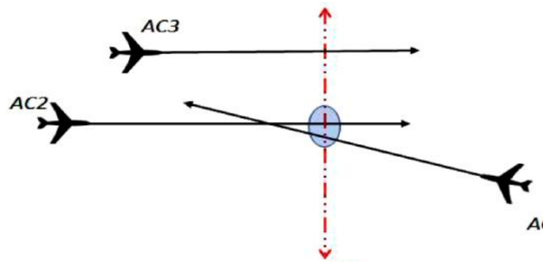

Figure 3: Ecosystem with three aircraft of which A/C1 and A/C2, as the conflicting ones, search for a solution

In contrast to Figure 3, Figure 4 illustrates a possible induced conflict between A/C2 and A/C3 at time t_1, propagated due to an earlier negotiated agreement between A/C1 and A/C2 at time t_0 - of which, a failure to arrive at a conflict – free solution between A/C2 and A/C3 meant that the negotiated solution between A/C1 and A/C2 at time t_0 is refuted.

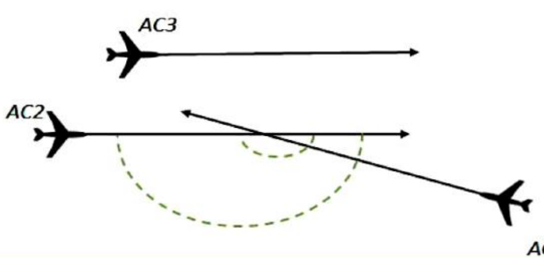

Figure 4: Solution space for A/C2 after identified induced conflict with A/C3 (surrounding traffic)

4.2.3. Negotiated Interactions

The divide and conquer approach is described in greater detail in this section. At the start of a negotiation between a pairwise aircraft, solutions are explored such that one aircraft deviates from its initial trajectory. The deviation to mitigate a conflict, however, results in efficiency disincentives due to additional fuel consumptions. A pairwise aircraft can, however, adopt this strategy so that the efficiency disincentives are distributed among the pair of aircraft. In mitigating a conflict, pair aircraft arrive at a conflict - agreement through accessible degree of freedom or a range of control actions as parameters of a probabilistic function, to which a probability value is assigned to a control action. Table 1 illustrates an example of the probability distribution function constructed by considering the number of spatiotemporal interdependencies any aircraft would have for a given control action taken.

Table 1: Number of spatiotemporal interdependencies between a pair of aircraft in conflict per each possible performed maneuver

	left	right	up	down
A/C1	0	3	2	0
A/C2	2	2	3	1

5. FLIGHT EFFICIENCY IN APPLIED RESOLUTIOM

5.1. Airspace Users' Preferences

The flight strategies in the planning phase for the creation of an RBTs is underpinned by the business model of the airspace users. The factors affecting the business model are flight schedules, airspace systems requirements, nature of flight (long-haul vs. short-haul) and aircraft types have a considerable impact on the generation of the business model and its efficiency output. The flight strategies employed are based on the multi-cost index (CI) analysis relative to the fuel – time efficiency along the entirety of the flight envelop. The advantage of the business model is two - fold:

- *generation of ecosystem scenario*: a business strategy for generated traffic data (flight plans), operational constraints and selection of aircraft performance model can be implemented to define the reference business trajectories. This applies only to customized flight plans in accordance to the user preferences;
- *MAS objective function*: with the OD design supporting the MAS approach, the business models are integral to the MAS functionality. While the negotiation process does not foresee human intervention in the simulation, the MAS model can express the objective function. Since the ecosystem scenarios are simulated in an en - route airspace, the objective function is valid only for the cruising phase. The greatest percentage of trip time and fuel are typically incurred during this phase.

Two principal variables that affect the cruising duration and fuel consumption are speed selection and altitude selection. The generation of the OD scenarios and speed selection can be analyzed using three objective functions:

- Maximizing the cruising distance for a fixed amount of fuel.
- Minimizing the consumption of fuel for a fixed give distance.
- Minimizing the trip time. While the speed variable in the resolution can regulated, the speed value must be selected based on the scenarios.

The algorithm does not foresee a significant change in the horizontal speed during the ecosystem process, unless the compulsory resolution is triggered. In this case, vertical speed might be subject to changes. Therefore, for agents applying the third objective function, the speed maintenance must be an objective function, that applies to both cruising and evolving aircraft. Further, from the selected BADA aircraft type the optimal speed value in cruise can be used as a reference (Poles, Nuic, and Mouillet 2010). The altitude selection can also rely on the relevant aircraft performance model. From a designing perspective, each aircraft has one optimal flight level (FL). However, the optimal FL is subjected to changes on grounds of airspace system requirements and weather conditions. While the generated RBT should include this consideration, this means a possibility of an altitude change during the cruising phase. Once an aircraft becomes an ecosystem member, the agents in cruising will have to maintain their current altitude until agreed resolutions or unless the compulsory advisory is issued. Once changed, the objective function will be to resume to the selected FL.

5.2. Cost Efficiency Function

In light of Section 5.1, a natural choice for qualitatively and quantitatively evaluating the additional economic cost to an agent would be the cost function with independent parameters Δ_{Fuel} and Δ_{Time}. Since the ability to enable agents the flexibility to adhere to different business models is of pertinent importance, the cost function should be as general as possible. In following standard models in literature and practice (Pritchett and Genton 2018), the cost function is introduced as:

$$f_{Cost} = (1 - Index_{Cost})\ Coefficient_{Fuel}\ \Delta_{Fuel} + Index_{Cost}\ Coefficient_{Time}\ \Delta_{Time} \quad (1)$$

where:

- $Index_{Cost}$ presents the cost index, defined as $\frac{Time_{cost}}{Fuel_{cost}}$;
- $Coefficient_{Fuel}$ is the fuel coefficient;
- $Coefficient_{Time}$ is the delay coefficient;
- Δ_{Fuel} denotes a change in a fuel consumption;
- Δ_{Time} is a time change.

The minimization of the scalar cost function, i.e.:

$$\min\left(f_{Cost}(\Delta_{Fuel}, \Delta_{Time})\right), \exists\, \Delta_{Fuel}, \Delta_{Time} \quad (2)$$

requires that:

$$\nabla f_{Cost} = \langle \frac{\partial}{\partial \Delta_{Fuel}}, \frac{\partial}{\partial \Delta_{Fuel}} \rangle f_{Cost}$$
$$= \langle (1 - Index_{Cost})\, Coefficient_{Fuel},$$
$$= \langle Index_{Cost} Coefficient_{Time} = \langle 0, 0 \rangle \quad (3)$$

In spite of the popularity of (1) as a model, it lacks the robustness to capture the time dependency of an MAS procedure due to $Coefficient_{Fuel}$ and $Coefficient_{Time}$ being constant with time. To accommodate time dependency of the MAS model, the paper introduces:

$$f_{Modified\ Cost} = (1 - Index_{Cost})\, Coefficient_{Fuel}(t)\, \Delta_{Fuel} + Index_{Cost}\, Coefficient_{Time}(t)\, \Delta_{Time} \quad (4)$$

where:

- $Coefficient_{Fuel}(t)$ is the fuel coefficient as a function of time;
- $Coefficient_{Fuel}(t)$ is the delay coefficient as a function of time.

The time rate of change gives:

$$\frac{\partial f_{Cost}}{\partial t} = (1 - Index_{Cost})\left(\frac{\partial Coefficient_{Fuel}(t)}{\partial t}\, \Delta_{Fuel}\right) + Index_{Cost}\Delta_{Time}\, \frac{\partial Coefficient_{Time}(t)}{\partial t}\, \Delta_{Time} \quad (5)$$

In a matrix form, (5) can be presented as:

$$\frac{\partial f_{Cost}}{\partial t} = [(1 - Index_{Cost})\ \ Index_{Cost}] \begin{bmatrix} \frac{\partial Coefficient_{Fuel}(t)}{\partial t}\, \Delta_{Fuel} \\ \frac{\partial Coefficient_{Time}(t)}{\partial t}\, \Delta_{Time} \end{bmatrix} \quad (6)$$

6. SIMULATON RESULTS

Three ecosystems, indexed 12, 363 and 452, were drawn at random and simulated. The simulation has shown demonstrates that the fuel and distance performance metric for each aircraft in the ecosystems 12, 363 and 452, in the Baseline - Negotiated approach has a net change in fuel and distance that is least equal or less than the net change in fuel and distance in the Baseline - Compulsory approach. This is evident through taking any aircraft and making a comparison in the net change of the fuel and distance between Base - Compulsory and Base - Negotiated approach of the ecosystem 12. Tables 2 and 3 illustrate this comparison, as well as Figures 5 and 6.

Table 2: Comparison of fuel and distance difference between Baseline and Compulsory approach in Ecosystem 12

Base. Fuel	Comp. Fuel	Δ_{Fuel}	Base. Dist.	Comp. Dist.	$\Delta_{Distance}$
6695.55	6722.68	-27.13	1216.2	1223.3	-7.1
5483.21	5510.26	-27.05	777.5	781.4	-3.9
2955.19	2955.96	-0.77	742.7	742.6	0.1
7822.12	7761.81	60.31	1448.1	1463.9	-15.8

Table 3: Comparison of fuel and distance difference between Baseline and Negotiated approach in Ecosystem 12

Base. Fuel	Negot. Fuel	Δ_{Fuel}	Base. Dist.	Negot. Dist.	$\Delta_{Distance}$
6695.55	6695.68	-0.13	1216.2	1216.2	0.0
5483.21	5510.26	-27.05	777.5	777.5	0.0
2955.19	2955.96	-0.77	742.7	742.7	0.0
7822.12	7761.81	60.31	1448.1	1448.5	-0.4

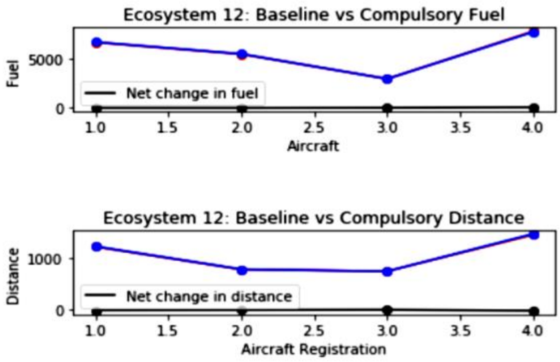

Figure 5: Baseline-Compulsory approach comparison in Ecosystem 12

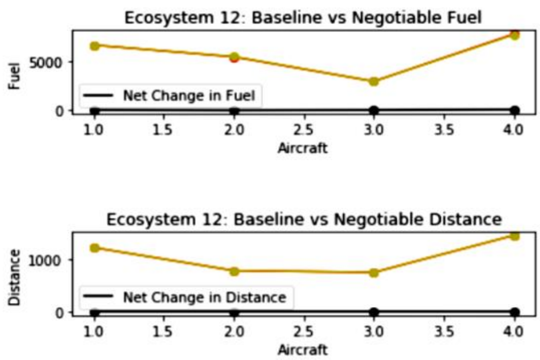

Figure 6: Baseline-Negotiated approach comparison in Ecosystem 12

The improvement in fuel and distance comparison for a Negotiated approach is seen also in the ecosystems 363 and 452, as evident from Tables 4 and 5, and Tables 6 and 7, respectively. Descriptively, those comparisons are provided in Figures 7, 8, 9 and 10.

Table 4: Comparison of fuel and distance difference between Baseline and Compulsory approach in Ecosystem 363

Base. Fuel	Comp. Fuel	Δ_{Fuel}	Base. Dist.	Comp. Dist.	$\Delta_{Distance}$
5639.80	5673.62	-33.82	1655.6	1667.5	-11.9
5517.41	5613.58	-96.17	1080.5	1087.4	-6.9
3473.42	3506.05	-32.63	1082.1	1087.7	-5.6
4754.30	4768.82	-14.52	933.1	939.7	-6.6

Table 5: Comparison of fuel and distance difference between Baseline and Negotiated approach in Ecosystem 363

Base. Fuel	Negot. Fuel	Δ_{Fuel}	Base. Dist.	Negot. Dist.	$\Delta_{Distance}$
5639.80	5662.31	-22.51	1655.6	1655.6	0.0
5517.41	5559.66	-42.25	1080.5	1082.1	-1.6
3473.42	3473.05	0.37	1082.1	1082.2	-0.1
4754.30	4760.52	-6.22	933.1	948.2	-15.1

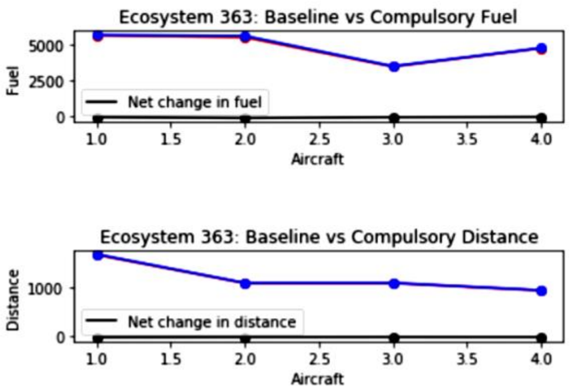

Figure 7: Baseline-Compulsory approach comparison in Ecosystem 363

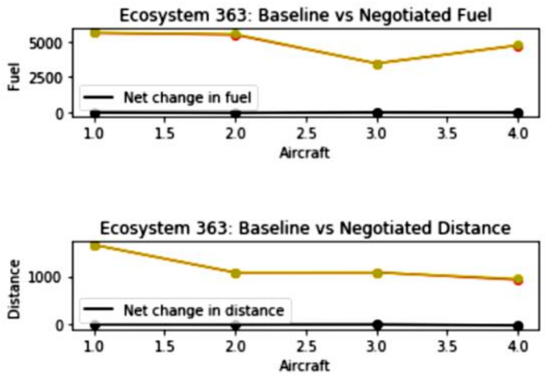

Figure 8: Baseline-Negotiated approach comparison in Ecosystem 363

Table 6: Comparison of fuel and distance difference between Baseline and Compulsory approach in Ecosystem 452

Base. Fuel	Comp. Fuel	Δ_{Fuel}	Base. Dist.	Comp. Dist.	$\Delta_{Distance}$
3312.00	3323.29	-11.29	886.80	894.30	-7.5
4026.14	4007.07	19.07	1265.60	1280.80	-15.2
7479.30	7535.60	-56.30	1473.00	1479.90	-6.9
3069.44	3096.24	-26.80	777.50	785.10	-7.6

Table 7: Comparison of fuel and distance difference between Baseline and Negotiated approach in Ecosystem 452

Base. Fuel	Negot. Fuel	Δ_{Fuel}	Base. Dist.	Negot. Dist.	$\Delta_{Distance}$
3312.00	3312.00	0.00	886.80	886.80	0.00
4026.14	4020.64	5.50	1265.60	1267.00	-1.40
7479.30	7489.71	-10.41	1473.00	1473.00	0.00
3069.44	3069.04	0.40	777.50	777.50	0.00

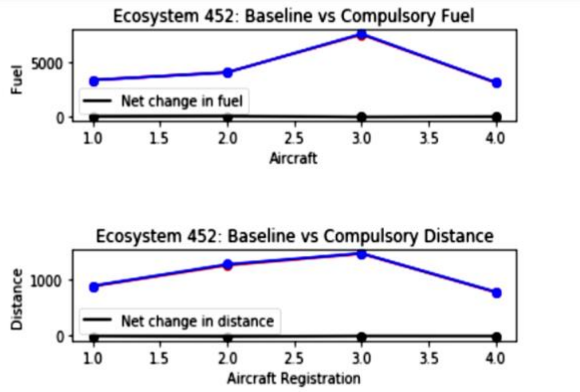

Figure 9: Baseline-Compulsory approach comparison in Ecosystem 452

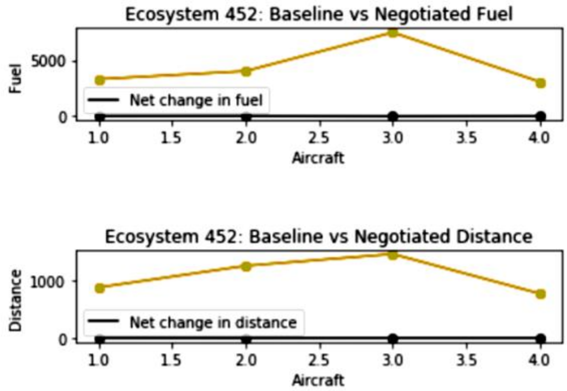

Figure 10: Baseline-Negotiated approach comparison in Ecosystem 452

Using a sample size of n = 3, Table 8 illustrates the computation of the mean net change in fuel and distance $\overline{\Delta_{NetChangeInFuel}}$ and $\overline{\Delta_{NetChangeInDistance}}$ for both the Baseline-Compulsory and Baseline-Negotiated approach. As can be seen, the Negotiated approach to conflict mitigation provides a lower mean net change in both performance metric of fuel and distance, with $\overline{\Delta_{NetChangeInFuel}}$ = -61.775 < $\overline{\Delta_{NetChangeInDistance}}$ = -10.69 in the Baseline-Compulsory and Baseline - Negotiated approach, respectively. Comparing also the distance performance metric, $\overline{\Delta_{NetChangeInDistance}}$ = -23.75 < $\overline{\Delta_{NetChangeInDistance}}$ = -0.55, between the Baseline-Compulsory and Baseline-Negotiated approach.

Table 8: Fuel and distance comparison across three ecosystems

Approach comparison	$\overline{\Delta_{NetChangeFuel}}$	$\overline{\Delta_{NetChangeDistance}}$
Baseline – Compulsory approach	-61.775	-10.69
Baseline – Negotiated approach	-23.75	-0.55

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From this, it may be inferred that the for a fixed fuel and distance value in the Baseline approach, the output value for the fuel and distance in the Negotiated approach differs only as much or greater in magnitude with the Compulsory resolution approach to conflict mitigation. With the Negotiated approach to conflict mitigation giving rise to an improved performance fuel and distance metric, the consequence is an improvement to the economic model of the airspace users.

7. CONCLUSION

This article has been studying a novel resolution approach in the multi-aircraft conflict scenarios using the multi-agent modeled behavior against against the conventional resulting directives coming from the air traffic control system. With this, it is deployed as a new airborne resolution model with an advantage over the conventional ground-based separation technique. The main driver in this successfully implemented multi-agent solution is an agreement on certain maneuver(s) in a timely manner that is acceptable from the airspace user's business preferences, conditioned on the available proximate airspace volumes and spatio-temporal interdependencies among the ecosystem actors. These interdependencies influence the resolution moment, the number of avoidance maneuvers and, consequently, the magnitudes of trajectory amendments. From the three simulated ecosystems, it is evident that the multi-agent concept provides more efficient solutions in terms of both the extra distance and fuel. Naturally, the efficiency metric cannot be significantly reflected in a short time interval as the ecosystem time is tactically measured in several minutes of flight. On the other end, this evidence provides an excellent insight for measuring the ecosystems resolution impacts on the air traffic flow and capacity management, considering the whole ecosystem configuration over the full operational days. At the macro-level, those solutions can provide significant improvements, not only to the flight efficiency but also in terms of the capacity and controller's workload which is pertinent to the present and future state of the air traffic management system.

Further research is two - directional: first, the integration of the aircraft performance model into the ecosystem resolution algorithms and automation in the flight efficiency analysis considering the whole aircraft trajectories in which a single aircraft might participate in more than one ecosystem. The first direction will consider the type of the aircraft and its performance characteristics in accepting the additional distance and fuel quantities. The second direction will consider the optimality in a decision -making process of any single aircraft, over the entire flight envelope, as well as the airspace capacity limited by the system requirements.

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REFERENCES

Bennett, Simon. 2004. "The 1st July 2002 Mid-Air Collision over Überlingen, Germany: A Holistic Analysis." Risk Management. doi:10.2307/3867933.

Bicchi, Antonio, and Lucia Pallottino. 2000. "On Optimal Cooperative Conflict Resolution for Air Traffic Management Systems." IEEE Transactions on Intelligent Transportation Systems. doi:10.1109/6979.898228.

Brooker, Peter. 2008. "SESAR and NextGen: Investing in New Paradigms." Journal of Navigation. doi:10.1017/S0373463307004596.

Cook, Andrew, Seddik Belkoura, and Massimiliano Zanin. 2017. "ATM Performance Measurement in Europe, the US and China." Chinese Journal of Aeronautics 30 (2): 479–90. doi:10.1016/j.cja.2017.01.001.

Enea, Gabriele, and Marco Porretta. 2012. "A Comparison of 4D-Trajectory Operations Envisioned for Nextgen and SESAR, Some Preliminary Findings." 28th Congress of the International Council of the Aeronautical Sciences, 1–14. http://skybrary.aero/bookshelf/books/2377.pdf.

Erzberger, Heinz. 2006. "Automated Conflict Resolution for Air Traffic Control." Congress of International Council of the Aeronautical Sciences, no. March: 1–28. http://www.aviationsystemsdivision.arc.nasa.gov/publications/tactical/index.shtmlz.

Gluchshenko, Olga, and Peter Foerster. 2013. "Performance Based Approach to Investigate Resilience and Robustness of an ATM System." Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), 7. http://atmseminarus.org/seminarContent/seminar10/papers/277-Gluchshenko_0127130117-Final-Paper-4-8-13.pdf.

Ljungberg, Magnus, and Andrew Lucas. 1992. "The OASIS Air Traffic Management System." In Proceedings of the Second Pacific Rim

International Conference on Artificial Intelligence PRICAI 92. http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.54.3133.
Lyons, Rhonda. 2012. "Complexity Analysis of the Next Gen Air Traffic Management System: Trajectory Based Operations." In Work, 41:4514–22. doi:10.3233/WOR-2012-0030-4514.
Mao, Xiaoyu, Nico Roos, and Alfons Salden. 2009. "Stable Scheduling of Airport Ground Handling Services by Heterogeneous Agents." In Belgian/Netherlands Artificial Intelligence Conference, 343–44.
Murugan, Sathyan. 2010. "TCAS Functioning and Enhancements." International Journal of Computer Applications 1 (8): 46–50. doi:10.5120/184-320.
Poles, Damir, Angela Nuic, and Vincent Mouillet. 2010. "Advanced Aircraft Performance Modeling for Atm: Analysis of BADA Model Capabilities." In AIAA/IEEE Digital Avionics Systems Conference - Proceedings. doi:10.1109/DASC.2010.5655518.
Prandini, Maria, Luigi Piroddi, Stephane Puechmorel, and Silvie Luisa Brázdilová. 2011. "Toward Air Traffic Complexity Assessment in New Generation Air Traffic Management Systems." Complexity 12 (3): 1–10.
Premm, Marc, and Stefan Kirn. 2015. Multiagent System Technologies. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). Vol. 9433. doi:10.1007/978-3-319-27343-3.
Pritchett, Amy R., and Antoine Genton. 2018. "Negotiated Decentralized Aircraft Conflict Resolution." IEEE Transactions on Intelligent Transportation Systems. doi:10.1109/TITS.2017.2693820.
Radanovic, Marko;, Miquel Angel; Piera Eroles, Koca; Thimjo, and Francisco Javier Saez Nieto. 2017. "Self-Reorganized Supporting Tools for Conflict Resolution in High-Density Airspace Volumes." In Twelfth USA/Europe Air Traffic Management Research and Development Seminar, 10.
Ramasamy, S., R. Sabatini, A. Gardi, and T. Kistan. 2014. "Next Generation Flight Management System for Real-Time Trajectory Based Operations." Applied Mechanics and Materials 629: 344–49. doi:10.4028/www.scientific.net/AMM.629.344.
Simon, Herbert A. 1956. "Rational Choice and the Structure of the Environment." Psychological Review. doi:10.1037/h0042769.
Verdonk Gallego, Christian Eduardo, and Francisco Javier Sáez Nieto. 2016. "Discussion on Complexity and TCAS Indicators for Coherent Safety Net Transitions." In 6th SESAR Innovation Days. http://sesarinnovationdays.eu/files/2016/Papers/SIDs_2016_paper_24.pdf.

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BUSINESS ECOSYSTEM DYNAMICS IN ITS: AN AGENT BASED MODELLING FOR A DEEP UNDERSTANDING OF INTANGIBLE FLOWS BETWEEN STAKEHOLDERS

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ABSTRACT

Technology transfer is considered as a difficult and long journey to reach a market share. It is well accepted that access to low cost technologies speed up the cycle to transform an innovative idea into a product to satisfy a particular market need. However, despite the enthusiasm when the new technology enters the market as a new product or service, sometimes the expectative generated often unmatched by the initial capabilities of the technology falls in the well-known "valley of death". This provides a time frame during which the technology matures and show up the potential benefits which in some cases provides enough sound to spark the "phase of enlightenment" and eventually start the productivity. The interaction between the relevant stakeholders of a particular innovation is a critical aspect to succeed in the early phases of the new product/service to transform the market need into market demand. In this paper it is presented the concept of business ecosystem and a modelling framework to analyse the interdependencies between the stakeholders and provide a mitigation mechanism to lessen the effects of barriers and enhance the enablers.

Keywords: business ecosystem, agent based modelling, Coloured Petri nets, decision support tool, intelligent transport system.

1. INTRODUCTION

Companies evolve adapting their skills and roles according to market evolution. In order to face new market challenges relying in social demand that requires the proper integration of different technologies to deal with a user friendly product or service, companies try to stablish different type of competitive-cooperative collaborations to fit the end-user expectations.

Unfortunately, the success rate of spin-off companies or consortium of companies trying to fit end-user needs with a new product/service relying on market technologies, is quite low. There are several barriers that usually affects this failure rate, among which, it is important to mention:

- Time-to-market: Time required to develop an innovation usually is a long journey that can be shortened if off-the-shelf technologies can be adapted and synergies can be established with the right competences in the consortium team.
- Cultural barriers: Despite the excellent expectations at the early phases of a potential successful idea, the resistance to change usually introduce extra delays both during the conceptual design phase and the implementation phase. Two important cultural shortages affecting the innovation processes are the risk aversion and closed networks due to lack of trust.
- Acceptability: Besides the trade-off factors that are used to predict the practical acceptability of a product/service such as utility (the match between user needs and functionality), usability (ability to utilize functionality in practice), likeability (affective evaluation), and cost there is also the social acceptability which is the result of a complex social dynamics in which the social status of early adopters social status can influence drastically on the market penetration.
- Risk: Despite there has been implemented different verification and validation methods to reduce the technological risk during the development phases of a new product/service, there is a lack of models that could help to minimize the risk associated with market entry and incorporate key learning into the business model before it is too late
- Trust: This is one of the most important intangible assets at early phases of most innovation processes which influence not only the effectiveness of the organization's work groups and structure, but also

how employees relationships allows the right flow of know-how to overcame barriers.

- Budget: Typical ‘‘business case’’ financial metrics are not appropriate for pushing and transforming innovative ideas into market products/services. Thus, new policies for funding the innovation processes at early stages are required considering also the long-term sustainability in which value creation plays an important role.

As it can be noted, besides the technological complexity inherent to the design of an innovative product/service, there is also a social complexity to drive the innovation to the market in which the above mentioned factors cannot be considered as isolated problems, instead their interdependencies can generate emergent dynamics that can cause the failure of its market acceptability. Easy to note that a lack of culture on dynamic re-organizational structures is a barrier for reducing time to market as a permanent challenge in the assumption of innovation objectives.

1.1. Business Ecosystems in ITS

Business Ecosystems (BE) are seen as a source of competitive advantages for the individual firms in the innovation field, in which the competencies of a group of companies complements in a cooperative framework to create value by putting together their assets and skills (NEWBITS D4.1, 2018).

Despite the benefits that business ecosystems can provide regarding sharing risk, financial budget and competencies to reduce the time to market, it must be noted that business ecosystems behave as a dynamic system in which the network of interdependent stakeholders evolve sharing the same fate. Regardless that stakeholders evolve together or in despair ways, it is important to identify the roles that construct the ecosystem and the non-linear dynamics of the interdependencies between these roles.

A deep understanding of the ecosystem behaviour is necessary to take the right decisions at the right time to drive the innovation process to a satisfactory result. There are theoretical works that support that BE could be studied as complex adaptive systems (CAS). These systems typically include multiple loops and multiple feedback paths between many interacting entities, as well as inhibitory connections and preferential reactions (Battistella et al, 2013). Business ecosystems as paradigms of CAS, change and evolve over time as a result of the interactions between the members of the BE and the interaction between the ecosystem and its everchanging business environment.

The complexity of business ecosystems suggests that the emergence and success of them is a dynamic process requiring a multifaceted responsiveness. As BE evolves during its life time, and interacts with the external environment, its capabilities define the level of services and the impacts to the society in an adaptive way. This process, leads to adaptations of the cooperative behaviour of the stakeholders too, as the ecosystem reaches higher levels of maturity over time.

Intelligent Transport Systems (ITS) is an area of particular interest to get a better understanding of the innovation processes to increase the successful deployment of services to tackle transport problems with better investment funds utilisation.

Among the different definitions of ITS, in this paper it is considered the definition elaborated in the Newbits project (Newbits D2.1 2017) in which the main function of ITS is to increase the efficiency in the transport system, with special focus on the service and information provision for the full spectrum of users (drivers, passengers, vehicle owners, network operators…) which involves a diversity of stakeholders (network operators, public authorities, OEMs, service providers, technology developers…).

Despite in the past years it was expected that ITS in general would provide a revolutionary change in the efficiency and safety of transport, the truth is that many of the most promising C-ITS applications have failed to make it beyond trial phases. In order to support increased commercially sustainable C-ITS deployments, the Newbits project has been working on adaptive and innovative business models for the actors along the C-ITS value chain, identifying potential incentives to accelerate deployment and limit the impact of a “last mover advantage” approach.

In this paper an Agent Based Model (Klusch et al. 2007) is presented, relying on results achieved in Newbits project to validate the use of socio-technological for a better understanding of business ecosystem dynamics at different phases of the innovation process in C-ITS which is a sector that requires new collaboration models, building sufficient confidence for the private and public stakeholders to invest steadily. Section 2 describes the ITS ecosystem dynamics and the tangible and intangible flows between stakeholders. Section 3 explains the use of ABM framework for modelling and simulation of business ecosystem dynamics. Section 4 discusses some generated results, directions for further research and some concluding marks are given in Section 5.

2. SOCIO-TECHNOLOGICAL APPROACH TO FORMALIZE BUSINESS MODEL

To tackle complex nature of ITS-markets and technological innovations, a cooperation mechanism is required between different stakeholders with complementary competencies since a single actor do not have all the capabilities required to offer value-added services or at least, to do so autonomously in order to reach the market. Cooperation in a competitive environment is not an easy task, rather it is considered a real challenge for an actor to integrate into a cluster of actors for creating and delivering value to the customers, and also manage to understand the risk of such cooperation while preserving its capacity to create value.

For a better understanding of value creation at individual stakeholder level and at network level, business models can help for pragmatic purposes to formalize the content, structure and governance of transactions designed so as to create value through the exploitation of business opportunities (Amit & Zott, 2001). The relationship between the stakeholders can impact positively and/or negatively on the value creation, but the dynamics of these relationships can be very sensitive to some small changes while at the same time very robust to some other changes. Furthermore, at initial stages of the innovation process, most relationships rely on intangible flows such as trust, knowledge sharing and information which are not easy to monitor and introduce corrective actions in case.

In order to react on changes quickly and efficiently, it is important to foresee what will happen considering present member ITS competencies, and the very fact that ITS solutions is being performed in a changeable environment, introducing in this way uncertainties in the dynamic evolution, and unfortunately introducing more difficulties in the decisions to be taken cooperatively by the stakeholders.

The analysis of the dynamic value flows between stakeholders, as interactions, would support the better understanding of the evolution of the business model dynamics, which following can contribute to the identification at early stages of business shortages that would lead to a poor acceptability of the proposed ITS service/product or the failure of the full innovation process. In fact, the nature and effect of the dynamic interactions in a BE can have profound implications for organisational success and determines the speed of the ecosystem's evolution to keep it sparkling, offering plenty of opportunities for its members.

A simulation model of a business ecosystem to get a deep understanding of the behavioural dynamics of stakeholders relationships has been formalized to describe multiple loops and chains, loops within loops, mutual cross feed relationships connecting them, inhibitory connections and preferential reactions in front of different events

The dynamic nature of a BE is considered as one of the pillars for adaptation not only to market uncertainties but also to the internal configuration to reach a stable structure with the right number of stakeholders necessary to be competitive with respect to other business ecosystems. To properly support and enhance business ecosystem adaptation mechanisms, a simulation model can contribute to identify those ecosystem parameter configurations under which the business ecosystem could be maintained and in consequence be sustainable.

3. INTANGIBLE FLOW DYNAMICS

The number of business ecosystem stakeholders and its interdependencies creates a layout scenario in which intangible flows can have a bigger impact on the sustainability of the ecosystem at early stages of the innovation process when tangible flows (ie. financial alike flows) are low. At these early stages, the evolution of the ecosystem behaves as a result of a trade-of of certain dynamics:

- Non – linearity: Accepting new stakeholders in the business ecosystem structure doesn't leads to proportional increments in the BE indicators.
- Non – predictability: A small change, at a certain point of time, in a particular value flow between stakeholders can block or improve the valuable relationships between the stakeholders. As an example, a lack of trust at a certain life-cycle period of the BE can have negligible consequences or can even affect the sustainability of the full ecosystem.
- Interdependency: Key relationships between stakeholders can direct the business ecosystem from one dynamic state into another, which provides an opportunity to design flexible strategies to tackle unexpected events.
- Synergetic conduct: The right engagement of the stakeholders with complementary competencies on the services or products under study can generate better results than an outsourcing of some key competencies to external firms, or to a stakeholder that is loosely networked in the ecosystem. Since each organization in the ecosystem has his own targets, costs and benefits, decisions taken by each member should enable to create globally coherent behaviour patterns unconsciously out of local component interactions.
- Reversed connections: There is a cyclical process in which ecosystem stakeholders take decisions that result in some value flow changes, and value flow changes again influences on stakeholder decisions that will be made later heading the BE toward success or failure.
- Self organisation: A BE can be seen as an organized group of interacting firms working together for a purpose.

In order to isolate the influence of some dynamics and provide a better understanding of the BE evolution considering only intangible flows, the ecosystem stakeholders agents have been defined by three attributes:

- Engagement: It represents the importance of the stakeholder in the ecosystem and is measured by the amount of stakeholders in which it can influence.

- Trust: Sharing organizations’ know-how is an important enabler for the ecosystem as a whole but it can weak the role of the stakeholder in the ecosystem if its competences can be absorbed by another stakeholder. It is measured by a value from 0 (no trust) to 10 (full trust with ecosystem members)
- Technological Risk: Despite some technologies have been tested and validated, its integration in an ITS development have inherent risks. This attribute considers only the technological risk of a stakeholder to fit the ecosystem expectations.

As it can be observed in Figure 1, Figure 3, Figure 6, Figure 7 and Figure 8 the BE evolution is highly dependent on the amount of stakeholders and its interdependencies. In the following sections different scenarios are evaluated.

3.1. Low Risk Business Ecosystems with 1 integrator

In Figure 1 it is represented the evolution of Trust and Technological risk assumed by each stakeholder of an ecosystem with 4 members that gears on key validated technologies provided by 3 companies that must be integrated by one stakeholder (stakeholder nº 1 in blue colour). Figure 2 describes graphically the intangible flows of the ecosystem layout.

Figure 1: Trust-Risk evolution in a BE loosely coupled

As it can be observed at the right hand side of Figure 1, the initial technological risk decreases according companies are evolving their technologies to fit the innovation target. The highest risk is for stakeholder 1 till the end of the first year (month 13) in which small difficulties are still present (risk bellow 1). At the left hand side it is represented the trust generated by each stakeholder which depends on the technological risk assumed by the stakeholder and the trust in the stakeholders that must share their competences to fit the innovation tasks.

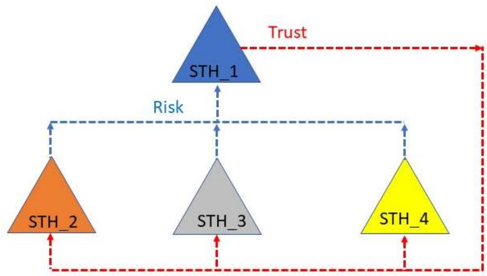

Figure 2: Trust and Risk intangible flows of ecosystem 1

Initially all the ecosystem members shows trust and engagement with the innovation process, however technological risk and sharing knowledge barriers introduces an initial decrement of trust due to mentioned difficulties. As it can be observed, stakeholder 1 and 4 during the first 6 month show similar risk evolutions, however the trust of stakeholder 1 decreases quicker than trust of stakeholder 4 because of its high dependency with the technologies to be integrated from the rest of the stakeholders. It can be observed also that once the risk is under control (ie. bellow 1) trust in the innovation process is stabilized.

3.2. Low Risk Business Ecosystems with 1 main Technology developer

In this scenario it is considered again 4 stakeholders but instead of considering 1 integrator which depends on the technology to be improved by the other ecosystem members, it is considered an innovative service that requires the improvement of a particualr technology which competence rely only in one member (stakeholder 4). The rest of the members must adapt software services to this technology. Figure 4 describes graphically the intangible flows of the ecosystem layout.

Figure 3: Trust-Risk evolution in a BE loosely coupled

As it can be observed at the right hand side of Figure 3, the initial technological risk decreases according companies are evolving their technologies but is quite dependent on the evolution of the risk of the technology to be developed by stakeholder 4. As soon as the risk of stakeholder 4 start decreasing at month 12, the risk of the rest of the ecosystem members decreases also.

At the left hand side of Figure 3 it is represented the trust generated by each stakeholder which depends on the technological risk assumed by the stakeholder and the trust in the stakeholders that must share their competences to fit the innovation tasks.

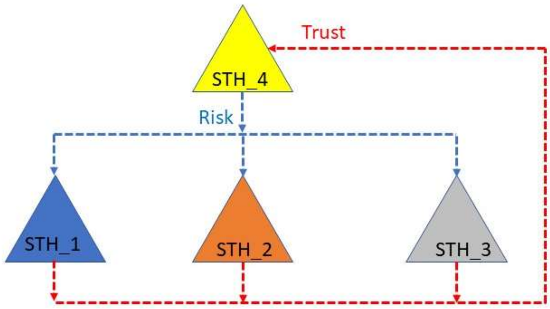

Figure 4: Trust and Risk intangible flows of ecosystem 2

The main risk in stakeholder 4 propagates in a smaller scale to the rest of stakeholders which depends on his technology. In a similar way, the trust of the ecosystem members with stakeholder decreases to low levels until first positive results are achieved in month 10 in which his trust increases and this intangible flow propagates to the rest of ecosystem members.

3.3. Low Risk Business Ecosystems with tight interdependencies

There are innovations that require the integration of different technologies which must be adapted to fit to a new product/service. In Figure 5 it is represented graphically the layout of interdependencies between 5 stakeholders each one supporting similar technological task developments.

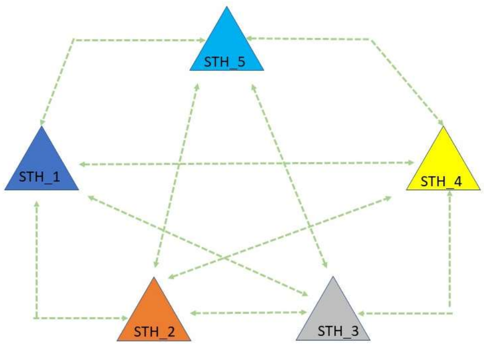

Figure 5: Trust and Risk intangible flows in ecosystem 3

In Figure 6 it is represented the evolution of Trust and Technological risk assumed by each ecosystem member.

Figure 6: Trust-Risk evolution in a BE tightly coupled

As it can be observed, the technological risk is decreasing while developments are implemented and tested, however trust between ecosystem members decreases and remains low even when technological risk is negligible. Trust evolution behaviour is well accepted by experts because each stakeholder rely on the proper competences of the rest of stakeholders assuming low risk technological developments. Thus, it is assumed that a stakeholder without reaching the objectives could be easily replaced by a new stakeholder with similar competences which leads to a sustainable ecosystem with low trust and engagement.

3.4. High Risk Business Ecosystems with tight interdependencies

There are several innovative products/services that are at very early stages of the innovation chain despite some technologies have been validated in other application areas. Consider for example an aerial ecosystem (Radanovic et al. 2018) in which technologies developed in the "car connectivity" sector could be replicated and adapted to fit similar problems in the UAV's arena. Note for example that despite V2V and V2I services are quiet similar to drone-to-drone and drone-to-ground functionalities, the underlying technologies are drastically different when the distance between drones are above a certain threshold. Despite the market expectations for these new services and the huge interest of car technology companies to adapt to the aeronautical market there is a well accepted underlying risk about the performance of the communication in the airside.

For these risky technological innovation ecosystems, the socio-technological behavioural underlying rules (Piera et al., 2016) are very different to those shown in the previous "low risk business ecosystems". Note for example that the substitution of a stakeholder with risk frontier technology by a new stakeholder is not considered as a feasible solution because there are a reduced number of stakeholders with key technologies and most of them are engaged in other competing ecosystems.

In Figure 7 it is represented the evolution of Trust and Technological risk considering high risk innovation in which all stakeholders are tightly interconnected and there is no leader taking particular risk. As it can be observed, there is a followers-like behaviour in which just one stakeholder with low confident is propagated to all the stakeholders without particular justification from the risk evolution. As soon as a technical risk emerge (see risk evolution in month 12^{th}), the risk assumptions of all partners increases and propagates to stakeholder's trust.

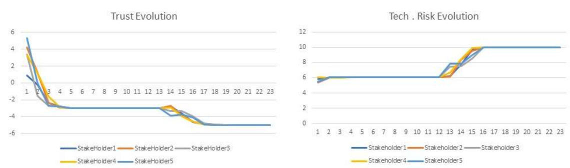

Figure 7:Trust-Risk evolution in a High Risk BE tightly coupled

Business Ecosystem facing huge technological risks and without a leading role with enough assets to motivate the ecosystem members when difficulties arises use to fail before the prototyping phase.

3.5. High Risk Business Ecosystems with controlled interdependencies

The members of a Business Ecosystem need to watch and foresee what will happen in the near future considering the volatile and changeable context. Understanding the ecosystem means not only identifying the stakeholders and its relationships in a certain moment in time, but understanding how it evolves by monitoring evolutionary trends. In order to react on changes quickly and efficiently, a keystone member of the ecosystem must be able to foresee what will happen considering present member competencies, and the very fact that some fields such as ITS are being performed in a changeable environment, introducing in this way uncertainties in the ecosystem dynamic evolution, and unfortunately introducing more difficulties in the decisions to be taken cooperatively by the ecosystem members.

In Figure 8 it is represented the trust and tech. risk evolution considering a business ecosystem with a strong keystone member in which it is assumed no constraints on budget and the possibility to replace a stakeholder by a better one in case of a failure in its competences.

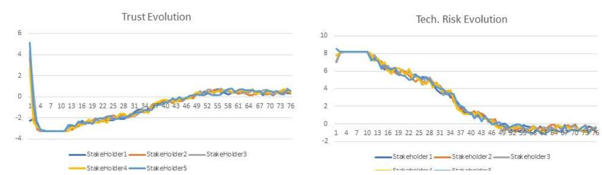

Figure 8: Trust-Risk evolution with a ketstone member

As it can be observed, under the described operational conditions of the keystone ecosystem member, ecosystem trust increases until reaching a steady state once the technological risk is under control.

This type of behaviour can be found also in business ecosystems supported by public funds in which the target is not to succeed with a new product/service, instead the target is to push technological research to improve their functionalities and performance.

4. AGENT BASED MODEL

The modelling target of a systemic ecosystem business dynamic in NEWBITS project has been the identification and description of the ecosystem stakeholders, its relationships together with decision rules and actions of the keystone in order to obtain a global view of the ecosystem behaviour.

Thus, an ABM framework has been implemented to identify some ecosystem behaviours by means of simulation MAS tool (Repast has been used), in which agents are formalized to describe the ecosystem members by means of behavioural rules:

- Each agent has a set of decision rules.
- agents' behaviour is described by rules with which it can be computed the effects of receiving tangible or intangible values.
- In these rules, the positive or negative network externalities they experience can be incorporated. This means that an agent will look at other agents' status in making its own decisions.

In Figure 9 it is represented the interfaces implemented in the ABM simulation for the business ecosystem which takes place as intangible or tangible flows between stakeholders.

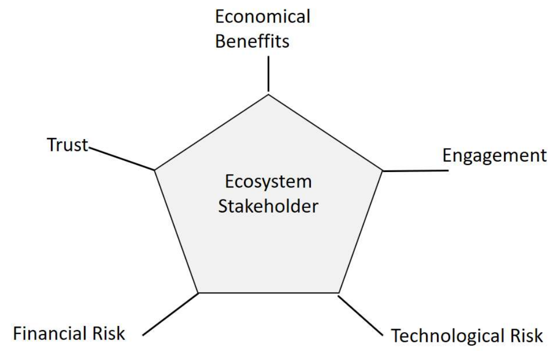

Figure 9: Agent Interfaces in a Business Ecosystem

Rule behaviour for low risk ecosystems assuming no financial risk and high stakeholder engagement for good economical benefit expectations are formalized by the relationship:

$$Trust = a_1 * ((Trust + \sum Trust\__k)/(n+1)) - a_2 * Risk$$

Each agent updates his trust considering the trust evolution of the agents has a dependency (ie. $Trust\__k$) and the Technological risk of the tasks to be implemented by his own company. In low technological risk ecosystems, the Risk decreases with the flow of time when work is progressing, which contribute to an increment on Trust. Parameters a_1 and a_2 must be complementary ($a_1 + a_2 = 1$) and are particular to each ecosystem type.

For those ecosystems with high technological risk and no keystone in the ecosystem, the trust behavioural rule that fits better the evolution is:

$$Trust = a_1 * (Trust - b_1 * Min(Trust\__k) + b_2 * Max (Trust\__k)) - a_2 * Risk$$

Each agent updates his trust considering his own trust on the task to be implemented considering his competences, the lowest trust and the highest trust of the agents with it has a dependency (ie. Trust_k) and the Technological risk of the tasks to be implemented by his own company. Thus, if a consortium member fails in the technological task assigned, all the stakeholders that depends on his technology are affected by a reduction of this trust which somehow propagates to the rest of the stakeholders. Parameters b_1 and b_2 must be complementary ($b_1 + b_2 = 1$) and are particular to each stakeholder profile considering its networking.

In case of a keystone stakeholder in the ecosystem the previous behavioural rule can be used considering that those ecosystem members with a Trust below a certain threshold will be fired and substitutes by other agents with higher initial trust.

5. CONCLUSIONS AND FURTHER RESEARCH

This paper describes an approach to explore relationships between stakeholders in a cooperative environment to implement an innovative product/service in the ITS arena.

Most innovations in the ITS sector rely on the adaptation of validated technologies which reduces the technological risk, however are subject of constant market changes in which the acceptability of a new product/service is influenced by several social aspects besides the technology developed.

Agent Based Modeling provides an excellent modelling framework to specify socio-technological dynamics. In the paper it has been illustrated different behavioural rules to describe the influence variables at early phases of the innovation chain, focussing mainly on the technological risks.

As future work, it is expected to extend the model to more mature phases of the innovation process, considering the acceptability risk, the market fluctuations and the financial problems. The new model will be validated with the data validated in the Newbits project considering different C-ITS case studies.

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REFERENCES

Amit, R., and Zott, C., 2001. "Value creation in e-business", Strategic Management Journal, 22, pp. 493-520

Battistella C., Colucci K., De Toni A., Nonino F., 2013. Methodology of business ecosystems network analysis: A case study in Telecom Italia Future Centre,Technological Forecasting & Social Change 80, 1194–1210

Klusch M., Hindriks K., Papazoglou M., Sterling L., 2007. Cooperative Information Agents XI. Lecture Notes on Artificial Intelligence.

Piera M., Buil R., Ginters E, 2016. "State space analysis for model plausibility validation in multi-agent system simulation of urban policies". Journal of Simulation. V10, pp 216 – 226.

Radanovic M., Piera M., and Koça T, 2018. "Sensitivity Analysis of Conflict-Free Resolutions for the Airborne Cluster–Ecosystem", Journal of Air Transportation, Vol. 26, No. 1 pp. 37-48.

D2.1 Overview of ITS initiatives in the EU and US. 2017. Newbits project. Available from: http://newbits-project.eu/publications/deliverables/

D4.1 Formalization of NEWBITS modelling method and systemic business dynamics. 2018. Newbits project. Available from: http://newbits-project.eu/publications/deliverables/

MULTI-CAPITALS SUSTAINABILITY FOR FIRMS COMPETITIVENESS

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ABSTRACT
Many executives wrongly believe that synchronizing organizational, environmental and societal needs in an integrated way is a noble initiative worthy of admiration but basically a waste of resources. Most of them prefer making data-driven business decisions and the holistic nature of sustainability does not encourage them to invest significantly in this direction. Therefore this article provides details on the definition of a Multicapital Sustainable Framework (MSF) as a fully-evolved, all-inclusive, both theoretical and applicable framework to support an organization-specific, multicapital-oriented, multi-method and quantitative enterprise's performance assessment.

Keywords: *Multi-Capital, Sustainability, Industry, Business Strategy, Decision Support System*

1. INTRODUCTION

Man has always interacted with the environment creating, in most of the cases, major problems such as greenhouse effect, deforestation, desertification, soil and atmosphere contamination, pollution, sea level rise and climatic alterations among others. After the first major event (Earth Summit in Rio de Janeiro in June 1992) addressing the sustainability problem, many other events and joint initiatives have been promoted and undertaken until the 2015 Paris agreement where 195 countries adopted the first universally and legally binding agreement on the global climate.

Therefore, over the last decades, the concept of sustainability has evolved rapidly. The most common and recognized definition of sustainability can be found in the report of the Brundtland Commission, which implies the capability of setting up growth processes avoiding either overexploitation of resources or damages for future generations. Consequently, resources preservation and efficiency are basic requirements to achieve sustainability and, in this perspective, technical, social, and environmental aspects have to be considered simultaneously.

In this perspective, it is undoubted that we do all have a responsibility to protect our earth; this must be done by single individuals and, above all, by companies. Each green investment companies do should, not only return business value, but avoid any false dichotomy between environmental protection and economic competitiveness (Porter, 1991) showing how profitability is only one element in the long-term success of companies and economies (Hay et al., 2005).

These beliefs are not at odds with each other as it seems, but are several sides of the same die. Indeed, this idea that for-profit corporations have an obligation to support social causes beyond their immediate interest in short-term profits dates back at least to the Corporate Social Responsibility (CSR) movement (Sahlin-Andersson, 2006) but it received its formal acknowledgement in 1994 with the Triple Bottom Line (3BL) accounting framework coined by Elkington (1997). This idea, however, highlights that traditional reporting and framework may be considered as inappropriate as they will not be useful in practice because only aspects related to tangible assets and finance are reported whereas social, human and environmental issues languish at the periphery of the organizational attention.

So far, the main question to be addressed today is the following: how can companies assess the firm's performance in a formal and structured way that takes into account the holistic nature of the human, social, and environmental corporate responsibility? Researchers and business leaders worked (and are currently working) on different methodologies, strategies and frameworks for an effective full-comprehensive reporting and accountability of sustainability. Indeed, it is now clear that frameworks able to consider only economic profitability are no longer an option (Kaplan and Norton, 1992). There is a need for paradigms able to consider people, profit and planet as part of extended concepts including nature, society, human well-being and economy (Atkisson and Hatcher, 2001) through quantitative indicators. However, a major research effort is required when dealing with the definition of quantitative indicators as, in this specific case, these indicators should include a number of different non-financial, environmental and social elements (e.g. employee satisfaction, social performance of suppliers, community relationships, philanthropic investments, material use per unit, energy use per unit, GHG emissions, etc.) as pointed out by Figge et al. (2002), Yongvanich and Guthrie (2006).

Moving in this directions, is then clear that if assets (capitals) are needed to run and maintain a business (and in a company there a number of different capitals, e.g. financial capitals, economic capitals, shareholder capitals, etc.), then natural and human resources must be included and all the capitals must be reviewed and redefined according to sustainability principles. Therefore the main goal of this article is to lay the foundation for a Multicapital Sustainable Framework as a fully-evolved, all-inclusive, both theoretical and applicable framework to support an organization-specific, multicapital-oriented, multi-method and quantitative enterprise's performance assessment.

2. THE MULTI-CAPITAL SUSTAINABIILITY

As the main goal is to re-review companies capitals according to sustainability principles, new concepts are required to be gradually embedded in the sustainability master concept. Indeed, today's trend of sustainability in business is too narrow and limited to green, environmentally sustainable practices and social entrepreneurship. According to the Oxford American Dictionary that states that capital is, "wealth in the form of money or other assets", a clearer prospectus and deeper analysis of such "other assets" is required. To this end, this paper identifies a full-comprehensive set of 12 capitals that are outlined below.

The Material Capital that can be defined as the non-living physical objects, such as raw materials and processed resources that can be "complexed" with each other to create more-sophisticated products. This capital can also include buildings, and other pieces of infrastructure along with tools, computers and other technologies.

The Financial Capital, the Stakeholders-related and Shareholders-related Capitals are the ones connected in some way to the organization's economic and financial aspects. The Financial Capital refers to the organization's financial wealth expressed in terms of economic resources (e.g. money) to start or maintain the business and it is the one executives are most familiar with. The Stakeholders-related Capital takes into account the needs and cultural values of each of the stakeholders (e.g. customers, suppliers) which are critical to success. Maximizing their returns and promoting a win for them is the key to the modern sustainability concept. The Shareholders-related Capital refers not only to a company's stock owned by shareholders but also to the expectation of the shareholders to maintain and increase the value of their assets to realize the long term growth of their value, and of the organization as well.

The Social Capital that can be split in three different types: Internal Social Capital, External Social Capital and Relational Capitals. The performance of individual employees is crucial for the organization's performance so the Internal Social Capital needs to be considered as one of the multicapitals. On the other hand, surrounding social communities (e.g. environmental groups, political parties) should be managed appropriately to yield the maximum return both in a tangible and intangible way. Then, the External Social Capital should be considered separately as a capital not internal to the organization but context-related. Finally, the Relational Capital is instead referred to the organization's relationships – market relationships, power relationships and cooperation – established between firms, institutions and people, which stem from a strong sense of belonging and a highly developed capacity of cooperation typical of culturally similar people and institutions.

At an upper-intermediate abstraction level, along with the Stakeholders-related Capital, the Image Capital is intended to be what people is supposed to see when the organization is mentioned, which can be improved by communications, brand selection and promotion, use of symbols, and by publicizing its actions.

The protection and enhancement of the Natural Capital, along with the Financial and Social Capitals, is one of the most common sustainability goals. It is defined as the stock of worldwide natural assets that include geology, soil, air, water and all living things. Overexploiting the natural resources can be catastrophic not just in terms of biodiversity loss, but also for humans as ecosystem productivity and resilience decline over time.

At the higher abstraction level, the organization's principles, its morality, experience gained over time and lessons learned constitute other three different types of capitals: the Identity and Ethical Capital, the Intellectual Capital and the Human Capital. The Identity and Ethical Capital involves the organization's morality and ethical principles. It is something related to the managers' imprint but, most of the times, it is affected also by people working internally. The Intellectual Capital is the "knowledge" asset used to create resilient and thriving organizations. In this article, the term "Intellectual Capital" can be labeled as "know-how" or "procedural knowledge" which is owned by employees and is used to refer to the knowledge and knowing capability of the organization in clear parallel with the Human, or Experiential Capital, which is a blended gathering of lessons learned accumulated over time owned by the organization itself. It concerns well-practiced skills and routines, acquired knowledge, skills, and capabilities that enable persons to act in new ways.

Therefore, the concept of sustainability has to pervade all the organization's capitals above-mentioned. To this end, this article provides the initial description and definition of a Multi-capital Sustainable Framework.

3. THE DEFINITION OF A MULTICAPITAL SUSTAINABLE FRAMEWORK

In order to move towards a Multicapital Sustainability concept, many competing frameworks that measures economic, social, human, intellectual and environmental impacts in an integrated way have been developed as already mentioned into the introduction section. Some are in rudimentary form (Atkisson and Hatcher, 2001); others are more sophisticated (McElroy and Thomas, 2015). However, given the growing need for guidance of executives facing the complexity of the context in which their company operates, a groundbreaking, multi-capitalistic, multi-method, organization-specific, and quantitative approach outmatching the traditional reporting and scorecards would be highly desirable. The above-mentioned reporting frameworks and approaches demonstrated how current methodologies provide some guidelines and offer a ready-to-use (to some extent) set of performance measures arranged, most of the times, in the form of executive dashboard and infographics. Nevertheless, writing complex reports or preparing some dashboards and infographics to convince others and build consensus is no longer proper as they are usually based on someone's thoughts and theories or on internal data gathering processes rather than on a deepened analysis of the system and unknown interactions among different elements (e.g. people, assets, ethics, financial capital). To outmatch such everlasting issues in reporting, in August 2015, the GRI Sustainability Reporting Guidelines proposed a series of reporting principles and standard disclosures for the preparation of sustainability reports for organizations, regardless of their size, sector or location (Global Reporting Initiative, 2015). The process for defining reporting content is represented in Figure 1.

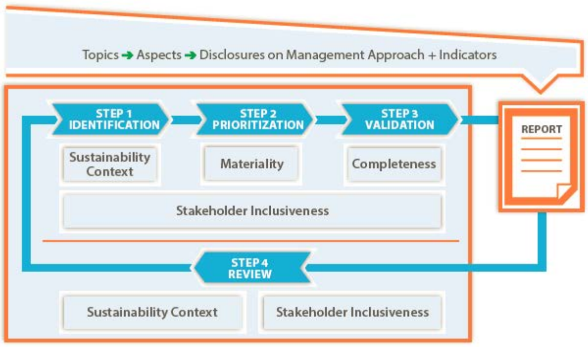

Figure 1 – Reporting content definition process (Global Reporting Initiative, August 2015)

Although this framework provides valuable principles and useful guidelines to be consulted by organizations when preparing a sustainability report, it jumps over some essential aspects that cannot be neglected. In fact, new dimensions of sustainability must be considered in an integrated way and sustainability reporting can no longer focus on economic, environmental and social impacts exclusively. Furthermore, this framework only concerns about the organization's impacts on the economic conditions of its stakeholders and on economic systems at local, national, and global levels but it does not focus on the financial condition of the organization.

Anyway, it is worth saying that the integration of all the organizational elements, their mutual interactions and their behaviors over time in a few simple graphics whose data have been obtained through more or less structured gathering processes is utopian. A simple look, no matter how precise at the organization's state and condition, cannot lead the corporate analyst straight to the results. An intermediate layer where different methodologies are combined is needed in order to improve our comprehension of the system-in-analysis and to provide sustainability-related performance assessment and forecasting. To this end, the process illustrated in Figure 1 has been modified as follows thereby obtaining the definition of a new Multicapital Sustainable Framework (see figure 2).

In order to answer all the what-if questions and to allow the user to explore new policies, operating procedures or methods without the expense and disruption of experimenting with the real system, the Multicapital Sustainable Framework is indicated to be the most valuable way of handling the process of preparing for change. Companies that accept reliable results, which have been modeled, tested, validated and visually represented instead of one person's opinion, have a major advantage over those who only use numbers, charts and Excel spreadsheets.

The Multicapital Sustainable Framework here proposed consists of four steps to be attentively followed in a circle where the results of its i-th application can be easily and quickly exported to draft the Sustainability Report and to carry out a more focused analysis of the context in which the organization is operating at the $(i+1)$-th application.

Figure 2 – The Multicapital Sustainable Framework (MSF)

The step 1 of the framework depicted in figure 2 deals with context analysis in order to carry out a theoretical analysis on sustainability issues based on a scenario conceptualization (also including market pressure and legislation constraints). The Step 2 aims at identifying and defining all the capitals that are involved in the Multicapitals sustainable concept taking into consideration the theoretical analysis carried out in Step 1. The results of Step 2 feeds the Step 3 where an advanced Decision Support System (DSS) based on the concurrent use of multiple methods is designed and implemented; the Step 3 provides the methodology backbone and, thanks to its implementation, the test bed for achieving acceptable levels of multicapitals sustainability. In other words, the Step 3 provides the methodological and technological way to the multicapitals sustainability implementation. Finally, Step 4 focuses on the selection of the correct efficiency based performance measures that allow the users to explore new policies, operating procedures or methods as way of handling the process of preparing for change. A description of each step is reported in the following sections and for each step the most important aspects and methodologies to be considered are depicted in figure 3.

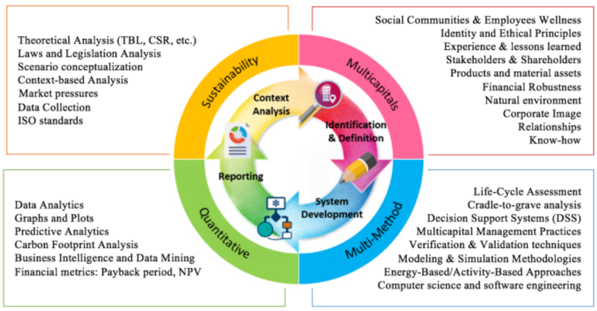

Figure 3 – Most important aspects and methodologies part of the MSF

3.1. Step1: Scenario Conceptualization oriented to Sustainability

The MSF is conceived for organizations in a broad sense: they are expected to offer different products or services, they are founded on smooth or complex routines and procedures, they are based on different value chains, and they have opposite organizational cultures depending on the leadership's imprint and on the context where they operate. Since no two organizations are alike, managers aim at reinforcing their own businesses through practices that suit them best and fit the context in which they operate. An ever-increasing number of organizations is monitoring and managing a far wider array of sustainability-related performance measures due to their everyday management activities. Although long-term profitability is today intended to go hand-in-hand with social justice and the environmental protection, sustainability – intended as the ability of something to endure – should pervade all the organizational aspects with all the parties working closely together towards a common goal.

Therefore, in order to carry out a preliminary theoretical analysis on sustainability, managers are required to hypothesize a scenario, check data availability for the hypothesized scenario, check legislation and law inputs and constraints and adherence to international standards (e.g. ISO standards), analyze the scenario in view of external factors (e.g. market pressure, market opinions, etc.). Examples of sustainability scenarios may include reduction of emissions, better power and energy management, waste management, use of electronic communications, etc. Once the basic scenario is defined, a schedule of data requirements should be prepared. In the best case, such data are already available and collected by the company and in the right format. Data may also be available in the wrong format or, in the worst case, data are not available. If data are available in the wrong format (e.g. insufficient precision, erroneous values, not-representative data, etc.) then reworking is needed to translate data in the correct format. When data are no available (and this may be particularly true for young companies or new processes/products or data are too expensive to be collected), Subject Matter Experts (SMEs) estimates are required. In all the cases, the most difficult part is to collect data with enough quality and quantity to perform reliable analysis. Furthermore, the nature of the data must be taken into account and opportunely treated. Deterministic and qualitative data may be usually taken as they are; random data generates stochastic processes and a statistic approaches are needed to use correctly such data (Montgomery and Runger, 2010).

Legislations and laws may provide input as well as constraints to the sustainability scenario that must be carefully taken into account (e.g. renewable energies are also accompanied by legislative instruments that further encourage their growth). Furthermore, if the company already implements ISO standards (e.g. ISO 14000) practical tools (and related data) for environmental management may be already available.

3.2. Step 2: Identification and Definition of Multicapitals

The theoretical analysis carried out in the previous step is the starting point for identifying all those capitals that may be involved in the Sustainability scenario. Indeed, in order to develop strategies and sustainability goals, different capitals should be considered at the same time (multicapitals). The MSF includes all the capitals already described in Section 2, managers have to select those capitals that apply to the scenario defined in the previous step.

3.3. Step 3: Multicapitals Sustainability Implementation by using a multi method based approach

The Step 3 takes into account both the results of Step 1 and Step 2. Indeed, the Step 3 proposes a set of methods to be concurrently used to support the implementation of the multicapitals sustainable concept defined in previous steps where a preliminary sustainable scenario as well as a number of involved capitals have been identified. It is worth mentioning that many attempts have been done to investigate specific sustainability-related issues but a full-comprehensive and integrated multi-method model wherein global impacts evaluation is coupled with economic and multi-capital analysis and all the issues and interactions are simultaneously considered, is still missing.

In order to achieve a significant competitive advantage, the multicapitals sustainability should be based on the design and implementation of soundly multi-method Decision Support System (DSS) that jointly uses at least the following three methodologies (also reported in figure 3), but it may also integrate additional methodologies:

1. Multicapitals Management Practices (MMP) to identify all those practices (and their effects) that may affect the multicapitals sustainability;
2. Life Cycle Assessment (LCA) and energy/activity based approach as a systematic cradle-to-grave "line of attack";
3. Modeling & Simulation (M&S) and Verification, Validation and Accreditation (VV&A) to obtain significant and validated results in a timely manner without disturbing the real-world system.

The main idea is to provide managers that take business decisions with an advanced DSS that implements – in an easy to use and effective way – the three points mentioned above. The description of the three main components of the multi-method DSS are reported below.

The Multicapitals Management Practices

The MMP should consider all those actions that may (at different levels) affect the multicapitals sustainability. Taking into account the preliminary sustainability scenario identified in Step 1, organizations must follow the procedure reported below:

1. determine which are the multicapitals Areas of Impact (AOI); the AOI can be regarded as those company areas that are affected by the sustainability scenario defined in Step 1.
2. identify a set of Multicapitals Management Practices (MMP) for each AOI; the MMP can be regarded as all those practices that affect the capitals identified in Step 2
3. identify where the MMP will have the major impact (in the company location or elsewhere)
4. identify all the capitals involved; at this time additional capitals may be added to the initial list according to the MMP.

Just to let the reader understand, let's consider the example of a real-world complex system where multicapitals sustainability is becoming a major issue: a marine port, specifically a container terminal (Bruzzone et al., 2009). In this case, examples of AOIs may include: reduction of energy consumption in the exterior lighting, reduction of machines fuel consumption, relationship-related policies, electronic communications, etc. In each AOI multiple MMP can be involved; as for our container terminal example, for the AOI "reduction of the energy consumption in the exterior lighting", MMP may include reduction of container flows during the night time, using of motion sensors lamps, use of high efficiency equipment based on LED technology. The MMP may have a localized or delocalized impact; the first one when the MMP major impact is where the MMP is implemented, the second one if there will be impacts somewhere else. This aspect plays a key role in the final carbon balance and whether or not the practice is ecofriendly or harmful to the global or local environment. For example, electric energy is generated at electric power plants somewhere located, so pollutants will be emitted there. Finally, the capitals affected by the MMP must be identified; as for our example, the MMP "reduction of container flows during the night time" may surely affect Financial Capital and Material Capitals.

Life Cycle Assessment and energy/activity based approach

The correct identification of AOI, MMP (and their impact locations) and capitals involved is the starting point for the multicapitals sustainability concept implementation. Since the main objective is to support business decisions, the impacts of MMP on identified AOI and capitals must be quantitatively evaluated and this must be done along the entire life cycle of the organization being considered. To this end, Life-Cycle Assessment (LCA) can be used, as a systematic "cradle-to-grave" approach (Petrillo et al. 2016; Mellino et al., 2017), to evaluate the effects of MMP throughout the entire life cycle.

LCA needs to be applied by using energy-based or activity-based approaches to evaluate quantitatively the impacts of processes and operations performed along the life-cycle. For example, let's consider once again the example of a marine port, the most accurate way of calculating emissions of a vehicle used for container handling equipment along its life cycle is not only to record energy and/or fuel consumption (to be converted in equivalent CO_2 emissions) but also to estimate equivalent CO_2 for its initial manufacturing and transportation as well as for its final disposal. Energy or activity based approaches must be used along the entire life cycle of all the resources being part of the system considered. To this end, the implementation of the DSS will provide the user with the possibility to carry out estimates and calculations along the entire assets life cycle.

Modeling & Simulation and Verification, Validation and Accreditation

The DSS part of the MSF framework should be used to support business decisions about the effects of the identified MMP on the AOI and on the identified capitals as part of the Sustainable scenario identified in Step 1. Needless to say that managers needs to take decisions in very short times; therefore any experimentations in the real-world system is not an option; a methodology able to recreate the complexity of real-worlds system is needed. Modeling & Simulation has proved to be one of the most powerful approaches for problem solving in real-world systems thanks to its capability to support fast time decisions (Banks, 1998). Furthermore, Modeling & Simulation is the ideal solution to tackle those real-world systems characterized by a number of stochastic variables whose behaviors evolve over the time (Bruzzone et al. 2013). Therefore, the heart of the DSS (part of the MSF) is a simulation model that is specifically implemented to draw inferences, analyze the behavior of systems considered and carry out what-if analysis concerning the implementation of the MMP and their effects on capitals involved. In this regards, the simulation model part of the DSS allows the analysis and understanding of all the interactions (most of the time among stochastic variables) that take place in the real-world complex system being considered. Diagnosing problems and gaining insights into the importance of these variables increases the understanding of their important effects on the performance of the overall system. Most important, the simulation model allows us to get information about how something will behave without disturbing the real system, helping to reduce costs, achieve a better return on investment and take decisions in shortest times.

Once the knowledge base, the simulation model and the user interface have been implemented, it is critical to assure the total quality of the simulation model results and this is usually done by conducting Verification, Validation and Accreditation (VV&A) activities downstream the simulation model development. On one hand, Verification must ensure the correct translation of conceptual models into a computer-recognizable form – "building the model right" – whereas, on the other hand, validation must check whether the simulation model is able to recreate accurately the supposed scenario – "building the right model" (Banks, 1998). Finally, Accreditation proves that the simulation capabilities are sufficient to support its intended use.

3.4 Quantitative Reporting

The DSS presented in section 3.3 must be supported by a quantitative reporting. In their article for the Harvard Business Review, McAfee and Brynjolfsson (2012) reported that "companies in the top third of their industry in the use of data-driven decision making were, on average, 5% more productive and 6% more profitable than their competitors". Executives usually prefer making data-driven (big or small, internal or external, experimental or observational data) business decisions and rely on quantitative analysis above all when dealing with stochastic variables affecting (with their interactions) the corporate performances. However, sustainability reporting has demonstrated its inability to present quantitative and forecasting outcomes. Marshall and Brown (2003) found that 82% of measures were descriptive, with only 13% having targets and only 5% being efficiency-based. Consequently, the DSS of the MSF is conceived and structured to provide the users with the capability of comparing performance metrics over time and across entities. Furthermore, performance indicators part of the DSS must be recognizable, consistently measurable and easily exportable to other formats in order to facilitate and support the drafting of the final Sustainability Report. Needless to say, the right set of performance measures to support the implementation of the multicapitals sustainable concept strongly depends on the type of systems being considered.

4. CONCLUSIONS

Core competence is a concept that is closely tied with sustainability because it offers a way for long-term competitive advantage. But the environment is not the only capital a company has to manage. Organizations are already under significant pressure to measure and report their social, environmental and economic performance. This will require firms to adopt a stakeholder view of value, and develop strategies that take into account more than simply shareholder performance. The key roadblocks to long-term benefits from multi-capital initiatives are short term thinking, focus on initiatives instead of business strategy, ignoring multiple stakeholder viewpoints, rigid, irreversible outlook to decision making, and lack of judicious use of qualitative and quantitative data. Successful organizations involved in developing or strategizing their sustainability practices, cannot rely on their past laurels in sustainability to remain leaders in the market. Instead they should innovate, deepen and deploy these competencies as well as leveraging on new MMPs to ensure continued success.

The definition of the strategic framework offered in this study can be very useful in overcoming the above-mentioned shortcomings thereby improving the longevity and impact of these initiatives. The main idea behind this study is the definition of a multi-capital Sustainable Framework as an innovative both theoretical and applicable framework that proposes an organization-specific, multi-capital oriented, multi-method and quantitative enterprise's performance assessment methodology**.**

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REFERENCES

Atkisson A, Hatcher L. 2001. The compass index of sustainability: prototype for a comprehensive sustainability information system. Journal of

Environmental Assessment Policy and Management 3(4): 509–532.
Banks J., (1998). Handbook of Simulation. John Wiley & Sons.
Bruzzone A.G., Tremori A., Massei M., Tarone F. 2009. Modeling green logistics. Proceedings - 2009 3rd Asia International Conference on Modelling and Simulation, AMS 2009, pp. 543.
Bruzzone A.G., Massei M., Poggi S., Dallorto M., Franzinetti G., Barbarino A., 2013. Quantitative simulation of comprehensive sustainability models as game based experience for education in decision making. 1st International Workshop on Simulation for Energy, Sustainable Development and Environment, SESDE 2013, Held at the International Multidisciplinary Modeling and Simulation Multiconference, I3M 2013, pp. 119.
Elkington J. (1997). Cannibals With Forks: The Triple Bottom Line of 21st Century Business. Capstone, Oxford, 1997, 402.
Figge F, Hahn T, Schaltegger S, Wagner M. 2002. The sustainability balanced scorecard – linking sustainability management to business strategy. Business Strategy and the Environment 11: 269–284.
Global Reporting Initiative (2015). G4 Sustainability Reporting Guidelines. Retrieved March 24, 2016 from the World Wide Web: https://www.globalreporting.org/standards/g4/Pages/default.aspx
Hay, Bruce L., Robert Stavins, and Richard Vietor, eds. Environmental Protection and the Social Responsibility of Firms: Perspectives from Law, Economics, and Business. Washington, D.C.: Resources for the Future, 2005.
Kaplan R., Norton D., 1992. The Balanced Scorecard. Harvard Business School.
Marshall S, Brown D. 2003. Corporate environmental reporting: what’s in a metric? Business Strategy and the Environment. 12: 87–106.
McAfee A., Brynjolfsson E. (2012). Big Data: The Management Revolution. Harvard Business Review, October 2012.
McElroy M.W., Thomas M.P., 2015. The MultiCapital Scorecard. Sustainability Accounting, Management and Policy Journal, Vol. 6 Issue 3 pp. 425 – 438.
Mellino S., Petrillo A., Cigolotti V., Autorino C., Jannelli E., Ulgiati SA, 2017. Life Cycle Assessment of lithium battery and hydrogen-FC powered electric bicycles: Searching for cleaner solutions to urban mobility. International Journal of Hydrogen Energy 42(3), pp. 1830-1840.
Montgomery D.C., Runger G.C. (2010). Applied Statistics and Probability for Engineers. John Wiley & Sons.
Petrillo, A., De Felice, F., Jannelli, E., Autorino, C., Minutillo, M., Lavadera, A.L., 2016. Life cycle assessment (LCA) and life cycle cost (LCC) analysis model for a stand-alone hybrid renewable energy system. Renewable Energy 95, pp. 337-355
Porter, M. E. (1991). America's Green Strategy. Scientific American 264, 4 (April 1991).
Sahlin-Andersson K., 2006. Corporate social responsibility: a trend and a movement, but of what and for what?. Corporate Governance: The international journal of business in society, Vol. 6 Issue: 5, pp.595-608.
Yongvanich K, Guthrie J. 2006. An extended performance reporting framework for social and environmental accounting. Business Strategy and the Environment 15: 309–321

BIOGRAPHIES

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DESIGN OF CRUCIAL ELEMENTS FOR INDUSTRIAL PLANTS, OFFSHORE PLATFORMS AND UNDERWATER FACILITIES

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ABSTRACT
The paper proposes some specific models to be used in design of crucial elements for Industrial Plants that previously were not easy to be addressed by simulation due their functional complexity. As examples of these kinds of elements are proposed autonomous systems for fire fighting and/or emergencies for on-shore and off shore plants as well as equipment for underwater operations. The paper proposes use of MS2G Simulation Paradigm (Modeling, interoperable Simulation and Serious Games) as solution in these specific cases to test concepts and capabilities.

Keywords: Industrial Plant, Off-Shore Platforms, On-Shore Infrastructures, Underwater System, Simulation

1 INTRODUCTION

Design of specific components in modern industrial plants is sometime quite difficult, especially in cases where major complexities are present; in particular, it is important to outline two principal typologies of complexities that correspond specifically to internal complexity and interactions among components.

In case of internal complexity, we have usually to deal with systems characterized by complex physical phenomena, in these case the solution of differential equation could result critical as well as the influence of boundary conditions and control systems; for instance, very good examples are proposed by systems including chemical thermo-dynamics or mechanics of cables under specific boundary conditions (Ablow et al., 1982; Reverberi et al.,2016; Bruzzone et al.,2017a; Buckman et al., 2004). The second typology of problems is represented by systems where several different objects interact dynamically and their mutual interference result difficult to be represented without simulation; a very good example is related to interaction among vehicles and handling devices in production plant or in operations (Williams et al., 1997; Smith 2013; Baruwa & Piera 2016). These cases are common in Industrial Plant Engineering over a wide spectrum of systems and components and traditionally there are procedures to support the design based on specific assumptions; the use of simulation in this cases represent the most effective approach, however, in the past there were some difficulties in cases when development of models and solutions for industrial applications was constrained by limited time and resources (Fowler & Rose 2004). From this point of view, the Lean Simulation approach results very effective and could be the proper solution for this problem (Bruzzone & Saetta 2002). In this paper the authors propose to combine Lean Simulation with MS2G (Modeling, interoperable Simulation and Serious Games) in order to create immersive, usable and intuitive simulation systems able to support interactively the design of new plants, new facilities and/or new components in complex systems (Bruzzone et al., 2014).

2 LEAN SIMULATION AND MS2G FOR PLANTS

In facts, the Lean Simulation deal with development of specific models starting from “model templates” customized on specific application fields which could be tuned quickly by small team of experts (Amico et al., 2000; Balci 2004). These teams are expected to use Design of Experiments in pragmatic way to face criticalities and to complete quickly validation, verification and preliminary analysis. By this approach fidelity level and confidence band of simulators are relaxed in order to speed-up developments, tailoring and analysis (Bruzzone & Saetta 2002; Tiacci, Saetta & Martini 2003); however, the Lean Simulation Protocols guarantee to keep variance under control and to be aware of tolerances as well as about the assumption hypotheses. By this approach, the VV&A (Verification, Validation and Accreditation) could be standardized on the specific sectors in order to be complete quickly; by the way one of the major advantages by this simulation development process is the capability to obtain quickly results in real industrial cases. From this point of view, the use of MS2G Paradigm is very promising because it enables two major properties: “interoperability” and “usability” (Bruzzone 2017). In facts the interoperable simulation allows to combine different models representing for instance different plant components, systems or subsystems; concurrently the adoption of Serious Game approach enhance the engagement of users within intuitive, immersive, interactive environments that could provide an effective and efficient way to test different design solutions and to support industrial plant engineering as it has been done in education for engineers (Bruzzone et al.,2016; Longo et al. 2017; Baghirolli et al., 2016).

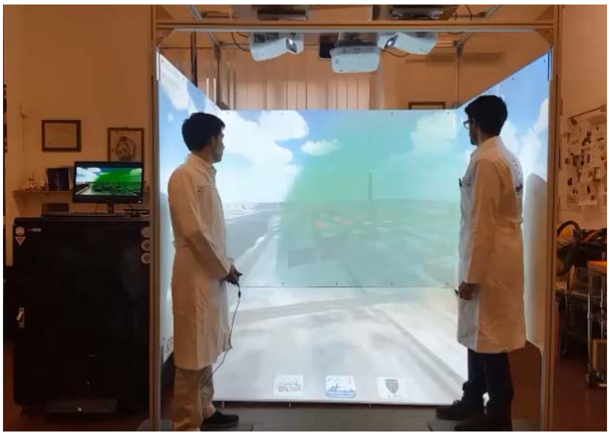

Figure 1. Hazardous Material Spill Simulation in a Plant

The opportunity to use simulation as support tool was evident since many decades, however, limitations caused by available methodologies, techniques and computational power, in some cases forced development of simplified approaches or models for complex processes. For instance, in 80's the computational fluid dynamics was already known, but available to relatively small number of big organizations, while nowadays such calculations could be performed on most of the consumer personal computers (Witherden & Jameson 2017). From the other side, increasing complexity of systems of interest requires the M&S researchers and developers to create more and more sophisticated models. One of reasons of constantly increasing complexity is related to the changes in processes and machines of interest, which, for example, could be caused by implementation of a new process with higher precision and bigger number of steps. Another important reason of increasing of complexity of systems of interest is related to their architecture and interactions. For example, in case of an industrial plant simulation, in order to estimate efficiency of the future system it could be necessary to consider management of a warehouse of raw materials and final products, physics of processes in production lines, influence of stochastic events on efficiency of machines and on the personnel (Merkuryev et al., 2010). Another example of complex model is related to the plant providing such services as Incineration of urban solid waste. In fact, many big and medium cities are now interested in implementation of these solutions and into combining them with Smart City paradigm, which allows to improve efficiency of the town by acquiring in real time a lot of available data related to the city's state from different sources; obviously in this case the next step is often related to support decision making by simulation, which allows to analyze situation and estimate potential alternative policies respect planned or proposed activities (Bruzzone et al.,2014). In this case the model should consider interactions between different independent systems, such as population demand and behavior, logistics transportation network, power grids, meteorological conditions, hence, such situation is closer to System of Systems (SoS) rather than to just a single one (Bruzzone et al.2017c).

For these reasons, in order to satisfy current and future requests of the industry, it is necessary to be able to develop not only very complicated models of single systems, but new methodologies able to couple different models that could support design and engineering. In the following some case studies are proposed to confirm the validity of this approach.

2 ONSHORE PLANT

In Industrial plants in case of emergencies it is necessary to adopt special procedures addressing often such emergency procedures as fire-fighting and contamination containment. The proposed case is related to industrial plants that could release contaminants due to spill of hazardous material in atmosphere. In facts the safety engineering focuses on identification, selection and design of proper solutions in order to to guarantee human safety as well as to reduce vulnerability of the plant. In this case there is a strong relation between the physical phenomena dealing with contamination, including transport of contamination agent due to wind, influence on toxicity level of different boundary conditions inhomogeneous respect the area and time evolution (e.g. temperature, luminosity, humidity), etc. In addition, it should be stated that there are innovative systems devoted to support operations in case of crisis; for instance, the proposed case deals with UAV (Unmanned Aerial Vehicles) devoted to carry operations indoor and outdoor the plant with special attention to collection of data related to contamination level in order to monitor situation, identify dangerous area and delimit the perimeter. In this case the model for contamination was developed to be interoperable with the UAV simulators just to test the effectiveness of these systems to operate in the complex environment as well as to be responsive respect criticalities due to changes in boundary conditions or crisis evolution (Bruzzone et al. 2015). In the proposed case we developed specific models devoted to reproduce the dynamic of the spills, the transport, the diffusion, the precipitation, the ground contamination, etc.

These models have been based on particle approach using differential equations for each element behavior combined with empirical fuzzy sets to estimate contamination level (Bruzzone et al. 1996). These models are able to run in real time with relaxed fidelity and to interoperate with the simulator of the UAV, as shown in figure 1, where is proposed the augmented reality used to present the contamination evolution to allow designer to check efficiency of UAV system.

It is interesting to state that, as proposed in this picture, the designers and engineers could easily operate these models within a CAVE (Cave Automatic Virtual Environment); for instance in this example they use the SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering) developed by Simulation Team.

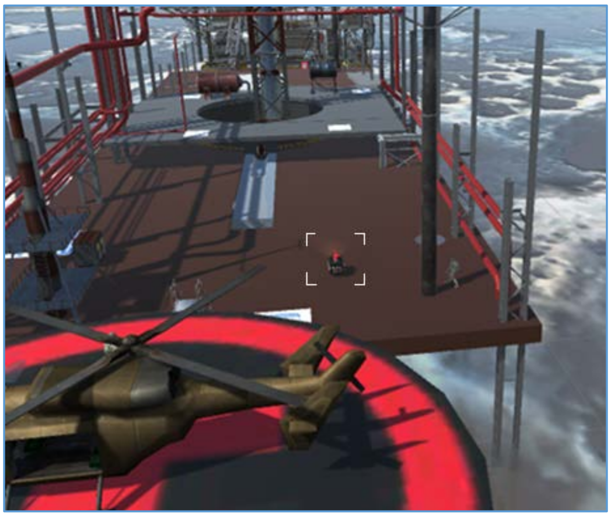

Figure 2. Simulation of Fire Fighting UGV for Off-Shore Platform

This capability emphasizes the Interactive and Interoperable aspects thanks to the special design of SPIDER that integrates up to six big touch boards (4 screens 2m x 1.5 m in proposed picture) within a compact “centripetal cube” (just 2m x 2m x 2.6m).

3 OFFSHORE PLATFORMS

In this case the problem addresses the design of a new specific system devoted to support operations on OffShore Platforms; in this case the system is an UGV (Unmanned Ground Vehicle) with a robotic arm able to control a fire hose and to operate in too dangerous areas for the people on board of the platforms in case of fire (Bruzzone & Figini 2004). In this case the robotic system design is complicated by the necessity to consider its capability to move and operate in complex environment and to interact with the fires as well as with other equipment; so concurrently to classical design approach to define power, weights, geometry of the UGV there is a real need to create an interactive immersive virtual world where to test different configurations and to identify best alternatives (Bruzzone et al.,2017d). In this case the adoption of MS2G is very promising considering that it allows to check mobility, interference and capabilities of chosen solutions. In this case the authors created a model using IA-CGF (Intelligent Agent Computer Generated Forces) logic and used a synthetic environment based on SO2UCI (Simulation for Off-Shore, On-Shore & Underwater Critical Infrastructure). This synthetic environment was originally developed for training of plants operators and principally devoted to security of Off-Shore Platforms (e.g. oil rig, gas rig), On-Shore Critical Infrastructures (e.g. power plants, refineries, ports) and Underwater Critical Infrastructures (e.g. cables, pipelines). SO2UCI includes models of different systems including autonomous and traditional vehicles, for example Rigid Hull Inflatable Boat, Helicopters, Sensors, UAV, Unmanned Surface Vehicle, Autonomous Underwater Vehicles (AUV), Gliders, etc. This a good example of MS2G that support interoperability through High Level Architecture. In facts this approach could be used in design and engineering to check the different alternatives on the simulator and eventually to test also interactions of the whole new robotic system, through hardware in the loop, with other real equipment, controls or sensors. In figure 2 is proposed the output of the simulator reproducing the dynamics the robotic system while it move over the off-shore platform.

4 UNDERWATER SYSTEMS

In some of industrial fields many crucial operations are performed in quite hostile environments, such as deep water, which is characterized by high pressure, low visibility and low temperature (Shukla et al.2016). In some cases, the risks of such activities could be carried out by autonomous systems, however, despite the advances offered by the new robotic systems, humans are still required due to higher flexibility in many of underwater operations. Hence, due to the risk of accidents, errors, mistakes and consequential injures of divers and damage of costly equipment, this simulation allows to support design and tests. So, it is clear that engineering support from M&S (Modeling and Simulation) is crucial in activities that deal with Oil and Gas Underwater Facilities. In addition, these aspects could be also very useful to support training activities, reduce costs and risks by substituting the real plant or equipment with a properly verified and validated simulators (Bruzzone et al., 2017b; Longo et al. 2015).

One of most crucial activities in this field is the life-support supervision of deep water divers that requires support vessels interacting dynamically with hyperbaric chambers and diving bell; the proposed case faces the necessity to models cable connections and their dynamics considering that major part of them are underwater, connected with different elements moved by waves (support vessel), current (diving bell) and interacting with the underwater plant components. The cables provide power, communication, but what is especially important, breathing gas mixtures; in fact, a crucial risk in deep water activities in general, is related to proper management of special gas mixtures, as well as to control their pressure and temperature (Shilling 2013); so it is evident that cable behavior could affect several aspects of operations and influence systems and subsystems' efficiency and reliability (Buckman et al., 2004); due to these reasons it is important to model these elements as happen since long time (Ablow et al., 1982). So the Life-Support System supervision and control to operate diving bells could require creation of models of these systems which considers their interactions; by the way it is important to outline that these models could be effectively used also to consider other kind of equipment for underwater facilities at higher deeps such as Exosuits and ROV (Remotely Operated Vehicle) where the cable transmits only power and data; finally also AUV (Autonomous Underwater Vehicles), supposed to be adopted in future in these field and to be free from cables for power and data, could also benefit of these simulation models, in facts there are hypotheses to equip them, in some case, with special new optical fibers, which allow to transmit data faster and with less losses respect to acoustic modems. These models have been tested in several applications (Bruzzone et al.,2017b, 2017d). The dynamic models of marine cables could be based on creating an interactive link of dynamic elements; in fact, these cables are widely used in the ocean environment to manage power, communications, transport of the gas mixture and even just to lift the equipment (Buckman et al., 2004). This case proposes two problems in the dynamic analysis of the cable. First, when the tension is zero, which is often the situation encountered, the geometry of the cable becomes a singular matrix that need to be addressed. Second, the transformation from local coordinates to global coordinates, through Euler angles, leads to quite a great number of unknown variables that could be corresponding to equivalent configuration of the cables respect known positions and constraints; these elements produce quite complex differential equations, so it is necessary to compute them and to add specific elements that represent physical constraints.

For instance major aspects are related to the mechanical characteristics such as bending stiffness of the cable; in addition to identify suitable configurations respect previous one and their dynamics respect different solicitation provided by internal and external forces, it result necessary to apply hypotheses on different fixed points; for instance the action of the boat motion affect the cable and transfer through it forces to the diving bell, but at the same time the current on diving bell affects the cable and also the boat; same concept applies to the diver connected by umbilical cable to the diving bell and vice versa. Obviously an iterative procedure based on computational integration of differential equations could introduce inconsistencies and singularities in the resolution of the problems.

So it is necessary to develop specific methodological approaches able to create an effective consistent three-dimensional model of the dynamics of marine cables. A point already mentioned, it is that the model should take into account the bending stiffness of the cables to overcome the singularities in the geometric stiffness matrix, in order to overcome any problem related to use of Euler angles. Therefore, it is also necessary to define an approach to introduce ad hoc displacement: in this way the displacement uses a differential that allows to estimate the curvature geometry and the torsion and allows to establish the transformation from the local coordinates to the global ones in consistent way.

In facts, as already mentioned, the general formula of marine cable dynamics could be applicable to a wide range of cases such as wires and ropes, but must be tested in terms of resolution, fidelity and computational efficiency to guarantee fast time and real time simulation as necessary to support engineering. All the models should be designed to address the dynamic evolution in 3D based on the differential equations. By adopting the Lean Simulation approach, it is possible to accept quite bland fidelity of this model providing in any case very valuable results for the engineering respect current simplified hypotheses. In facts by this approach it is possible, theoretically, to reconstruct the dynamic response of the cables respect to the motions of all elements including the ship as well as the effect of waves over different axis which affects speed and course. The three-dimensional solution must be computed on equations of motion as functions of Euler's angles by spatial integration using a finite element model, which uses a finite number of elements for temporal integration; in facts this approach is valid also to study the influence of transverse currents in the cable configuration.

The simulation of a virtual prototype of boat or vessel (including underwater elements such a submarine or a diving bell) requires special models to reproduce the motion stimulated by waves and generated by the buoyancy dynamics. In this sector complex models have been developed, which, however, sometimes are ill-suited for real-time simulations while they could be very useful for the detail aspect of naval engineering; in this case it is necessary to address some kind of balance between the fidelity of the cable virtual prototyping and the requirements to be able to run the simulator in order to support engineering.

In general, respect the effects of waves, usually, the models are based on a set of hull points that allows to consider the part immersed considering the Archimede’s forces along with that weights on the body; in addition it consider the impact of ship motion. In particular the models of sea are expected to keep into account the intensity of weather conditions and to reproduce the motion of ship, usually these results are quite complex and computational heavy in case of surface ships, while submerged bodies are easy to compute (no wave effects); considerations on the support vessels devoted to operate our equipment over underwater facilities simplify a little bit the problem considering that the focus is on the dynamics of the cables and that these one are just partially influenced by wave movements of the support vessels; so their fidelity is not very critical; however proposed approach could be extensively applied to a wide spectrum of surface entities.

In facts, as anticipated, the prediction of the ship's motions has always been a problem in the simulation of the ship's motion and in the evaluation of its impact on the on-board systems and sensors. In this regard, many models have been developed in the past to study this topic. On the other side the analysis of the systems and mechanisms subjected to these movements is very demanding, so usually for these simulations approximations relative to the elementary forms of movement are used. In this case it is expected to simulate the motion of the bell, but it could be valid also to support the design of cranes placed on the pontoon or support vessel considering the impact of their dynamics.

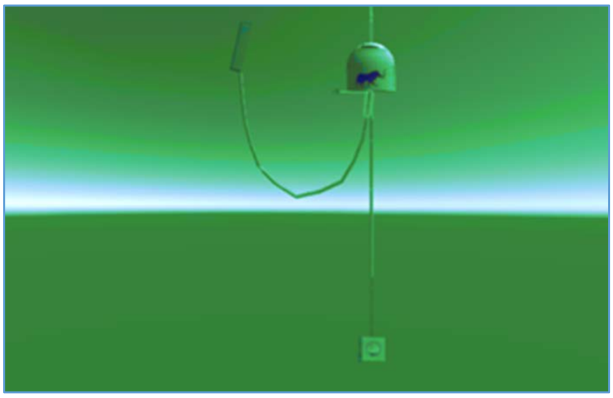

Figure 3 Simulation of Cable Dynamics for an Underwater System

Obviously it is critical to consider weather and boundary conditions (e.g. wind on surface infrastructures, current, waves) in order to reproduce sea keeping and motion. From a dynamic point of view this system is not very complex for underwater floating element (e.g. the diving bell) while the crucial aspect is the capability to mdoel the interactions on cable itself and its behavior. The sea model is based on Jonswap / Bertschneider functions reproducing the wave spectrum (Zini 1999). In this way it becomes possible to obtain different wave spectra corresponding to different values of the significant wave height, the peak wave period and the direction of the wave itself.

In this case it is necessary to define functions that returns the history of the six DOF movements (Degree of Freedom), speeds and accelerations of the marine element. It is convenient to leave up to the designer the possibility to interactively change the parameters of the simulator defining the wave profile (i.e. spectrum or frequency, wave height, direction angle) and characteristics of the marine vessel (e.g. course and speed); indeed, by this approach during design it is immediately evident the impact of the waves on support vessels as well as on the underwater equipment and its operations. From this point of view, the first step is to develop a 3D simulation of a marine operations and the 3D geometries of the vessels and the equipment of interest. In the proposed case, the 3D model of the ship can be obtained from the CAD system database where available. The Models of Cable and Floating are created by defining their volumes and weights; for instance, for the diving bell in this case the geometry is elementary consisting of a hemisphere superimposed to a cylinder. Bell buoyancy, like all the other models, is regulated by a physical engine (i.e. Unity Physx, Bullet) where the forces due to weight and Archimedes's principle are modeled as follows:

$$\boldsymbol{F_c(t)} = \begin{cases} \boldsymbol{h_c(t) \geq 0} & \boldsymbol{F_c(t) = -g \cdot m_c} \\ \boldsymbol{h_c(t)} < 0 & \boldsymbol{F_c(t) = g \cdot \left(V_c \rho_{H_2O} - m_c\right)} \end{cases}$$

For simplicity, a constant volume has been assumed, in reality when one is on the surface of the water one should use only the portion of immersed volume. Also the mass for simplicity has been assumed constant even if it varies according to the diversities inside.

The diver has been modeled in a simple way with a mass and volume similar to those of a human being. In the model it is connected via an umbilical cable to the bell while its flotation is regulated together with the remaining models by a physical engine where the weight and thrust of Archimedes are modeled as follows:

$$\boldsymbol{F_d(t)} = \begin{cases} \boldsymbol{h_d(t) \geq 0} & \boldsymbol{F_d(t) = -g \cdot m_d} \\ \boldsymbol{h_d(t)} < 0 & \boldsymbol{F_d(t) = g \cdot \left(V_d \rho_{H_2O} - m_d\right)} \end{cases}$$

It is important to underline that, being connected to the umbilical, which has its own mass and it is regulated by Archimedes's Principle, the diver is affected by several forces. Here too it should be mentioned that, similar to the model of the bell, volume and mass for simplicity are supposed to be constant.

The model of the ballast has been recreated defining its volume and weight in accordance with a real case where it is a block of concrete. This weight is connected, by a cable to the bell, with the difference that in this case it was assumed that this is just steel cable, while previous ones include also umbilical and power transmission lines.

The floatation of the ballast is regulated like all the remaining models through the simulation by physical engine, where the weight and Archimedes's Principle are summarized by following relationships:

$$\boldsymbol{F_z(t)} = \begin{cases} \boldsymbol{h_z(t) \geq 0} & \boldsymbol{F_z(t) = -g \cdot m_z} \\ \boldsymbol{h_z(t)} < 0 & \boldsymbol{F_z(t) = g \cdot \left(V_z \rho_{H_2O} - m_z\right)} \end{cases}$$

Similarly to the other models, the volume and mass of the ballast for simplicity has been assumed to be constant.

The ship present in the scenario has been recreated through an elementary geometry composed of several blocks scaled and interconnected between each other. The ship is connected by the cable to the bell that can be positioned at various depths (e.g. 200 meters below sea level). Its buoyancy is regulated differently than the other objects in order to have a fluctuation that considers the phenomenon of sea keeping linked to the wave motion without requiring too much intense integration of differential equations; so the model used in this case is structured as follows:

The mass assigned to the ship is subdivided in different hull points (e.g. corresponding to 4 elements at 3 different levels on the hull) and geometrically balanced so, in every moment, the simulator is able to consider how much each block is submerged and/or over sea level.

Depending on the position relative to the sea, a vertical force is applied to each single point defined as follows:

$$\boldsymbol{F_g(t)} = \begin{cases} \boldsymbol{h_{rel}(t) > l_s} & \boldsymbol{F_g(t) = -F_{down}} \\ \boldsymbol{l_s \geq h_{rel}(t)} > 0 & \boldsymbol{F_g(t)} = -\left|\boldsymbol{F_{down}} \cdot \dfrac{\boldsymbol{h_{rel}(t)}}{\boldsymbol{l_s}}\right| \\ \boldsymbol{0 \geq h_{rel}(t) > -l_s} & \boldsymbol{F_g(t)} = +\left|\boldsymbol{F_{up}} \cdot \dfrac{\boldsymbol{h_{rel}(t)}}{\boldsymbol{l_i}}\right| \\ \boldsymbol{h_{rel}(t) \leq -l_s} & \boldsymbol{F_g(t) = +F_{up}} \end{cases}$$

$h_{rel}(t) = z(t)_{point} - z_{mare}(x, y, t)$ relative height between the hull point and the sea level in the coordinates x, y and at time t

$F_{down} = \frac{g \cdot m_b}{n^{\circ}_{punti}}$ force weight of the vessel divided by the number of points taken into consideration (in this case 12)

$F_{up} = \frac{g \cdot m_b}{n^{\circ}_{pgal}}$ force weight of the vessel divided by the minimum number of points that touch the water necessary for the ship to float (e.g. 8 over 12).

For instance in Figure 3, it is proposed a configuration of an Underwater System devoted to operate down to 300 m including a ballast, two divers interconnected by umbilical to a diving bell, the diving bell itself and the support vessel on surface (not visible on the figure, but interacting dynamically with others); all these elements are interconnected by different kind of cables with specific characteristics and reacting dynamically along simulation; this simulation run both in real and fast time and it was effectively implemented by Simulation Team using C# and Unity 3D while interoperability is based on a specific module in Java created at Genoa University.

CONCLUSIONS

The current paper proposes a quick overview on different MS2G approaches to support engineering of industrial plants and facilities; these models effectively reproduce complex systems and are virtual prototypes capable of interaction with users as well as with real hardware to test and evaluate design solutions.

Indeed, it is also possible to immerse the engineers within a CAVE to experience “from inside” the situations and to review all the technical reports on output and controlled variables; this supports engineering and allows to tune the system parameters. It is evident that these simulators should be intuitive and interoperable, but also to be completed in reasonable time to be ready respect the main plant engineering project that drive the corresponding initiatives; due to these reasons it is necessary to adopt Lean Simulation solutions; this is not a limitation, because, often, these *quick and dirty models* could be easily extended in terms of fidelity thanks to potential new improvements of computational efficiency and so they could be the starting point for further upgrades and developments. Currently the authors are extending these examples by developing new improved models for similar applications and to support different use of the simulators.

REFERENCES

Ablow C.M., Schechter S. (1983) Numerical simulation of undersea cable dynamics, ocean engineering,10(6),443-457.

Amico V., Bruzzone A.G., Guha R. (2000) "Critical Issues in Simulation", Proceedings of Summer Computer Simulation Conference, Vancouver, July

Balci O. (2004), “Quality Assessment, Verification, and Validation of Modeling and Simulation Applications,” In Proceedings of the 2004 Winter Simulation Conference (Washington, DC, Dec. 5-8). IEEE, Piscataway, NJ

Baruwa, O. T., & Piera, M. A. (2016). A coloured Petri net-based hybrid heuristic search approach to simultaneous scheduling of machines and automated guided vehicles. Int.Journal of Production Research, 54(16), 4773-4792.

Braghirolli, L. F., Ribeiro, J. L. D., Weise, A. D., & Pizzolato, M. (2016). Benefits of educational games as an introductory activity in industrial engineering education. Computers in Human Behavior, 58, 315-324.

Bruzzone A.G., (2017) "Simulation, IA & Mixed Reality within Industry 4.0", Invited Speech at the 21st International Conference on Knowledge - Based and Intelligent Information & Engineering Systems, Marseille, France

Bruzzone A.G., Massei M., Reverberi A., Cardelli M., Di Matteo R., Maglione, G. (2017a) Simulation of Power Plant environmental impacts within the Extended Marine Framework. Chemical Engineering Transactions, 61

Bruzzone, A.G., Agresta, M., Sinelshchikov, K. (2017b). Hyperbaric plant simulation for industrial applications. In Proceedings of IWISH 2017, (p. 80-86). Barcelona, Spain

Bruzzone A.G., Massei M., Maglione G.L., Sinelshchikov K., Di Matteo R. (2017c) “A strategic serious game addressing system of systems engineering”, Proc.of MAS, Barcelona, September

Bruzzone A.G., Massei M., Agresta M., di Matteo R., Sinelshchikov K., Longo F., Nicoletti L., di Donato L., Tommasini L., Console C., Ferraro A., Pirozzi M., Puri D., Vita L., Cassara F., Mennuti C., Augugliaro G., Delle Site C., Di Palo F., Bragatto P. (2017d) "Autonomous Systems & Safety Issues: the Roadmap to enable New Advances in Industrial Application". Proc. of EMSS, Barcelona, September

Bruzzone A.G., Longo F., Nicoletti L., Vetrano M., Bruno L., Chiurco A., Fusto Caterina, Vignali G. (2016) "Augmented Reality and Mobile technologies for Maintenance, Security and Operations in Industrial Facilities", Proc. of EMSS, Larnaca, Cyprus

Bruzzone A.G., Cirillo L., Longo F., Nicoletti L. (2015) “Multi-disciplinary approach to disasters management in industrial plants”, Proc.of the Conference on Summer Computer Simulation, Chicago, IL, USA, July, pp. 1-9

Bruzzone A.G., Massei M., Agresta M., Poggi S., Camponeschi F., Camponeschi M. (2014) "Addressing strategic challenges on mega cities through MS2G", Proceedings of MAS2014, Bordeaux, France, September.

Bruzzone, A. G., & Figini, F. (2004). Modelling human behaviour in chemical facilities and oil platforms. Simulation Series, 36(4), 538.

Bruzzone, A., & Saetta, S. (2002). LESNEX: Lean simulation network of excellence. In HMS2002 and MAS2002 International workshops, (Bergeggi, SV, Italy, October 3-5)

Bruzzone A.G., Giribone P., Mosca R. (1996) "Simulation of Hazardous Material Fallout for Emergency Management During Accidents", Simulation, vol. 66, no.6, June, 343-355.

Buckham B., Driscoll F. R., Nahon M. (2004). Development of a finite element cable model for use in low-tension dynamics simulation. Journal of Applied Mechanics, 71(4), 476-485.

Fowler, J. W., & Rose, O. (2004). Grand challenges in modeling and simulation of complex manufacturing systems. Simulation, 80(9), 469-476.

Longo F., Chiurco A., Musmanno R., Nicoletti L., 2015. Operative and procedural cooperative training in marine ports. Journal of Computational Science, vol. 10, pp. 97-107.

Longo F., Nicoletti L., Padovano A., 2017. Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. Computers and Industrial Engineering, vol. 113, pp. 144-159.

Merkuryev, Y., Merkuryeva, G., Piera, M. A., & Guasch, A. (2009). Simulation-based case studies in logistics. Warehouse Order Picking Process.

Reverberi, A. P., Klemeš, J. J., Varbanov, P. S., & Fabiano, B. (2016). A review on hydrogen production from hydrogen sulphide by chemical and photochemical methods. Journal of cleaner production, 136, 72-80

Shukla, A., & Karki, H. (2016). Application of robotics in offshore oil and gas industry—A review Part II. Robotics and Autonomous Systems, 75, 508-524.

Smith, J. S. (2003). Survey on the use of simulation for manufacturing system design and operation. Journal of manufacturing systems, 22(2), 157-171

Tiacci, L., Saetta, S., & Martini, A. (2003). A Methodology to Reduce Data Collection in Lean Simulation Modelling for the Assembly Line Balancing Problem. In Summer Computer Simulation Conference (pp. 841-848). Society for Computer Simulation International; 1998.

Williams, E. J., & Narayanaswamy, R. (1997, December). Application of simulation to scheduling, sequencing, and material handling. In Proceedings of the 29th conference on Winter simulation (pp. 861-865). IEEE Computer Society.

Witherden, F. D., & Jameson, A. (2017). Future Directions in Computational Fluid Dynamics. In 23rd AIAA Computational Fluid Dynamics Conference (p. 3791).

Zini A., Rocca, A., Raffa M. "Virtual Prototyping in Ship Design". The International Workshop on Harbour, Maritime & Industrial Logistics Modelling and Simulation. Sept 16-18, 1999 Genoa – Italy. Pages 147 – 152.

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