THE 18TH INTERNATIONAL CONFERENCE ON HARBOR, MARITIME & MULTIMODAL LOGISTICS MODELLING AND SIMULATION

SEPTEMBER 26 - 28 2016

CYPRUS

HMS
2016

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PRINTED IN RENDE (CS), ITALY, SEPTEMBER 2016

ISBN 978-88-97999-69-0 (Paperback)
ISBN 978-88-97999-77-5 (PDF)

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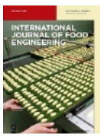

De Gruyter
International Journal of Food Engineering

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WELCOME TO HMS 2016!

Welcome to the 18th International Conference on Harbor, Maritime & Multimodal Logistics Modeling and Simulation (HMS 2016), that is a great opportunity for worldwide scientists and experts to share experiences, recent research efforts, studies and applications related to maritime environments, logistics and supply chain management issues.

Within this framework the papers selected for publication in the HMS 2016 proceedings cover different areas and they have been organized in multiple sessions such as Simulation Airports Design and Management, Modeling & Simulation in Logistics, Intermodal Transportation Systems and Services. Furthermore some of the articles have been scheduled as part of joint sessions (with the other I3M conferences) because they focus on specific applications including Logistics in Defense and Homeland Security as well as Human Behavior Modeling.

Therefore, the HMS 2016 program clearly shows the inner nature of this conference and its ability to collect scientific contributions that are strictly related each other; this is also strongly reflected by the conference sessions where authors have the possibility to join an environment where researchers and scientists present and discuss similar topics and problems (this automatically provides the opportunity to create new collaborations, synergies and joint research projects).

The considerations provided above are not the only keys of the HMS success; the most important part of the work – along the years – has been done by authors (with their scientific contributions) that continuously recognize the importance of the HMS conference, by the International Program Committee and by the work done by reviewers to assure the high scientific quality of the selected papers.

We are also proud to host HMS 2016 in the fantastic setting of Larnaca (Cyprus) and therefore we take this opportunity to thank the Local Organization Committee (Prof. Loucas S. Louca from University of Cyprus) and we wish all the conference attendees a pleasant stay and a fruitful conference.

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ACKNOWLEDGEMENTS

The HMS 2016 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 2016 IPC would like to thank all the authors as well as the reviewers for their invaluable work.
A special thank goes to Prof. Loucas S. Louca from University of Cyprus as local organizer and to all the organizations, institutions and societies that have supported and technically sponsored the event.

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Index

SIMULATION RESEARCH ON SEAPORT FAIRWAY CAPACITY AND ITS PROMOTION MEASURE: A CASE STUDY OF JINGTANG PORT AREA IN CHINA

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ABSTRACT
This paper aims at solving the problem of how to improve the fairway through capacity for Jingtang port area in China. The problem is figured out by building a simulation model of the ships' navigation operation system. First of all, the model is constructed based on the Rockwell Arena software to simulate how the port is operated with the increasing number of arrival ships. Then, the total annual tonnages of ships when the fairway reaches the through capacity can be obtained. After that, we use a method of changing navigation rules (from one-way to two-way) for the ships with a tonnage of not more than 50,000 tons to see whether the fairway through capacity can be improved. Finally, the results show that the fairway through capacity can be promoted by changing the navigation rules by 13.7%, which provides a theoretical foundation for fairway construction and management of Jingtang port area.

Keywords: Jingtang port area, fairway through capacity, navigation rules, simulation

1. INTRODUCTION
Jingtang port area is one of the important regional port areas in coastal areas in China. The overall plan of Jingtang port area is shown in Figure 1 (Website of coal in Qinhuangdao 2009). As the development of throughput capacity of the port area together with the continuous increase of scale of berths, there will be ore bulk carriers with a tonnage of 250,000 tons arriving the port area. However, the exiting 200,000 tons fairway fails to meet the demand of these ships. Therefore, Jingtang port area is currently planning on expanding the fairway to 250,000 tons. Then, the operators of the port area want to know how much the through capacity of the 250,000 tons fairway is and how to improve the fairway through capacity, which are the problems that need to be solved in this paper.

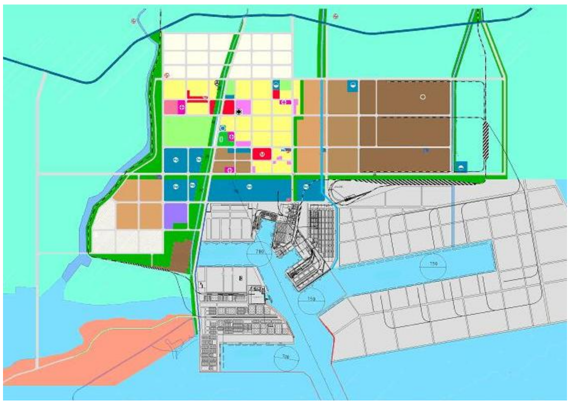

Figure 1: Overall Plan of Jingtang Port Area

As the vigorous development of the shipping industry together with the continuous increase of shipping traffic flow, the fairway is becoming the restriction of port development. Therefore, it has generated considerable research interests on fairway through capacity these years. Early research on the fairway through capacity mostly focused on fairway through capacity of the inland waterway. Researchers devoted special attentions to propose empirical formulas, such as the Western Germany formula, Yangtze Estuary Deepwater Channel formula (Changjiang Waterway Bureau 2005a) and Chuan River Channel formula (Changjiang Waterway Bureau 2005b).
Compared with the inland waterway capacity, research on the seaport fairway through capacity started relatively late. However, the methods has become rather mature with the efforts by researchers. Due to the complexity of the seaport operation system, the simulation method has been generally applied in port design and management. Angeloudis et al. (2011) provided an overview of the domain of container terminal simulation. Lin et al. (2013) addressed an investment planning problem for a container terminal in Humen Port using simulation with Arena software. Longo et al. (2013) developed a simulation model to recreate the complexity of a medium-sized

Mediterranean seaport and analysed the performance evolution of such system with particular reference to the ship turnaround time. Peng et al. (2016) modeled the energy replacement problem with the purpose of minimizing the carbon emissions by combining an allocation resource mathematical model and a simulation model of the whole transportation network together. Sun et al. (2013) proposed an integrated simulation framework to facilitate the design and evaluation of mega container terminal configurations with integrated multiple berths and yards.

Further more, the simulation method is also widely used to obtain the seaport fairway through capacity. Guo et al. (2010) and Wang et al. (2015) gave the definition of seaport fairway through capacity and analysed the influence of port service level or safety level on fairway through capacity, respectively. Shang (2005) constructed a simulation model for Huanghua Port and studied the relationship between fairway through capacity and port capacity. Song et al. (2010) used simulation methods to find out the relationship between shipping navigation duration and fairway through capacity of single-channel. Tang et al. (2014a) chose the annual average turn around time, average waiting time, and average waiting time/average service time ratio as the performance measures of port service to explore the feasibility of building a ships-passing anchorage and to determine its dimensions. Tang et al. (2014b) discussed the optimal channel dimensions problem with limited dredging budget constraints in an integrated way. Zhang (2009) and Wang et al. (2012) studied the influence of ship traffic rules in bulk cargo port or Y-type fairway intersection water on port service level, respectively.

In conclusion, the above literatures involve various aspects of the research on fairway through capacity, which provide a strong foundation for further studies. However, most of them only focus on constructing universal models instead of modeling for practical engineering projects. Besides, few consider various types of arrival ships combining with the rule of two-way navigation for small ships. There are only a few literatures about the promotion measures of the fairway through capacity, however they are not suitable for being used to solve the proposed problem in this paper directly.

Combining with the actual operation status of Jingtang port area, this paper simulates ships' navigation operation system, obtains the fairway through capacity of the 250,000 tons fairway as measured by port service level, and tries to see whether changing navigation rules can improve the fairway through capacity. The remainder of this paper is organized as follows. The problem is presented in Section 2. The simulation model is given in detail in Section 3, followed by verification and validation in Section 4. The simulation experiments and results analysis are listed in Section 5. Finally, the main conclusions and future works are drawn in Section 6.

2. PROBLEM DESCRIPTION

The 250,000 tons ore berths are of vital importance in Jingtang port area. In order to satisfy the requirements of the big ships berthing at the 250,000 tons berths, the port operators decide to expand the exiting 200,000 tons fairway to 250,000 tons. Then, there comes two issues: one is what the fairway through capacity of the 250,000 tons fairway is based on the current berth state and other information, such as future ship traffic, natural conditions, allocation and scheduling rules of ships, navigation rules of ships and performance indicators, which is described in Section 2.1 to 2.5 separately; the other is how to improve the fairway through capacity.

2.1. Ships

There are totally six types of arrival ships: ore bulk carriers, coal bulk carriers, chemical carriers, LPG carriers, general cargo ships and container ships. The tonnage of the ships is from 7,000 to 250,000 tons. The detailed description of the type and tonnage of the arrival ships is shown in Table 1.

Table 1: Type and Tonnage of Arrival Ships

Type	Tonnage (Tons)
Ore bulk carriers	250,000
Ore bulk carriers	200,000
Ore bulk carriers	70,000
Ore bulk carriers	50,000
Ore bulk carriers	35,000
Coal bulk carriers	200,000
Coal bulk carriers	100,000
Coal bulk carriers	70,000
Coal bulk carriers	50,000
Coal bulk carriers	35,000
Chemical carriers	40,000
Chemical carriers	7,000
LNG carriers	30,000
General cargo ships	30,000
General cargo ships	20,000
Container ships	100,000
Container ships	70,000
Container ships	30,000

For container ships, the distribution of inter-arrival time is taken as constant when they are liner ships. However, the arrival pattern of other types of ships are quite random, we analyse one month's actual data of ships' arrival time intervals in Jingtang port area, as shown in Figure 2, and find out that the inter-arrival time of these ships follows negative exponential distributions. Thus we take the arrival pattern of these ships as a Poisson process.

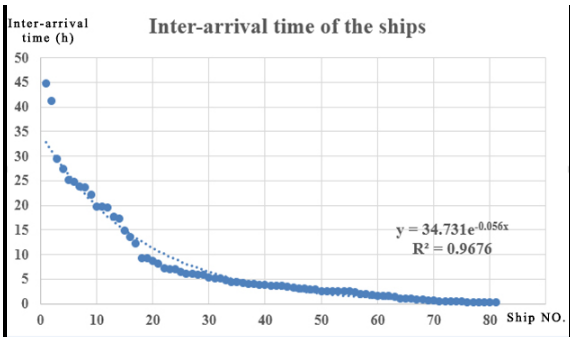

Figure 2: Inter-arrival Time of the Ships

2.2. Natural conditions

Considering the influences of air temperature, rainfall, winds, fogs, storms and tidal conditions on ships' navigation comprehensively, the number of navigable days is 350 days per year.

The tide of waters around Jingtang port area belongs to irregular semidiurnal tides. The tidal data is described as follows: the mean high tide level is 1.69 meters, the mean low tide level is 0.82 meters, the mean sea level is 1.27 meters and the mean range of tides is 0.88 meters.

2.3. Allocation and scheduling rules of ships

Ships can be served at idle berths with the same type and tonnage. When ships are allocated, the priority of container ships is higher than the other types of ships, and big ships are prior to small ships as well. Other allocation and scheduling rules obey first-come-first-service basis.

2.4. Navigation rules of ships

The rules of one-way navigation and two-way navigation for the ships with a tonnage of not more than 50,000 tons are considered in this paper. Under the one-way navigation rule, all the ships in opposite directions are not allowed sailing in the fairway at the same time. While under the two-way navigation rule, for the ships with a tonnage of not more than 50,000 tons, two ships with a tonnage of not more than 50,000 tons in opposite directions can sail in the fairway simultaneously.

2.5. Performance indicators

The fairway through capacity for a given fairway of a certain seaport under normal operation status is defined as the total annual tonnage of ships going through the fairway at a specified port service level (Guo et al. 2010). In this paper, we choose *AWT*/*AST* as the performance indicator (United Nations, 1985). *AWT* refers to ships' average waiting time including the time waiting for both fairway and berth, and *AST* is the average service time of ships at berth. The smaller the value of *AWT*/*AST* is, the higher the port service level is. When *AWT*/*AST* reaches 0.5 for the first time, the total annual tonnage of ships going through the fairway at the time is taken as the fairway through capacity.

2.6. Simulation scenarios

The simulation scenarios include the arrival process, service process and departure process of ships in the port area. The simulation scenario under the rule of two-way navigation for the ships with a tonnage of not more than 50,000 tons can be depicted through Figure 3.

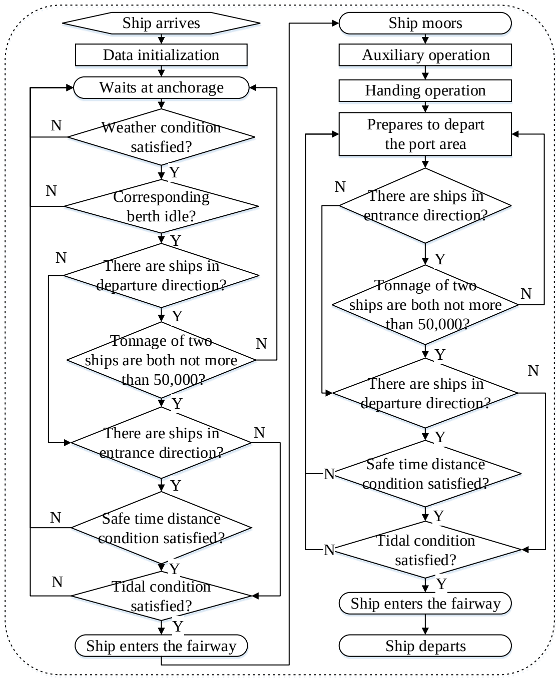

Figure 3: Simulation Scenarios of the Port Operation System under the Rule of Two-way Navigation for the Ships with a Tonnage of not more than 50,000 Tons

At first, a ship is created and enters the system. Then, data initialization should be done to make every ship unique. For example, each ship should be given the ship type, tonnage, arrival time, priority and so on. After initialization, the ship will wait for idle berths at the anchorage until the weather condition is satisfied. Next, after berth allocation, it should be checked whether the tidal condition, navigation condition and safe time distance condition are satisfied. Only if all the three conditions are satisfied, the ship is allowed to move into the fairway. After mooring in the arranged berth, the ship starts auxiliary operation and handing operation. Finally, after handing operation, it moves into the fairway and departs the port area when the above three conditions are satisfied as well.

The difference between the simulation scenario under the rule of one-way navigation and two-way navigation for the ships with a tonnage of not more than 50,000 tons is how to check the navigation conditions. Under the rule of one-way navigation, only if there has been none ship in opposite direction, the navigation condition can be satisfied.

3. SIMULATION MODEL

This paper constructs a complicated and valuable simulation model to obtain the fairway through capacity for Jingtang port area, which is based on the following assumptions:

1. The port area is under normal operation status and the resources are taken full use of.
2. The number of anchorage berths in the port area are enough, which can well provide service for ships waiting for the fairway and berths.
3. Ships maintain good technical conditions and keep a safe distance between each other. The average speed of ships is 7 knots and running is noninterference.

The whole simulation model is composed of four systems: Ships waiting for berths at anchorage system, ships entering the port area system, ships handing operation system and ships departing the port area system. We use the Arena software to implement the modeling work.

3.1. Ships waiting for berth at anchorage system

This system begins with ships arriving the port area and ends up with ships being allocated an idle berth. All these processes are completed at the anchorage. The system is shown in Figure 4.

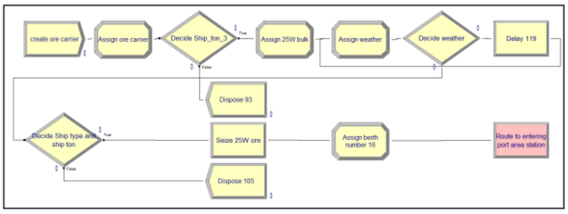

Figure 4: Ships Waiting for Berth at Anchorage System

3.2. Ships entering the port area system

This system includes the processes of deciding whether the tidal condition, navigation condition and safe time distance condition are satisfied and ships entering the fairway. The system is shown in Figure 5.

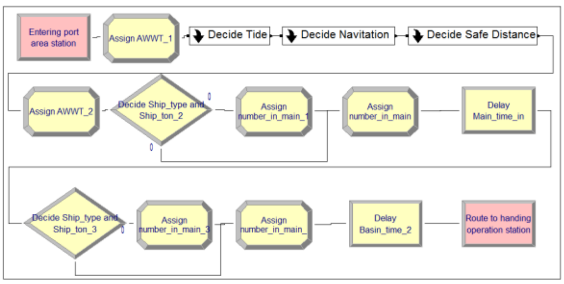

Figure 5: Ships Entering the Port Area System

3.3. Ships handing operation system

This system begins with ships mooring at the berth and ends up with ships finishing handing operation. Ships handing operation system is shown in Figure 6.

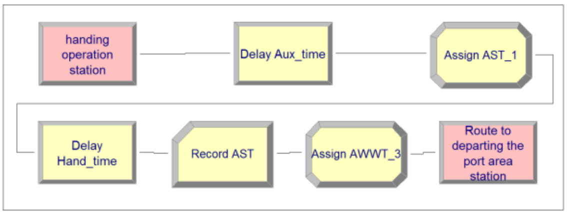

Figure 6: Ships Handing Operation System

3.4. Ships departing the port area system

This system is quite similar to the ships entering the port area system, so it won't be repeated here. Figure 7 shows the ships departing the port area system.

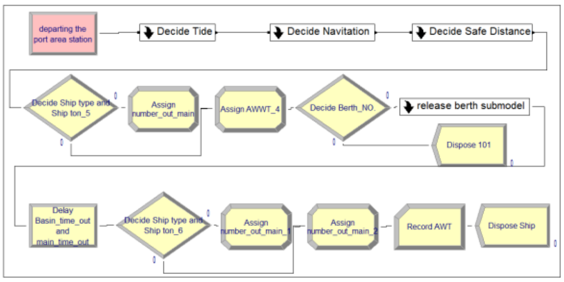

Figure 7: Ships Departing the Port Area System

4. VERIFICATION AND VALIDATION

Our model has to be checked to see if it is working in the way it is planned. For example, we take good advantages of the tracing approach, which is quite convenient and effective in Arena software. Besides, animation is also an effective way to verify our simulation model logically. Finally, we output the important moments of the ships in the whole life cycle, so that we can verify whether the model is correct.

For validation purposes, we have run some simulation experiments based on real data from the operators of a container port area in Dalian. The number of the berths of the first-stage project in the port area are shown in Table 2.

Table 2: The number of the Berths of the First-stage Project in the Port Area

Tonnages of the Berths (Tons)	Number of the Berths
10000	2
25000	1
30000	2
50000	2

The total number of ships arriving the port area is counted, which reaches 223. The inter-arrival time of these ships is proved to follow negative exponential distributions.

Once the arrival distribution and actual operation status are input into the simulation model, we run it and obtained the results listed in Table 3. Compared with the real statistics, the maximum relative error is below 10%, which indicates that the model is reliable and can well reflect the actual operation status of the seaport system.

Table 3: Simulation Results of Model Validation

Item	Number of Arrival Ships	*AWT* (h)	*AST* (h)	Average Berth Occupancy Rate (%)
Simulation Results	225	2.73	9.13	49.34
Real Statistics	223	2.99	10.04	51.85
Relative Errors (%)	0.90	8.70	9.06	5.09

5. SIMULATION EXPERIMENTS AND RESULTS ANALYSIS

Since the model has been constructed and validated, it can be used to obtain the fairway through capacity of the fairway and analyse the systems under different navigation rules by designing the simulation experiments. The total annual number of arrival ships increases from 4,962 to 6,947.

We design two simulation experiments: one is under the rule of one-way navigation, and the other is under the rule of two-way navigation for the ships with a tonnage of not more than 50,000 tons. Each experiment runs 50 replications. The replication length is set to be 365 days. The simulation results under the rules of one-way navigation and two-way navigation for the ships with a tonnage of not more than 50,000 tons are shown in Table 4 and Table 5, respectively.

Table 4: Simulation Results under the Rule of One-way Navigation

Number of Arrival Ships	4962	5160	5359	5557	5756	5954
AWT	5.29	5.71	6.22	6.40	6.81	7.33
AST	13.6	13.5	13.5	13.6	13.5	13.5
AWT /AST	0.39	0.42	0.46	0.47	0.50	0.54

Table 5: Simulation Results under the Rule of Two-way Navigation for the Ships with a Tonnage of not more than 50,000 Tons

Number of Arrival Ships	5954	6153	6351	6550	6748	6947
AWT	5.62	6.00	6.43	6.77	7.33	7.63
AST	13.5	13.5	13.6	13.6	13.6	13.5
AWT /AST	0.42	0.44	0.47	0.50	0.54	0.57

From the tables, we can see that *AWT/AST* relies on linear growth basically with the increment of the number of arrival ships. Under the rule of one-way navigation, *AWT/AST* reaches 0.5 when the number of arrival ships is 5756, and the corresponding berth occupancy rate is about 29%. While under the rule of two-way navigation for the ships with a tonnage of not more than 50,000 tons, *AWT/AST* reaches 0.5 when the number of arrival ships is 6550, and the corresponding berth occupancy rate is about 33%.

The variation of total annual tonnage of ships along with *AWT/AST* under two navigation rules is shown in Figure 8. The increases of the total annual tonnage of ships under the rule of two-way navigation compared with the one under one-way navigation are shown in Table 6.

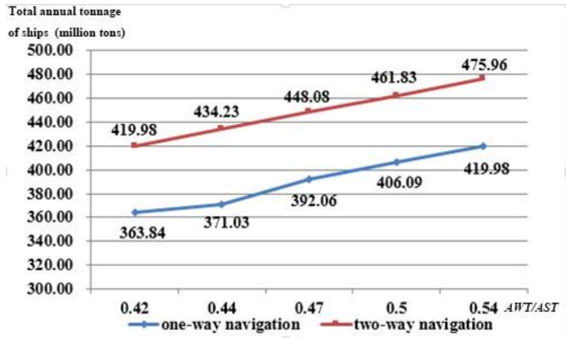

Figure 8: Variation of Total Annual Tonnage of Ships along with *AWT/AST*

Table 6: The Increases of the Total Annual Tonnage of Ships under Different Navigation Rules

AWT /AST	0.42	0.44	0.47	0.50	0.54
Tonnage under One-way Navigation (Million tons)	363.8	371.0	392.1	406.1	420.0
Tonnage under Two-way Navigation (Million tons)	420.0	434.2	448.1	461.8	476.0
Increases (%)	15.4	17.0	14.3	13.7	13.3

It can be seen from Figure 8 that under the rule of one-way navigation, the total annual tonnage of ships is 406.09 million tons when *AWT/AST* reaches 0.5. While under the rule of two-way navigation for the ships with a tonnage of not more than 50,000 tons, the value is 461.83 million tons when *AWT/AST* reaches 0.5. In other words, the fairway through capacity of the 250,000 tons fairway in Jingtang port area is 406.09 million tons annually and 461.83 million tons annually under the rules of one-way navigation and two-way navigation for the ships with a tonnage of not more than 50,000 tons, respectively. The rule of two-way navigation for the ships with a tonnage of not more than

50,000 tons promotes fairway through capacity by 13.7% compared with the rule of one-way navigation.

Besides, it can be seen from Table 6 that the total annual tonnage under two-way navigation for the ships with a tonnage of not more than 50,000 tons are greater than the one under one-way navigation when *AWT/AST* reaches different values. The increases are from 13% to 17%, which are relatively stable.

6. CONCLUSIONS AND FUTURE WORKS

This paper focuses on solving the problem of how to improve the fairway through capacity for Jingtang port area in China and aims at determining the fairway through capacity of the fairway under different navigation rules. To better simulate and analyse the real system, we consider various types of ships, real natural conditions, flexible allocation and scheduling rules and complicated navigation rules. A simulation model is then proposed based on Arena software. Real data of a container port area in Dalian is used to validate the model.

In the paper, we undertake two simulation experiments to see whether the fairway through capacity can be improved. One is under the rule of one-way navigation, and the other is under the rule of two-way navigation for the ships with a tonnage of not more than 50,000 tons. The simulation results show that:

1. *AWT/AST* relies on linear growth with the increment of the number of arrival ships.
2. Under the rule of one-way navigation, the fairway through capacity for Jingtang port area is 406.09 million tons annually.
3. Under the rule of two-way navigation for the ships with a tonnage of not more than 50,000 tons, the fairway through capacity for Jingtang port area is 461.83 million tons annually.
4. It can promote fairway through capacity by 13.7% under the rule of two-way navigation for the ships with a tonnage of not more than 50,000 tons compared with one-way navigation.

The results obtained in this paper can provide a theoretical foundation for fairway construction and management. The proposed methodology can serve as a pattern to solve similar problems.

However, our work still has some limits. If ships overtaking is considered, the speed of ships cannot be set as constant, which may need to build ships-passing anchorages to solve the problem.

ACKNOWLEDGMENTS

The authors would like to acknowledge National Natural Science Foundation of China (No. 51279026 and No. 51309049) for supporting this research.

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Discrete Event System Conceptual Modelling for a Logging Company

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ABSTRACT

As conceptual modelling may be defined as a process of representing a real world model that could change anywhere along the simulation life-cycle study, it is therefore necessary for the conceptual model to be accurate in order for the simulation results not to be misleading. This is important especially because modelling and simulation can be exploited in decision making as any node and link of an organization can be represented by the simulation processes. Hence, an error in a conceptual model would lead to inaccurate simulation results. The fact that, many research papers have not emphasized much on conceptual model has actually motivated the authors to conduct a research in this area. This article therefore portrays how to develop a conceptual model within a discrete event system by exploiting a logging company as an example.

Keywords: discrete event system, conceptual model, framework for conceptual modelling, DEVS

1. INTRODUCTION

When exploiting modelling and simulation especially in decision making, it is vital to have an accurate conceptual model representing the real world model. However, it is not necessary to represent all the components of the real world as this would make the model cumbersome. It is therefore advisable to include only the components that are relevant to the study. Taking the logging companies for example, many of them face uncertainties due to risks that can affect their harvesting and operating processes which might lead to lower productivity and profitability. In order to avoid these uncertainties, it is therefore vital for these companies to be resilient. Once the problem has been identified, for example, *'how resilient the company is to disruptions'*, a conceptual model is then developed by utilizing the relevant components of the real world system. The necessity of obtaining an accurate conceptual model or abstract model of the real world system in order for the simulation results not to be misleading is of great importance. This is because it is transformed into a simulation model where various scenarios can be tested for accurate decision making that would yield to a resilient strategy. The **objectives of the research** is to develop a conceptual model of a discrete event system, using a logging company as an example, in order to obtain accurate simulation results that would yield to better decision making to facilitate a resilient strategy. The **research methodology** is obtained from scientific articles, journals and other relevant publications as well as the authors' professional knowledge and experiences in the field of modelling and simulation and management, which are then utilized in developing a conceptual model for a logging company. The article is divided into five sections. The first section elaborates on discrete event systems and their components with respect to a logging company. Conceptual modelling and its requirements are then discussed in the second section. The third section then highlights the framework for conceptual modelling. In order to understand the DEVS model, DEVS is briefly portrayed in the forth section followed by the DEVS model in the last section.

2. DISCRETE EVENT SYSTEMS

In discrete event systems, the state variable(s) changes at a discrete point in time (Banks, Carson, Nelson and Nicol 2005). Taking figure 1 into consideration, the logging company is an example of a discrete event system in which the state variable, for instance the volume of harvesting trees in the forest, changes only when the trees are cut down into logs and or when the logs are forwarded to the roadside warehouse. Hence, the volume of harvesting trees changes only at a discrete point in time. The necessary components of the logging company considered in this study are given below:

<u>Some Components of the Logging Company:</u>

System
- Logging company (L)

Entities
- Forest, warehouse

Attributes
- Volume of trees, quality of trees, capacity

Activities
- Harvesting, Forwarding, withdrawing

Events
- Arrival of customers' orders; starting and ending time of snowfall, rainfall, road closure

State Variables
- Volume of harvesting trees, forwarding and withdrawing logs

The system addressed is a logging company '*L*' with the forest and warehouse as its entities as they are objects of interests of the system. As the attributes belong to the entities, the forests and warehouses have attributes of volume of trees and capacity respectively. The activities which represent a time period of specific length are mainly harvesting (which is cutting down the trees into logs) and forwarding the logs to the roadside warehouse. Withdrawing the logs from the roadside to be distributed to the customers is another activity with respect to the warehouse entity. The events include arrival of customers' orders, the starting and ending time of heavy snowfall and rainfall as well as road closure which occur instantaneously and might change the state of the system. The state variables are the volume of 'harvesting trees', volume of 'forwarding logs' to the warehouse, and withdrawing the logs from the warehouse to be distributed to various customers, as they can describe the system at anytime relative to the objective of the study. After analysing the component of the system, conceptual modelling can then be developed as discussed in the next chapter.

3. CONCEPTUAL MODELLING

According to Robinson (2008a), 'conceptual modelling is a non-software specific description of the computer simulation model describing the objectives, inputs, outputs, content, assumptions and simplifications of the model'. Simplifying the definition, conceptual modelling is a process of abstracting a real world model which could change anywhere along the simulation life-cycle study. Moreover, Becker and Parker (2011), highlighted that the hypothetical complete description of the original system is formed by the conceptual model. Hence, when forming the conceptual model, having adequate knowledge about the objectives, inputs and outputs of the real world model is important. It is also vital to consider various assumptions and simplifications in decision making related to the content of the model. Assumptions and simplifications are also quite distinctive concept in conceptual modelling (Robinson 2008a), as they are made due to uncertainties and simplification respectively. From figure 1 below,

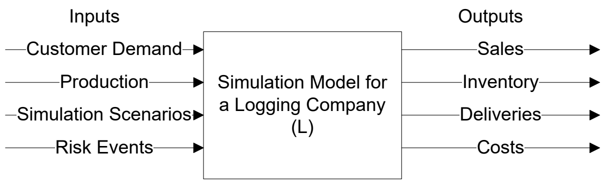

Figure 1: Conceptual Model of Logging Company 'L'

the conceptual model of a logging company *'L'* in which the simulation model receives inputs from the left side of the diagram and delivers output on the right is portrayed. The inputs, which represent experimental data and events, consist of demand, production, simulation scenarios and risk events. On the right side of the diagram, the outputs -performance measure estimates- consist of sales, inventory, deliveries and costs. The performance measures could be expressed in monetary units as risks in the supply chain should be measured, valued and managed by costs. As the risk events the system faces such as heavy rainfall, heavy snowfall, road closure, wood quality etc might have an impact on the system's output, the key question is therefore; '*how resilient is the system if affected by these risks and what is the impact on the system's performance*? This is where the requirements of a conceptual model play a great role as discussed below.

Requirements of a Conceptual Model:
The requirements of a good conceptual model include validity, credibility, feasibility and usefulness (Robinson 2008a).
Validity:
Nance (1994), points out that it is important for the model to be correct and can be easily tested. Hence, the model should be able to produce sufficient and accurate results for the purpose: For example, understanding the impact of the risks on the volume of logs delivered.
Credibility:
Unlike validity, credibility is more from the perspective of the client. It is therefore important for the modeller not only to include the important components and their relationships in the model, but to also be able to convince the clients about the accuracy. The model should also be easy to understand (Brooks and Tobias 1996a) by the clients who have to be capable of interpreting the results and believing in their accuracies.
Usefulness:
This is when the model is sufficiently easy to use, flexible, visual and quick to run. Nance (1994), further highlights that the model should be adaptable, reusable and maintainable. Consequently, the model could be used again for the same or different researches.
Feasibility:
Pritsker (1986), highlighted that feasibility should be timely; whilst Brooks and Tobias (1996), further elaborate on time and cost to build and run a model, as well as analysing the results. Hence, the modeller should be able to build the model within the available data and time constraints. The aforementioned will help develop a simple model and the results will be easy to interpret. The framework for conceptual modelling is discussed next as it helps to support the formation of the conceptual modelling of the logging company 'L'.

4. FRAMEWORK FOR CONCEPTUAL MODELLING

Taking the framework for conceptual modelling into consideration provides guidance by utilizing a set of steps and tools as given below. Figure 2 portrays a framework for conceptual modelling (Robison 2008), consisting of five activities which are as follows:

- Understanding the problem situation.
- Determining the modelling and general project objectives.
- Identifying the model outputs (responses).
- Identify the model inputs (experimental factors).
- Determining the model content (scope and level of detail), identifying any assumptions and simplifications.

The first step which is 'understand the problem situation' and this is clearly defined with respect to the conceptual model in figure 1.On the other hand, if the problem situation is not fully understood, it may lead to difficulties and therefore assumptions have to be made in this case to get a better understanding of the problem situation. After which, it is vital to determine the modelling and general project objectives given in the second step.

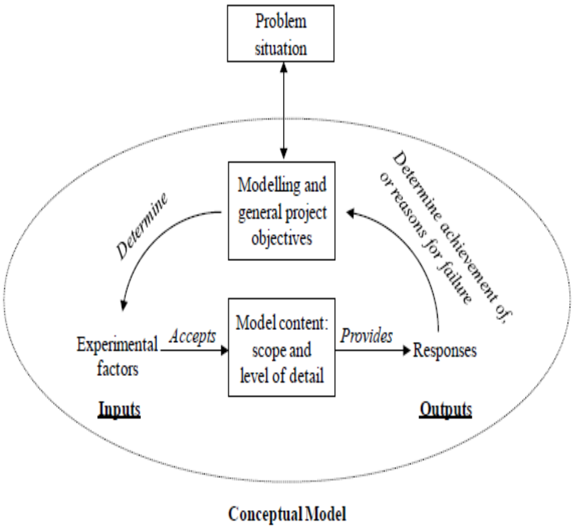

Figure 2: A Framework for Conceptual Modelling (Robinson 2008b)

Flexibility, run-speed, visual-display and the reuse of the model and its components are considered within the general project objectives. These objectives help to derive the conceptual model by defining the inputs (experimental factors) and the outputs (responses) of the model which are the third and forth steps respectively. The input data can be experimented in order to meet with the model's objectives with the output determining if the objectives have been met and this is also illustrated in figure 1. The output could be represented statistically or graphically. The last step is defining the content of the model in terms of its scope and level of detail. Throughout this process, it is also necessary to identify assumption and simplification. Subsequent to understanding the problem situation, and obtaining the requirements and framework of the conceptual model, data is then collected whereby a simulation model is developed for research analysis by testing various scenarios. From another perspective, a DEVS model is considered in developing a conceptual model as discussed in the next paragraph.

5. DEVS

Before exploiting the DEVS model, it is necessary to grasp a better understanding of DEVS which is one of the discrete event methodologies introduced by B. Zeigler in 1976. It is important for discrete event models as well as discrete time and differential equations because of its computational capabilities for implementing behaviours (Zeigler 1976). Moreover, it works with an infinite number of states that is useful for numerical integration. The early form of DEVS is known as Classic DEVS, but after 15 years, a modified version was introduced, namely Parallel DEVS. Classic DEVS is considered in this case since it is relevant to developing the model for the logging company system portrayed in figure 1. In addition, DEVS (discrete event system specification) is a structure '*M' in which;* $M = \{X, S, Y, \delta_{int}, \delta_{ext}, \lambda, ta\}$

Where;

X- is the set of input values

S- is a set of states

Y- is the set of output values

δ_{int}*,: S→S is the internal transition function*

$\delta_{ext:}$ *Q x X→S is the external transition function*

The total state set: $Q = \{(s,e)|s \in S, 0 \leq e \leq ta(s)$ *where 'e' is the elapse time since last transition.*

λ: S→Y is the output function

ta: $S \rightarrow R^{+}_{0,\infty}$ *is the set of positive reals with zero and infinity.*

According to Castro and Kofman (2000), 'DEVS is a system theoretic-based representation of the systems whose input/output behaviour can be described by sequences of events. Thus, the state variable(s) changes at a discrete point in time. From a practical point of view, a logging company is an example of a discrete system in which the state variables, volume of harvesting, forwarding and withdrawing logs, changes only when the trees are cut down into logs and or when the logs are forwarded to the roadside warehouse, and withdrawn from the warehouse to be distributed to customers. Hence, the volume of trees harvested changes only at a discrete point in time. In figure 1, the system gets its input from the environment, which is then transformed and sent back into the environment as output.

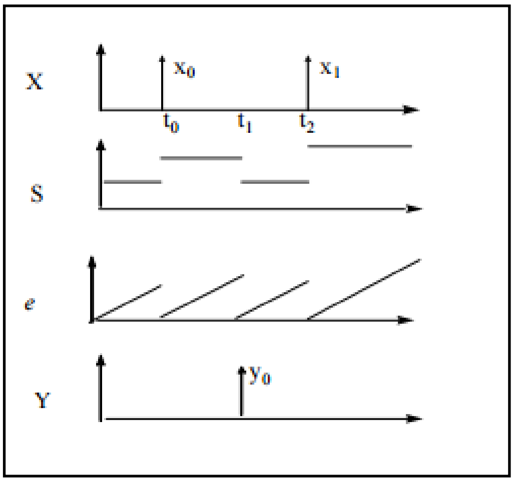

Figure 3: DEVS Trajectories

However, the risk events might affect the process of transformation which could cause an impact on the output. The behaviour of DEVS is illustrated in figure 3 where the input trajectory '*X* 'is a series of events occurring at t_0 and $t_2$with time t_1 representing an internal event. The state 'S' changes with respect to the input trajectory with the upper lines reacting to external events and the lower ones with the internal events. The elapsed time trajectory 'e' shows the flow of time that resets to zero at every event. The output trajectory 'Y' shows the output events generated by the output function 'just before applying the internal transition function at internal events' (Zeigler 1976). When taking the logging company into consideration, the demand of the volume of trees to be harvested is realized at the time $t_{0.}$ This then changes the state *'S'* and the elapse time is reset to zero. At the time $t_{1,}$ which is an internal event, the trees are harvested and forwarded to the roadside resulting in a change of the system *'S'* and yielding to an output Y_0 in the form of pile of logs on the roadside ready to be distributed to the customers. The DEVS model is discussed next.

6. DEVS MODELS

DEVS is divided into two classes of models, namely Atomic models and Coupled models. The Atomic models are exploited in basic formalism and the Coupled models are expressed using the coupled model specification. After careful examination, a pipeSimple Classic DEVS (Coupled) is selected to be exploited in developing a model with respect to the logging company illustrated in figure 1. The pipeline coupled model is elaborated in figure 4.

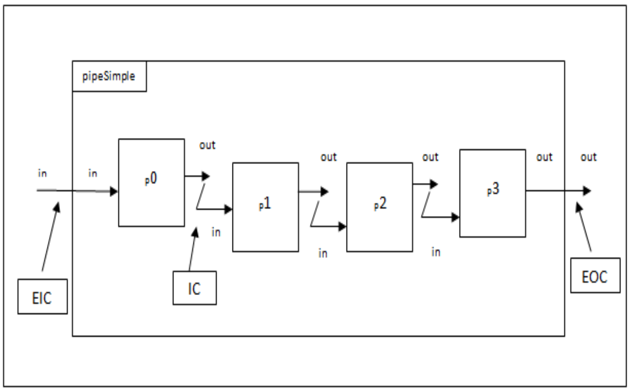

Figure 4: Pipeline Coupled Model for a Logging Company System 'L'

With reference to figure 4, four processors are connected in series to form a pipeline in order to construct a coupled model for the logging company system.
Where:

- p0- representing the input, for example the customers demand etc indicated in figure 1.
- p1- harvesting of trees into logs
- p2- forwarding the logs to the roadside
- p4- the output, for example, distribution to the customers as shown in figure 1.

The output port of the first processor(p0) is coupled with the input port of the second processor(p1) and the rest of the processors are connected in a similar way known as internal coupling(IC). The input port of the first processor 'in' is connected to the input port of the pipeline know as external input coupling(EIC). Similarly, the output port of the 4^{th} processor is linked with the external output port(EOC).

Hence, the DEVS formalism is meant to build models from components. DEVS specification with ports includes the external interface(input and output ports and values), the components (that is DEVS models) and the coupling relations.
From, N = (X, Y, D, {M_d|d ϵ D}, EIC, EOC, IC, select)
X is a set of input ports and values
Y is the set of output ports and values
D is the set of component names
M_d is a DEVS
The pipeline coupled DEVS specification is given as:
N = (X, Y, D, {M_d|d ϵ D}, EIC, EOC, IC).
where;
InPorts = {"in"},
X_{in} = V (an arbitrary)
X = {("in",v)|vϵV}
OutPorts = {"in"}
Y_{out} =V
Y = {("out", v)|vϵV}
D ={processor0,processor1, processor2,processor3}
$M_{processor3} = M_{processor2} = M_{processor1} = M_{processor0=processor}$
EIC = {((N, "in'), (processor0, "in")}
EOC = {((processor3, "out"), (N, "out")}
IC = {((processor0, "out"), (processor1, "in")),
((processor1, "out"), (processor2, "in")),
((processor2, "out"), (processor3, "in"))}
Select (D ') = the processor in D ' with the highest index.
The DEVS model can then be transformed into a simulation model by using DEVS tools such as DEVS-C++, DEVSim++ etc, for obtaining simulation results.

7. CONCLUSION

This article has discussed how to develop a conceptual model in a discrete event system by exploiting a logging company as an example. The discrete event system and its components were considered from a practical point of view with respect to the logging company. This was followed by exploiting two conceptual models namely the Robinson's model and the DEVS model. The requirements of Robinson's model namely validity, credibility, feasibility and usefulness were discussed followed by the framework for building the model. The DEVS structure and its behaviour were described in theory which were they applied in practice onto the logging company. This was followed by developing a DEVS model in which a pipeSimple Classic DEVS (Coupled) was selected and its specification given as: *N = (X, Y, D, {M_d|d ϵ D}, EIC, EOC, IC),* where M_d is a DEVS. The DEVS model seems to be more complicating when compared to the Robinson's model which is simpler and very practical.
Future research
Translating both conceptual models namely Robinson's and DEVS into simulation models by exploiting

SIMUL8 and DEVSim++ respectively in order to study the system of the logging company, analyze the impact of the risks on the system and develop a resilient strategy will be considered next. Moreover, application of the Six Sigma processes within the SIMUL8 software in order to develop a resilient strategy will also be considered.

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AN EFFICIENT CONSTRAINT PROGRAMMING MODEL FOR COOPERATIVE FLIGHT DEPARTURES

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ABSTRACT

Nowadays, air transportation is considered the fastest way to transport people and goods within the shortest time over long distances. Due to growing air traffic trends, the development of advanced Decision Support Tools (DSTs), based on technological advances in communications and navigation in Air Traffic Management (ATM), is important to guarantee sustainable transport logistics to balance airspace capacity with user demands. In this paper, the tuning of Calculated-Take-Off Times (CTOTs) as a tool for mitigating the propagation of perturbations between trajectories in dense sectors is analysed. The proposed methodology uses a powerful tool for predicting potential spatio-temporal concurrence events between trajectories over the European airspace that are removed by considering bounded time stamp adjustments on strategic agreed points of the aircraft trajectory. The proposed approach is based on a robust Constraint Programming model aimed to determine the feasible time stamp agreements considering the Trajectory Based Operation (TBO) interdependencies.

Keywords: Air transportation, Constraint programming, Air traffic management, Decision support tools

1. INTRODUCTION

Air transport is an integral part of transport infrastructure and a significant sector of the economy predicted next decades with steady growth. Therefore, the identification of operational and managing policies for better performance of existing airspace procedures is important in order to cut European Air Traffic Management (ATM) costs, increase capacity and operational safety and decrease the environmental impact. The intention of this innovative approach is to design a competitive ATM system, supporting up to a certain extent the Airspace User (AU's) demands at the right time (i.e. departure slots), at the right cost (i.e. suitable level of Air Traffic Control (ATC) service) at the right place (i.e. AU's preferred trajectories) and at the right service quality (i.e. safety) without extra investments, just by removing the ATM non-added-value operations that indirectly impact on present ATM capacity.

By empowering the concept of Trajectory-based operations (TBO) as a flexible synchronization mechanism towards an efficient and competitive ATM service a precise description of an aircraft path in space and time can be retrieved. Under this TBO approach, airspace users should fly precise 4-dimensional trajectories (4DTs), previously agreed upon with the network manager.

Europe has some of the busiest airspace in the world, managed by a network covering 11.5 million km² of airspace (SESAR 2015). The Network Manager Operations Centre receives, processes and distributes up to 35,000 flight plans a day (Eurocontrol 2016). This concerns over 500 European airports and airfields. To safely operate this demand any AU intending to depart from, arrive at or overfly one of the 42 countries which form part of the EUROCONTROL operations area must submit a flight plan that has to be approved in advance. Once the flight plan has been approved, the Reference Business Trajectory (RBT) is agreed and the aircraft is authorized to proceed in accordance with the RBT by defined conflict free segments. This set of business objectives may be updated or revised.

Although the ATM network is becoming designed to be robust and resilient to a whole range of disturbances, due to its dynamic and complexity unforeseen disruption can occur at any time and influence the functionality. Delay causes can be found for example in the rotation of aircrafts, in the turnaround processes, in Air Traffic Flow Management (ATFM) and Air Traffic Control (ATC) restrictions, in maintenance problems and weather conditions. When the delays exceed the agreed *green delay* of [-5,10] minutes, the extant aircraft must be rescheduled (Nosedal 2016).

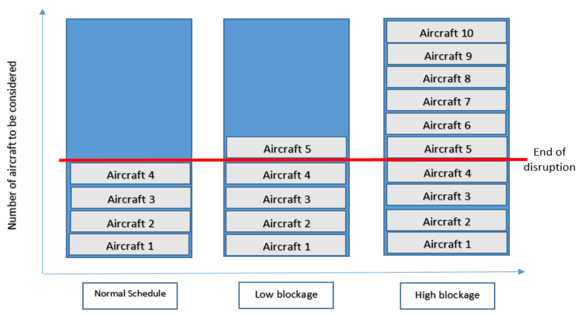


Figure 1: Example of delay and resulting combinatorial possibilities

As it can be seen in Figure 1, low blockages might occur when for example one aircraft is delayed due to maintenance problems whereas high blockages might result due to weather problems or strikes.

The presented approach supports the recovery process by rescheduling the sequence of delayed aircraft for takeoff in a way that the departure-time-bounded adjustment process that preserves the scheduled slots will be used while relaxing tight 4DT interdependencies to mitigate demand-capacity imbalances.

Small adjustments within the $[-5,10]$ interval around the Calculated Take-Off Time, along with bounded modifications on the flight duration, will be considered as the actions to be taken considering the trajectory and the impact on potential ATC interventions. Using this approach, the decision variables and their domains are included in the Constraint Programming (CP) model which leads to more combinatorial possibilities to find a more robust solution in which tight interdependencies can be removed. For instance, the Figure 2 illustrates how after a high blockage the combinatorial possibilities to adjust the departure sequence are much higher, which brings the opportunity to likely find optimal solutions avoiding tight interdependencies.

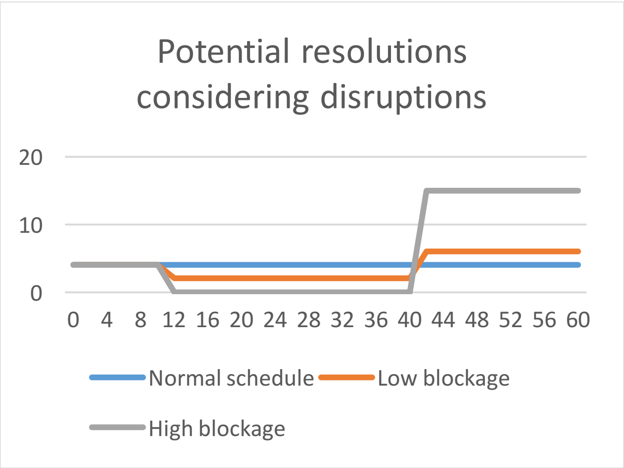


Figure 2: Potential resolutions considering disruptions (x-axis time in minutes; y- axis sequencing alternatives)

Whether by huge delays, slight delay impacts or by regular running of operations, whenever the complexity becomes too high, the proposed approach introduces small time adjustments on the aircraft to remove the detected tight interdependencies.

Two kind of time adjustments are considered:

- Introduce ground delays with a time offset of $[-5,10]$ minutes, remaining in the boundary of *green delays* to achieve fairness between airlines, since greater delays are quite unpopular as they can be very costly and would affect the strategic airspace configuration.
- Issue slight modifications on time stamps for relevant trajectory points. Since a simple shifting of the whole trajectory does not contribute in preserving the Target Time of Arrival (TTA), a more flexible approach is proposed considering additional small time adjustments at strategic points to have a control over the Time-To-Overfly (TTO) on relevant points close to the hotspot areas.

Using this approach, the goal of reaching the TTA on time as expressed in the ATM concept could be guaranteed by combining the relaxation of the CTOT and the total flight duration see Figure 3. The relevant points are identified according to the potential concurrence events that are computed in the detection of tight trajectory interdependencies and the TTO stamp of these points is calculated by the conjunction of both, the CTOT and the duration of the segments that separate these concurrence events. This approach leads to the resolution of tight interdependencies maximizing the adherence to the RBT.

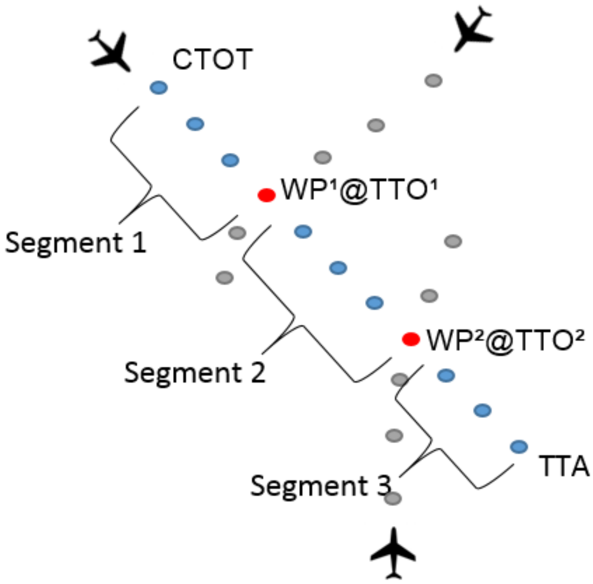


Figure 3: Dynamics of CTOT, segments, points with a TTO stamp and TTA

The depicted problem belongs to the class of Constraint Satisfaction Problems (CSP). During the mapping process, a list of proximate events is detected: two or more aircrafts losing the separation minima. This situation can be represented in terms of constraints able to describe the conditions to be met in order to avoid such proximate event. For removing these interdependencies, the approach proposes two action mechanisms, that is, two kind of decision variables for adjusting the relevant time stamps in a way that the constraints modeling the interdependencies are satisfied.

Moreover, this problem can be considered as an optimization problem, since maximizing the adherence to the RBT will be included as a goal. Since the decision variables belong to the integer domain, the overall problem falls in the category of combinatorial problems.

The paper is organized as follows: Section 2 explains the methodology description to retrieve the input for the CP Model, section 3.1 describes the constraint model that has been developed to tackle the problem considering one degree of freedom and section 3.2 outlines the extension of the model introducing speed changes between segments. The validation of results, conclusions and opportunities for further work are discussed in section 4.

2. METHODOLOGY DESCRIPTION

The detection of tight trajectory interdependencies is realized in four constituent processes which will be presented in the following. The output of the detection of tight trajectory interdependencies allows the resolution of these tight trajectory interdependencies using CP.

To identify tight trajectory interdependencies, the entire European Airspace is classified into so called collective microregions. Based on the TBO concept the en-route trajectories are initially projected on a discrete grid by flight level covering the European Airspace (longitude -20 and 30 degrees and latitude of 0 to 80 degrees). The trajectories and relevant flight information must be supported by computational efficient algorithms and databases.

2.1. Macro-mapping process

One objective when developing the search algorithm to detect tight trajectory interdependencies is to solve the scalability problem and to design a computational efficient algorithm. Therefore, the airspace is first divided into macrocells with a size of 12NM (22,224 km). The position tracking is stored as a vector. Each position in the vector can assume a binary value of 0 or 1. Presence in a cell is represented by 1 and absence by 0 (see Figure 4). The entry and exit times of an aircraft into a cell are registered and stored in a vector.

2.2. Micro-mapping process

After the initial mapping, the macrocells with an occupancy rate equal or greater than two are partitioned for the identification of collective microregions, that is the set of cells showing potential concurrent events. The microcells represent square cells of 6NM that are in use by at least two aircraft simultaneously (Barnier and Allignol 2012). The size 6NM (11.112 km) has been chosen with respect to the safety distance two aircrafts always have to respect. For collective microregions, entry times and exit times are used to determine the size of the overlap or clearance between aircraft pairs. As it can be seen in Figure 4, the process is identical to the previous presented macro-mapping process considering smaller cells. To improve the reliability of the collective microregion identification, four areas located on the boundaries of surrounding cells, macro- and micro-mapping processes are applied in order to detect any concurrence event between trajectories neighbor cells.

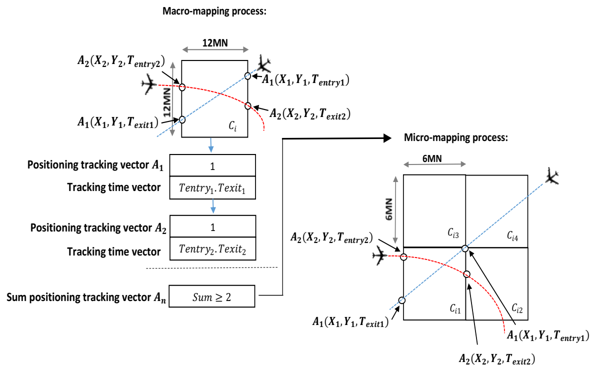


Figure 4: Macro- and micro mapping process

2.3. Filtering process

Finally, the detected concurrence events are filtered for each pair of aircraft. The outcome after the filter are ''tightest'' potential concurrence events for each pair of aircraft (see Figure 5), since aircraft that have enough clearance to guarantee the safety minimum do not have to be considered in the resolution of tight trajectories that will be explained in the following section.

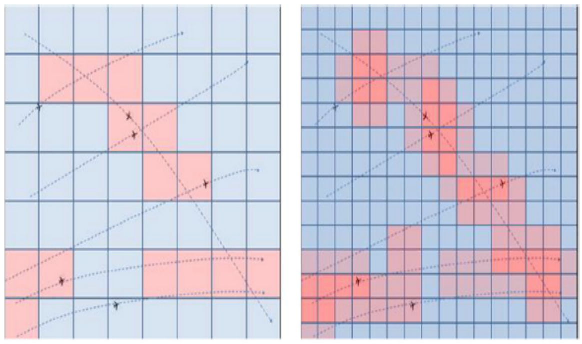


Figure 5: Detection of "collective microregions"

3. CONSTRAINT MODEL

CP is a powerful paradigm for representing and solving a wide range of combinatorial problems. In the last few decades it has attracted much attention among researchers due to its flexibility and its potential for solving hard combinatorial problems in areas such as scheduling, planning, timetabling and routing. CP combines strong theoretical foundations (e.g. techniques originated in different areas such as Mathematics, Artificial Intelligence, and Operations Research) with a wide range of application in the areas of modelling heterogeneous optimization and satisfaction problems. Moreover, the nature of CP provides other important advantages such as fast program development, economic program maintenance and efficient runtime performance. Problems are expressed in terms of three entities: variables, their corresponding domains, and constraints relating them.

The presented approach recognizes the synchronization problem as a scheduling problem, similar to some extend to the well-known Job Shop Scheduling Problem (JSSP). Roughly, this problem consists in allocating the proper resources to the list of jobs facing an optimization goal to minimize some temporal, productivity or efficiency cost function.

Drawing lines to the JSSP, the available cells as portions of the airspace can be considered as the existing resource and the aircraft as the jobs that are performed requiring the resource.

3.1. Tight trajectory interdependencies resolution

In this CP model version, the tight trajectory resolution is modeled using one control action: shifting the entire trajectory by the delay applied on the CTOT as is can be seen in Figure 6. The CTOT of aircraft 2 is shifted ahead of its original schedule and the CTOT of aircraft 3 is delayed in order to guarantee that all three aircraft arrive to the cell in conflict at different time windows.

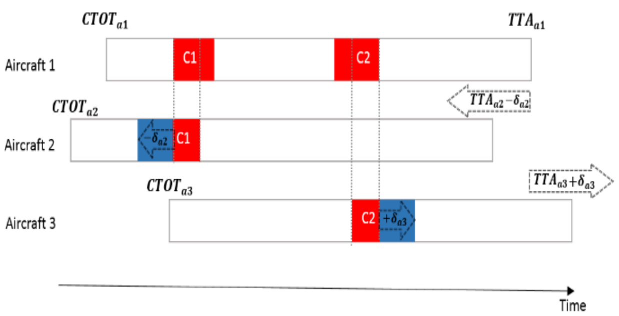


Figure 6: Resolution of tight trajectory interdependencies with one freedom degree (C=Conflict)

After the mapping and filtering process we obtain a representation of all the conflicts that must be removed by the optimization model. This information is then processed in order to define the following data structures.

Let A be the set of aircrafts, C the set of cells belonging to one collective microregion and $c_a =< c, a >$ the pairing between the aircraft a using a given cell c at the microregions. The pairings $c_a \in C_A$ is defined as:

$$C_A = \{< c, a > | \forall c \in C, \forall a \in A\}$$

Finally, the time occupancy of the cell c by aircraft a is defined by the two parameters:

$$c_a^{te} \equiv entry\ time \qquad (1)$$
$$c_a^{ts} \equiv exit\ time$$

3.1.1. Decision variables

To ensure that the departure adjustment of the aircraft remain in the defined timeframe of [-5,10] minutes, the integer decision variable δ_a is defined as the delay applied to the CTOT of aircraft a:

$$\delta_a \in [-\delta_{min}, \delta_{max}],$$

where $\delta_{min} = 5$ and $\delta_{max} = 10$, expressed in minutes, sets the domain for the delay decision variable.

The use of a cell by an aircraft is modeled by means of interval decision variables. Interval decision variables represent time periods whose duration and position in time are unknown in the optimization problem. The interval is characterized by a start value, an end value and a size. Addressing this concept as a scheduling problem, the interval is the time during which something happens (e.g. an activity is carried out). In this case, it is the occupancy of the cell c by an aircraft a is modeled by the interval decision variable:

$$P_{ca} = [s_{c_a}, e_{c_a}), \qquad \forall\ c_a \in C_A \qquad (2)$$

and the size:

$$sz(P_{c_a}) = e_{c_a} - s_{c_a} (= c_a^{ts} - c_a^{te})$$

where s_{c_a} and e_{c_a} are the interval start and end time respectively.

Since the shifting applied to the trajectory to avoid the proximate events is determined by the delay δ_a and no speed adjustment are accepted, the domain of the interval variable can be defined as (see also Equation 1):

$$P_{c_a} \in [c_a^{te} - \delta_{min}, c_a^{ts} + \delta_{max}], \forall c_a \in C_a \qquad (3)$$

As illustrated in Figure 6, the time occupancy of the cell that is involved in a concurrent event remains constant. The aircraft takeoff time instants are shifted according to the delay δ that is applied to avoid the concurrent event in the cell.

Each of the cells can be occupied by one aircraft at a time, so the aircrafts going through the cell must be sequenced accordingly. The decisions on the use of conflicting cells are modeled by sequence variables, which are defined as:

$$F_c = \{P_{c_a} | c_a \in C_A\}, \qquad \forall c \in C \qquad (4)$$

with the permutation π of the sequence variable F_c as the function

$$\pi: F_c \to [1, m]$$

where $m = |F_c|$ is the number of aircrafts going through the cell c. The elements of the sequence meet the following conditions:

$$P_{c_{ai}} \neq P_{c_{aj}} \Rightarrow \pi(P_{c_{ai}}) = \pi(P_{c_{aj}}), \forall P_{c_{ai}}, P_{c_{aj}} \in F_c$$

3.1.2. Constraints

Two constraints are identified in order to define the space of feasible solutions. The first constraint aims to model the shifting of every interval variable according to the applied delay:

$$s(P_{c_a}) = c_a^{te} + \delta_a, \forall c_a \in C_A \qquad (5)$$

where the function $s(\cdot)$ is defined as the interval start time (aircraft entry to cell c):

$$s(P_{c_a}) = s_{c_a} \qquad (6)$$

The second constraint is the *no overlap* constraint that imposes a set of interval variables to not overlap each other in time. In this case, all aircraft in a cell c with proximate events should have no overlap:

$$\begin{aligned}&\forall P_{c_i}, P_{c_j} \in F_c \\ &NO(F_c) \Leftrightarrow \pi(P_{c_i}) < \pi(P_{c_j}) \Rightarrow e(P_{c_i}) \leq s(P_{c_j})\end{aligned} \quad (7)$$

where the function $e(\cdot)$ are defined as the interval end time (aircraft exit from cell c):

$$e\left(P_{c_a}\right) = e_{c_a} \quad (8)$$

and the no overlap is guaranteed for the proximate event P_{c_i} at a position prior to any P_{c_j} by constraining its exit time to be lower or equal to the entry time of the subsequent proximate events P_{c_j}.

3.1.3. Optimization goal

The objective function was chosen to enhance adherence with a synchronization mechanism, though flexible, does not preserve the TTA at destination airport. Therefore, it aims to minimize the differences between actual takeoff times and the planned or CTOTs.

The optimization goal of the solution is to minimize the total aircraft delays, and it is formulated as follows:

$$\sum_{a=1}^{n} |\delta_a| \quad (9)$$

where a refers to the aircraft and δ_a is the delay applied.

The whole optimization model is listed here:

A set of aircrafts
C set of cells at a collective microregion
$C_A = \{< c, a > \mid \forall c \in C, \forall a \in A\}$
d.v. $\delta_a \in [-\delta_{min}, \delta_{max}], \forall a \in A$
d.v. $P_{c_a} \in [c_a^{te} - \delta_{min}, c_a^{ts} + \delta_{max}], \forall c_a \in C_a$
d.v. $F_c = \{P_{c_a} | c_a \in C_A\},\ \forall c \in C$

minimize $\sum_{a=1}^{n} |\delta_a|$
subject to {
$s\left(P_{c_a}\right) = c_a^{te} + \delta_a, \forall c_a \in C_A$
$\forall P_{c_i}, P_{c_j} \in F_c$
$NO(F_c) \Leftrightarrow \pi(P_{c_i}) < \pi(P_{c_j}) \Rightarrow e(P_{c_i}) \leq s(P_{c_j})$
}

This model was applied to successfully solve an over-stressed realistic scenario. The scenario was composed of a set of 4010 real 4D trajectories in the European airspace for a time window of 2 h, showing more than 65.000 proximate events. Nevertheless, the modified trajectories do not meet the TTA, since no speed adjustment possibility is included in this model. Next section extends the model in order to improve the RBT adherence of the modified trajectories.

3.2. Tight trajectory interdependencies resolution with speed adjustments

TTA adherence is a main objective to enhance capacity at arrival airports. Clearly, the TTA cannot be preserved by shifting the CTOT and therefore, the full trajectory. The TTA in ATM has a small margin of [-1,1] minute. Therefore, its compliance is of high importance. To meet these conditions, the model described in section 3.1 has been extended by introducing the concept of segments for describing the full trajectory from departure (CTOT) until the arrival time to the destination (TTA). The Figure 7 illustrates this concept. For instance, aircraft 1 in the figure is divided into five segments: C1 and C2 represent the concurrence events while S1, S2 and S3 are the segments between the concurrence events. In the modified trajectory, the segment S1' is shifted according to the applied delay on the CTOT to avoid the first concurrence event while S3' is shortened in time by speed change in order to preserve the TTA within the margin. The intermediate segment S2' is extended in time by flying with reduced speed to avoid concurrence event C2.

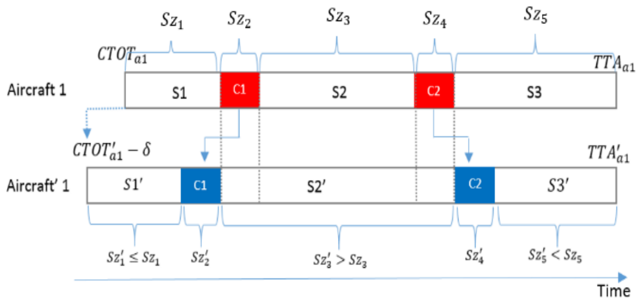


Figure 7: Resolution of tight trajectory interdependencies with speed change (C=Conflict; S=Segment; Sz=Size)

The speed adjustments are realized under the condition that the segment between proximate events are of a certain minimum duration. That allows to introduce a speed change that is efficient in the sense of fuel consumption and in the effect on the resolution of the conflict while trying to preserve the TTA.

New data structures are included to model the trajectory segments for speed adjustments. Let $\hat{g}_i^a$ be a segment of the aircraft a trajectory. Therefore, the RBT can be noted as:

$$RBT_a = \{\hat{g}_i^a\}, \qquad i = 1..p(a)$$

where $p(\cdot)$ is the number of segments required for describing the trajectory. For instance, the Figure 7 shows the trajectory segments of aircraft 1, represented as $RBT_a = \{S1, C1, S2, C2, S3\}$ with

$$\begin{aligned}s(\hat{g}_i^a) &= \text{start time of } \hat{g}_i^a, \\ \mathrm{e}(\hat{g}_i^a) &= \textit{end time of } \hat{g}_i^a\end{aligned}$$

where the functions $s(\cdot)$ and $e(\cdot)$ yield the start and end times of the corresponding RBT segments (see Equation 6 and 8 for the function definition).

Finally, the concept of segment elasticity $l(\hat{g}_i^a)$ is introduced to denote the allowed speed variation as a percentage of the $\hat{g}_i^a$ segment duration $sz(\hat{g}_i^a)$.

3.2.1. Additional decision variables

In this new CP model approach, the duration of the entire flight becomes an unknown itself, since CTOT can be delayed while keeping the intend to preserve the TTA.

A decision interval variable G_a is introduced for representing the entire flight:

$$G_a = [s_a, e_a)$$

where s_a will be the takeoff time and e_a the arrival time in the solution.

Secondly, the interval variables representing the segments of the G_a solution trajectory are modeled. Let g_i^a be the interval variable:

$$g_i^a = [s(g_i^a), e(g_i^a))$$

and the size of the g_i^a segment is

$$sz(g_i^a) = e(g_i^a) - s(g_i^a)$$

The domain of the g_i^a segment can be defined as:

$$sz(g_i^a) \in [sz(\hat{g}_i^a) - l(\hat{g}_i^a), sz(\hat{g}_i^a) + l(\hat{g}_i^a)] \quad (10)$$

Note that in this model version, interval duration can differ from RBT segment duration, since some elasticity is enabled by the bounded speed changes, whereas the domain for the interval start and end time cannot be specified, since their values at the solution are a combination of the takeoff delay and the bounded speed adjustments.

Finally, a sequence variable T_a is introduced to set the relationship between the trajectory segments g_i^a and the entire trajectory G_a:

$$T_a = \{g_i^a \mid \forall a \in A, i \in 1..p(a)\}$$
$$\pi: T_a \rightarrow [1, n] \quad (11)$$
$$g_i^a \neq g_j^a \Rightarrow \pi(g_i^a) \neq \pi(g_j^a), \forall g_i^a, g_j^a \in T_a$$

3.2.2. Additional Constraints for speed change

The duration of the flight is determined by the constraint of the takeoff time and the time to arrival.

$$s(G_a) = CTOT_a \pm \delta_a \quad (12)$$

$$e(G_a) \in [TTA_a - 1, TTA_a + 1] \quad (13)$$

The relationship between the flight interval variable and its segments is modeled by the following *span* condition:

$$span(G_a, \{g_i^a\}), \forall a \in A, \forall g_i^a \in T_a$$

This constraint sets the following time relationship among the interval variables:

$$\begin{cases} s(G_a) = \min_{i \in [1,p(a)]}(\{s(g_i^a)\}) \\ e(G_a) = \max_{i \in [1,p(a)]}(\{e(g_i^a)\}) \end{cases} \quad (14)$$

The constraint *span* states that the interval flight spans over all present intervals from the set segments. That is, interval flight G_a starts together with the first present segment interval and ends together with the last one.

Additionally, the following three constraints are set to order the trajectory segments:

1. The *no overlap* constraint to ensure that interval variables to not overlap each other.

$$NO(G_a) \Leftrightarrow \pi(g_i^a) < \pi(g_j^a) \Rightarrow e(g_i^a) \leq s(g_j^a) \quad (15)$$

2. The constraint that one segment has to start before the next:

$$e(g_i^a) \leq s(g_j^a), \forall i, j: i \leq j \quad (16)$$

3. The constraint that ensure that the start of segment j results after the end of segment i.

$$e(g_i^a) = s(g_j^a), \forall i, j: j = i + 1 \quad (17)$$

The graphical representation of this three constraints is shown in Figure 8. Aircraft 1 has a flight duration and the projection of the segments onto the flight duration with the three conditions is shown.

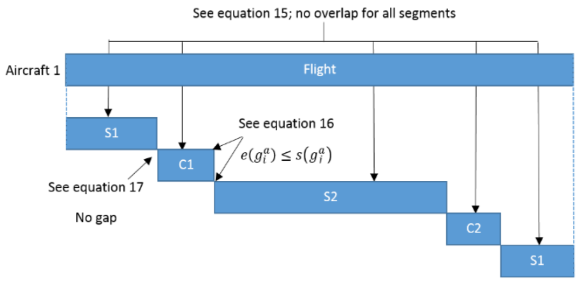


Figure 8: Representation of function flight and RBT segments

Finally, the P_{c_a} interval variable, that is used in combination with the sequence variable F_c to remove the concurrence events at cell c, must be linked with the concurrence segments of the trajectory T_a (e.g. C1 and C2 in Figure 8), since they are representing the same time windows. This is accomplished by the following constraint:

$$\begin{cases} s(g_i^a) = s(P_{c_a}) \\ e(g_i^a) = e(P_{c_a}) \end{cases} \Leftrightarrow \begin{matrix} s(\hat{g}_i^a) = c_a^{t_e} \\ e(\hat{g}_i^a) = c_a^{t_s} \end{matrix}, \forall c_a \in c_A$$

3.2.3. Objective function

The constraint in Equation 9 binds to the TTA attainment, but it might happen that no solution is found because time adjustment is bounded so it is possible that the required delays δ_a cannot be compensated by the speed adjustments. For this reason, the TTA constraint is relaxed. The following logical function is added:

$$L(G_a) = \begin{cases} 1, & e(G_a) \notin [TTA_a - 1, TTA_a + 1] \\ 0, & \text{otherwise} \end{cases}$$

With this function, the number of TTA violations can be counted for introducing its minimization as an objective that can be combined with the objective function stated in Eq. 4 to minimize the total delay of the aircraft takeoffs. The following equation weights both objectives to get the optimization goal:

$$\min w_1 \sum_{a=1}^{n} |\delta_a| + w_2 \sum_{a=1}^{n} L(G_a) \qquad (18)$$

The extended optimization model is listed here:

A set of aircrafts
C set of cells at a collective microregion
$C_A = \{< c, a > \mid \forall c \in C, \forall a \in A\}$
$RBT_a = \{\hat{g}_i^a \mid \forall a \in A,\ i = 1..p(a)\}$
d.v. $\delta_a \in [-\delta_{min}, \delta_{max}], \forall a \in A$
d.v. $P_{c_a} \in [c_a^{te} - \delta_{min}, c_a^{ts} + \delta_{max}], \forall c_a \in C_a$
d.v. $F_c = \{P_{c_a} | c_a \in C_A\},\ \forall c \in C$
d.v. $G_a,\ \forall a \in A$
d.v. $g_i^a,\ \forall a \in A,\ \forall i \in 1..p(a):$
$\quad sz(g_i^a) \in [sz(\hat{g}_i^a) - l(\hat{g}_i^a), sz(\hat{g}_i^a) + l(\hat{g}_i^a)]$
d.v. $T_a = \{g_i^a\}, \forall a \in A$

minimize
$w_1 \sum_{a=1}^{n} |\delta_a| + w_2 \sum_{a=1}^{n} L(G_a)$
subject to {
$s(g_i^a) = CTOT_a \pm \delta_a\ \forall a \in A$
$\forall P_{c_i}, P_{c_j} \in F_c$
$NO(F_c) \Leftrightarrow \pi(P_{c_i}) < \pi(P_{c_j}) \Rightarrow e(P_{c_i}) \leq s(P_{c_j})$
$span(G_a, \{g_i^a\}), \forall a \in A, \forall g_i^a \in T_a$
$\forall a \in A,\ \forall i, j \in 1..p(a)$
$NO(G_a) \Leftrightarrow \pi(g_i^a) < \pi(g_j^a) \Rightarrow e(g_i^a) \leq s(g_j^a)$
$e(g_i^a) \leq s(g_j^a) :\ i \leq j$
$e(g_i^a) = s(g_j^a) : j = i + 1$
$\begin{cases} s(g_i^a) = s(P_{c_a}) \\ e(g_i^a) = e(P_{c_a}) \end{cases} \Leftrightarrow \begin{matrix} s(\hat{g}_i^a) = c_a^{te} \\ e(\hat{g}_i^a) = c_a^{ts} \end{matrix}, \forall c_a \in c_A$
}

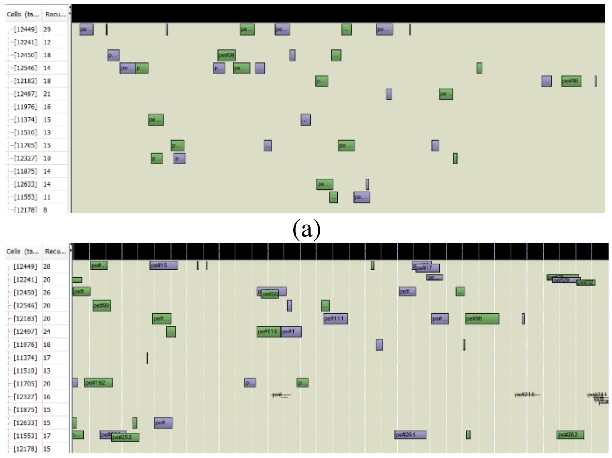
4. RESULTS

The model was applied to an over-stressed realistic scenario. The scenario was composed of a set of 4010 real 4D trajectories in the European airspace for a time window of 2 h. In this work, we assumed TBO without uncertainties. In this context, the trajectories were discretized at each second, and each position was specified in terms of geographic coordinates and a time stamp. This scenario was designed and analyzed in the STREAM project (Ranieri et al. 2011), a EUROCONTROL SESAR WP-E project. The CP model has been implemented with the ILOG Optimization Suite (IBM 2015) and the following results were obtained.

4.1. Macro and Micro Mapping

The detection of the concurrence events in this paper is based on the algorithms and results presented at (Nosedal et al. 2014) and (Nosedal et al. 2015). The aforementioned scenario is analyzed in these works, leading to the detection of the collective micro-regions that have been used in this work to find the optimal adjustments on CTOT and speed changes to reduce proximate events and, therefore, ATC interventions.

In Figure 9 (a) the en-route traffic thought the collective micro-regions is shown. The cells with potential concurrence events are detected based on the RBT trajectories of those aircrafts ready to depart, but still on ground, according to their CTOT. Therefore, en-route trajectories are conflict free at the given time instant.



(a)

(b)

Figure 9: Gantt diagrams showing the traffic through the cells with potential concurrence events. Diagram (a) shows the conflict free en-route traffic and (b) shows the emerging conflict after inserting the departing traffic for the same time period.

The Figure 9 (b) shows the situation found when the grounded aircrafts depart according to their RBT CTOT. As it can be seen, for instance, at cells 12241, 12449 and 12450 among others, concurrent events will appear between several aircraft if they depart according to their CTOT. In this case, aircraft regulations could be issued by ATM or, later on, ATC interventions would be needed to remove the proximate events caused by the inserted traffic.

4.2. Trajectory adjustments

The proposed CP model is used to determine the proper adjustments on the CTOT and aircraft trajectories to remove the potential concurrence events.

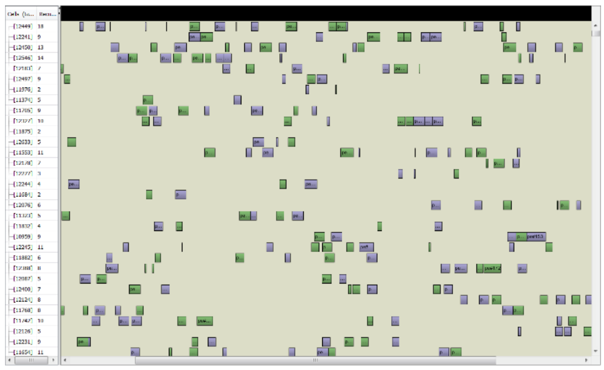
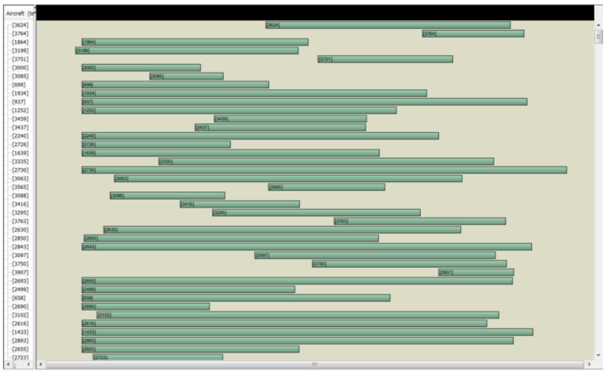
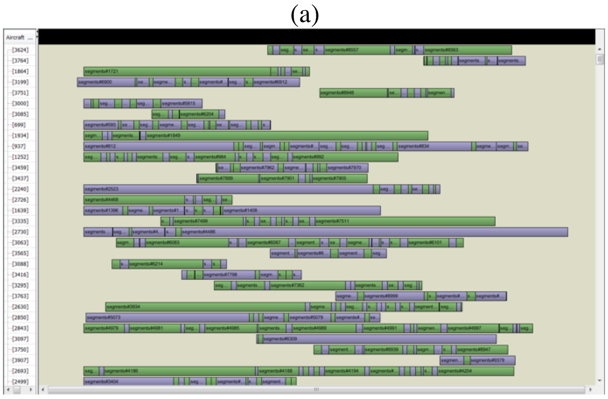


Figure 10: The diagram shows the conflict free solution after applying small adjustments on CTOT and segment' speed.



(a)



(b)

Figure 11: The (a) Gantt diagram shows the full flight interval of the aircrafts in potential concurrence events; the (b) diagram shows their segment structure.

As Figure 10 illustrates, all the potential concurrence events are removed by applying a combination of bounded delays on CTOT and/or speed adjustments, leading to a conflict free scenario. The bounded adjustments impose the actual takeoff time to be within the $[-5{,}10]$ minutes of the aircraft CTOT (see Equation 12) and the speed adjustments to be less than 10% of the RBT proposed by the airline (see Equation 10). The ILOG CP solver was limited to 180 seconds to get the best suboptimal solution. All the experiments were performed on a Window 10 computer with an Intel Core I7 CPU 2,30 GHz and 16GB RAM.

4.3. Solution analysis

Since the adjustments on CTOT and speed changes are bounded, the TTA fulfilment cannot be ensured. As stated at Equation 18, the TTA requirement was relaxed, and its fulfilment was included in the optimization goal. The used weights were $w_1 = 10\%$ and $w_2 = 90\%$, so giving priority to the TTA preservation.

The Figure 12 shows the correlation between the actual time of arrival (ATA) compared to the TTA with respect to the applied CTOT delay. As it can be observed, in most of the cases the bounded speed adjustments are not enough to recover the effect of the applied delays. In Figure 13 it is shown the absolute numbers of aircrafts not able to meet their TTA with respect to the applied delay. There are two main reasons explaining this results.

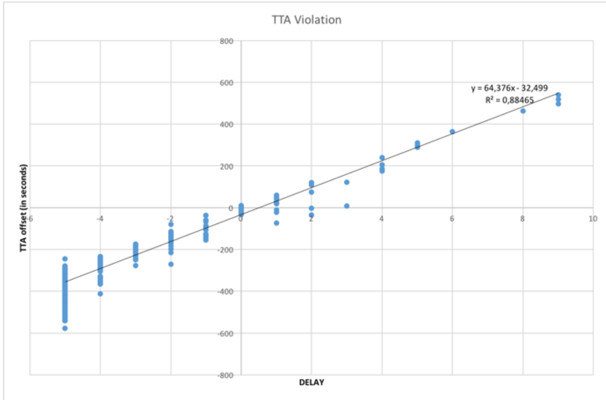


Figure 12: Correlation between TTA violation and the delays applied to the aircraft takeoff times.

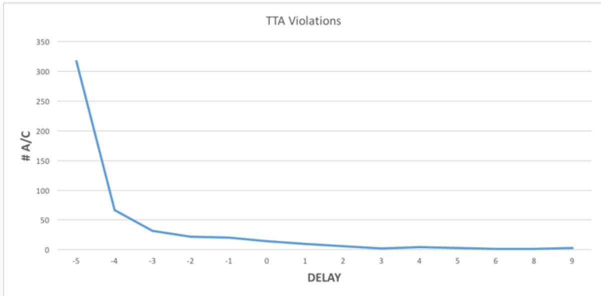


Figure 13: A/C not meeting their TTA with respect to the applied CTOT delay.

The first observable one is that most of the aircrafts are moved ahead of their CTOT. This is a consequence of the solver search strategy (Van Beek 2006), since time to get the suboptimal solution was limited to 180 seconds. This strategy is the default one and first takes the smallest values in the decision variable domains. In this case, this value is -5 minutes for the δ_a delay. Further research is required to define search strategies leading to better solutions.

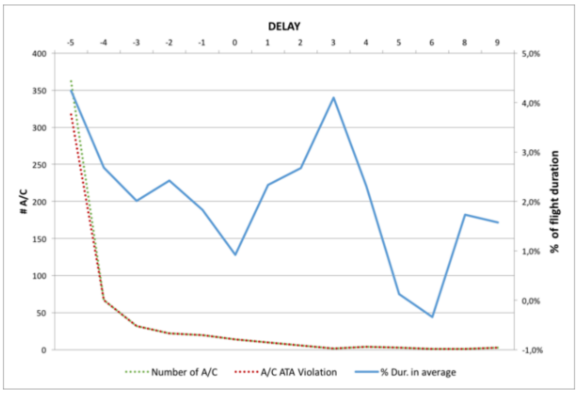


Figure 14: blue line represents the average modification of flight duration with respect to the applied delay; dotted lines represent the number of A/C with the respective delay and the number of A/C not meeting their TTA.

The second reason can be explained from the curves at Figure 14. The number of aircrafts not meeting their TTA is tightly related to the applied delay, as it can be observed from dotted curves. However, the average modification on flight duration is not related to the applied delay. The margins enabled by the bounded speed adjustments are not enough for compensating the applied delays. This fact could be overcome only if, first, solutions with lower absolute delays can be found (better search strategy) and, second, if the aircraft trajectory allows a bigger absolute elasticity. The latest does not depend on the solution method, but on the duration of the flight and on the number and relative position of the proximate events where it is involved.

5. CONCLUSIONS

In this work a CP model is presented for solving the concurrence events that might happen when the departure traffic is inserted into the en-route traffic. The model has been proved in a realistic and overstressed scenario and it has been able to find suboptimal solutions in a timeframe of 180 seconds for all the performed experiments.

The model constraints ensure that all the proximate events are resolved by introducing small time adjustment both on the CTOT and relevant TTO's while maximizing the adherence to the RBT's. Although the model is not able to ensure that the ATM concept of preserving the TTA in a strict time frame is met, the CP solver can find solutions that remove all the conflicts reducing the number of potential ATC interventions.

The concept of preserving the TTA has been relaxed and the objective function penalizes the TTA violation. The reason for this is the limit of the trajectory elasticity, since speed adjustments are bounded to a percentage of the total RBT duration.

Furthermore, the quality of the solution found so far is directly linked to the solver search strategy. In this work, default parameters for searching have been used, leading to a solution where the smallest domain values at the delay variable are tested first. The search starts with -5 minutes of adjustment on the CTOT and, due to time restriction for finding a solution, possible better solutions cannot be explored by the solver. In consequence, the obtained total delay requires extra effort for recovering the TTA and, since the trajectory elasticity is limited, no acceptable speed change can be found to meet the TTA. Further research is required to define search strategies favoring the selection of adjustments close to zero in first term. This way speed adjustment efforts are expected to be smaller.

6. ACRONYMS

ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
AU	Airspace User
CP	Constraint Programming
CSP	Constraint Satisfaction Problems
CTOT	Calculated-Take-Off Time
DST	Decision Support Tool
JSSP	Job Shop Scheduling Problem
TBO	Trajectory Based Operation
TTA	Target Time of Arrival
TTO	Time-To-Overfly
RBT	Reference Business Trajectory
4DT	4-dimensional trajectories

ACKNOWLEDGMENTS

This research is supported by the European Union' s Horizon 2020 research and innovation program. The Project related to this research is PARTAKE "Cooperative departures for a competitive ATM network service" with Grant Agreement No. 699307. Opinions expressed in this paper reflect author's views only.

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- Production technologies//Logistics and Intelligent Transport Systems: modelling and simulation methodologies for production and logistics systems
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- Information and Communication Technology: distributed systems and real time systems
- Industrial collaboration and Technology transfer: real-time decision making tools for logistics and transportation problems.

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SIMULATING THE IMPACT OF INTER-REGIONAL RAIL DISRUPTIONS

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ABSTRACT

Rail disruptions can have severe consequences on inter-regional supply chains. To investigate such impacts and the resulting delays of shipments, this work introduces a simulation-based decision support system to model rail disruptions and corresponding supply chain vulnerabilities. Therefore, to enable a quick modeling approach and the generation of multiple disruptions scenarios, openly available road and rail network data are combined with simulation tools and open source routing and graph-theory libraries. This enables to automatically generate a high-level rail network to investigate various settings. As a result, critical links and industrial locations at risk are identified and decision-support is given.

Keywords: rail vulnerabilities, disruptions, simulation model, decision support system

1. INTRODUCTION

Rail networks are highly vulnerability to a wide-range of internal and external risks. Examples include natural disasters or extreme weather events such as earthquakes, mudslides or avalanches as well as man-made disasters. Impact on industrial locations of such events can be severe and may result in substantial increases in lead times and potentially even shortages in supply. As such disruptions occur with a low frequency; however, results in high damages, preparedness is further difficult to achieve. To improve such critical preparedness, modeling and simulation allows to improve supply chain resilience, improves understanding of supply chain risks and further enables to test various risk scenarios (Longo and Ören 2008).

In the context of rail disruptions and the resulting impact on supply chains, Fikar et al. (2016) introduce a decision support system (DSS) to simulate inter-regional rail networks. The provided computational experiments focuses on industrial locations in Tyrol, Austria and further enables transshipment at various terminals in Central Europe. A disruption of the 'Brenner Pass' is investigated and implications based on various disruptions scenarios are discussed. Expanding on this DSS, this work gives implementation details on the rail network generation based from openly available network data, introduces simulation components to model rail disruptions and further presents ways to incorporate extensions to the model. Consequently, the contribution of this paper is twofold: it introduces a simulation-based DSS to model the impact of inter-regional rail disruptions facilitating openly available network data and further provides guidance for the implementation of various extensions.

The remainder of this work is structured as follows: Section 2 introduces related literature with a focus on simulation literature. The generation of rail networks with openly available rail network data is presented in Section 3. Section 4 introduces the developed simulation to model traffic and rail disruptions. Results of a computational study simulating a disruption of the 'Brenner Pass' are presented in Section 5. Section 6 discusses results and implications of this work and concluding remarks are given in Section 7.

2. RELATED LITERATURE

Rail transportation is highly impacted by disruptions as networks are sparse, limiting the possibility of alternative routes in the case of rail closures. Nevertheless, even though this high importance, relatively little work on the vulnerability of rail networks is found in the literature (Mattsson and Jenelius 2015).

To investigate rail networks and rail disruptions, multiple authors use simulation approaches. Burgholzer et al. (2013) develop a traffic microsimulation to analyze disruptions in intermodal transport networks considering rail, road and inland waterways. Therefore, the authors apply both agent-based and discrete-event based simulation and facilitate various events to trigger changes in the system. In contrast to our work, the network has to be specified manually in advance and no impact on industrial locations in the study area is investigated. Rodríguez-Núñez and García-Palomares (2014) focus on the vulnerability of public transport networks. Therefore, the metro systems of Madrid is modeled and various random disruption scenarios are simulated to identify critical links in the system**.** Jansons et al. (2015) use Monte-Carlo multidimensional statistical modeling to model transportation risks. Various modes of transportation including rail shipments are considered to derive insurance-related premiums and the impact on cargo costs. In Gronalt and

Schindlbacher (2015), an agent-based simulation is presented to investigate intermodal freight transportation networks. Therefore, road and rail links as well as terminal operations are extensively modeled; however, in contrast to our work, no analysis of railway disruptions is included.

Beside the usage of simulation models, other common methods to study rail disruptions include optimization procedures (e.g., Peterson and Church 2008; Azad et al 2016) as well as semi-empirical methods (e.g., Dawson et al 2016).

3. RAIL NETWORK GENERATION

To generate the rail network, the DSS requires an input file specifying terminals and industrial locations with a railway sidings in the study area. Furthermore, a network file acquired from OSM (2016), preferably filtered to exclude redundant data such as walking and bike paths, has to be specified. This openly-available network includes both rail and street segments and is used in the DSS to generate a routing graph. Therefore, the open source routing library GraphHopper (2016) is facilitated.

In the first step, all terminals and industrial locations are geocoded and the network data is imported. Based on the coordinates of the locations, shortest paths between all locations on the rail network are calculated. In the following step, to exclude duplicate routes, each path is checked if it crosses any of the geocoded locations. If so, the path is removed. On the remaining paths, every single point of the route is compared to all points on other routes. If two paths merge or diverge at the same point, this location is stored as an intersection, the corresponding paths are split and the duplicates are removed. As a result of this procedure, each unique railway path between two intersections is modeled as an individual railway link, i.e. to travel between two locations, the train potentially passes multiple railway links crossing various intersections. This is required to consider capacity of the railway link in the simulation. In a final step, to model alternative routes in case of a disruption, the same procedure is repeated considering that each link is currently not available due to a disruption. Therefore, the weight of the link in the network is set to infinity. As a consequence, the shortest path does not contain this link, but instead takes the fastest alternative route. After all additional paths and intersections are added, the list of railway links and intersections is saved.

To reduce the set-up time, this data is imported at the start of each simulation experiments. At the start of a simulation run, a directed weighted graph is generated from the imported list of paths and intersections. Therefore, each path represent an arc in the graph, associated with the travel duration derived by GraphHopper (2016), while each intersection and imported location represent a vertex. This graph is used in the simulation to decide on routing decisions of each shipment.

To summarize, the following steps are performed to automatically generate the rail network from openly available network data:

1. Geocode locations and load network data.
2. Calculate shortest paths between each location.
3. Remove paths crossing any other location between origin and destination.
4. Find and add intersections between the remaining shortest paths.
5. Calculate alternative routes and add new paths and intersections.
6. Save paths and intersections to generate the routing graph for the simulation at the start of each simulation run.

Depending on the size of the study area, a symmetric or asymmetric representation can be selected. While the earlier allows one to reduce memory requirements and speeds up the generation of the rail network, the latter enables a more detailed modeling of rail capacities by considering driving directions. In our implementation, an asymmetric representation was selected.

3.1. Intermodality

To enable the option of switching the mode of transportation as a result of a rail disruptions, the routing graph is further extended by road links. Therefore, each shortest path on the road network between two locations is calculated and an arc for each connection is added to the graph. In our implementation, no capacities on the street network are considered. To model transshipments, additional arcs at the terminals are added. These arcs enable switching from the road to the rail network or vice versa. To consider time delays, the weight is set based on expected transshipment times at the terminal.

The same procedure can further be utilized to generate various mode of transportation such as inland waterways if network data is available.

4. DISRUPTION SIMULATION

Based on the generated rail network, a traffic simulation was developed to investigate the impact of disruptions (Fikar et al. 2016). Therefore, both elements from agent-based simulations, to model railway links as well as shipments and vehicles, and from discrete event simulations, to model queues at crowded railway segments and terminals, were incorporated.

4.1. Agent-based Modeling

Each arc in the graph is modeled as an agent. Therefore, the agent is specified with a capacity as well as with the calculated expected travel duration. To model rail movements, a FIFO-queue is assumed, i.e. the train which arrived first, is processed first and if the process is fully utilized, the remaining shipments wait. A similar approach is further implemented to model transshipments at terminals, for which only a limited number of resources are available to perform such tasks. To generate freight movements, each industrial location requests, based on a Poisson-distributed arrival rate, shipments from uniformly random terminal locations. Additionally, to set up a base utilization of the rail network, random transit shipments as well as passenger trains are added to the rail network. Therefore, it is assumed that passenger trains are always prioritized in the queues. Furthermore, a day-night cycle is implemented to consider the fact that less passenger trains travel at night by dynamically adjusting arrival rates.

4.2. Modeling of Rail Disruptions

To model disruptions, the simulation further includes an agent for each disruption. This agent is initialized with the coordinates of the disruption as well as a start and end time. These times trigger an event to start or end the disruption and to adjust the weight of the corresponding disrupted railway link, e.g. to set the travel duration on the arc to infinity in case of a complete closure. In the case of the start of a disruption, all agents currently on the railway link or in the queue, are rerouted. Therefore, as shown in Figure 1, the shipment agent can either wait at the disrupted railway link until the disruption is over or travel on an alternative route, which potentially includes a transshipment to the road network.

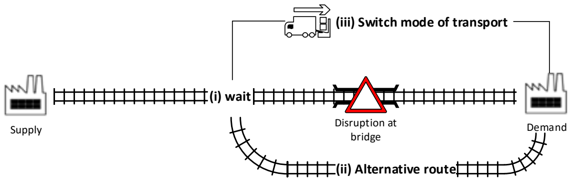

Figure 1: Potential agent decisions to a disruption

4.3. Modeling of Routing Decisions

In the simulation, it is assumed that each shipment aims to minimize its travel time to the destination and further has no knowledge on the planned routes of other shipments in the system; however, complete information on the current situation as well as the disruption duration is present. To perform routing decisions, each time a shipment agent reaches an intermediary stop, e.g., an intersection or a terminal, the agent calculates the remaining shortest path to the final destination and performs the next link on the derived route.

To consider utilization in the network, the corresponding weight of each railway link is constantly updated depending on the current number of agents waiting in the queue. Furthermore, in the case of a disruption, the remaining time until the disruption is over is added to the weight of the arc. As a consequence, the shipment either waits for the disruption to be over or travels a detour on open arcs, potentially including transshipments at terminals.

4.4. Modeling of Rail Restrictions

In the OSM data, various railway links are included. These are further specified with keys indicating the type of railway as well as specific features such as if the corresponding link is electrified or passenger-only. In specific cases, it can be of interest to exclude certain links as these are not relevant for the simulation experiments. This is enables in the DSS by simply setting a disruption, which is active for the entire simulation horizon, to the restricted link. As a consequence, both the rail network generation and the traffic simulation do not consider this link.

Additionally, it can be possible that certain trains are not enabled to traverse specific railway links, while other trains can. Potential reasons include operational restrictions such as gauges and the slope of the railway link as well as various regulative restrictions, e.g., driving bans for hazardous material. Therefore, each shipment agent is initiated with a list of restricted railway links based on the vehicle and shipment type. Before the routing is performed, these links on the routing graph are set to infinity. As a result, the routing algorithm calculates the shortest path on enabled railway links, while restricted links for this train are excluded from the routing procedure. After the calculation is performed, restricted arcs are reset to the initial value to reopen this connections for the following routing requests.

4.5. Modeling of Transshipment Restrictions

Additional restrictions may occur due to limited transshipment possibilities at terminals, e.g., due to a lack of specific equipment required to transship certain cargo types. To model such requirements, a similar approach as presented in the previous subsection is implemented. Therefore, each train is initialized with a list of restricted terminals and restricted arcs are set to infinity before the shortest path is calculated.

5. COMPUTATIONAL EXPERIMENTS

The simulation was developed with AnyLogic 7.2 (AnyLogic 2016) with network data from OSM (2016) to represent both road and rail networks. GraphHopper 0.4 (2016) was used to generate routing graphs and to calculate initial arc weights. The graph within the DSS was implemented with the Java library JGraphT (2016).

In the following part, results based from a study on the impact of a sudden closure of the alpine mountain range 'Brenner Pass', which connects Austria with Italy, are presented. The study area with a disruption of the Brenner Pass is shown in Figure 2.

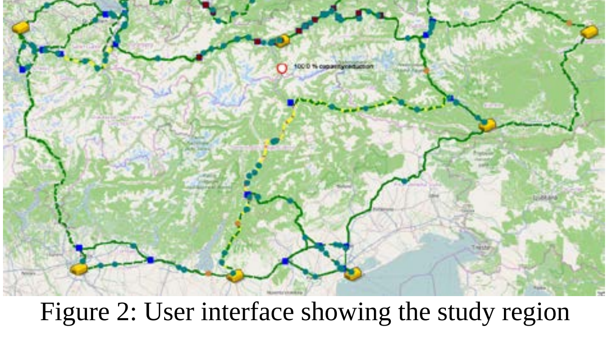

Figure 2: User interface showing the study region

To evaluate a disruption, the average disruption delay time (ADDT) is calculated, which states by how much time shipments are on average delayed (Burgholzer et al. 2013). Therefore, the actual travel duration is compared to the theoretical travel duration derived on the shortest path considering no wait times. Without disruptions of railway links, delays result from wait times at railway links due to insufficient capacity. In all scenarios, the simulation starts at midnight and simulates a full day to generate a base utilization. The disruption starts occurring at 11 am on the second day and lasts for a user-defined duration. Additionally, a full day after the disruption is over is simulated to consider the ramp-down period in which the system restabilizes. The impact of a 24 disruption scenario is shown in Figure 3. Therefore, the ADDT is reported with a single data point representing all shipments, which started in the stated hour, i.e. a value of 20 includes all shipments, which left a supply agent between 8 pm and 9 pm on the first day. All simulation experiments were executed with 250 replication runs and average values are reported in this section. Fluctuations are a result of the stochastic components of the individual simulation runs.

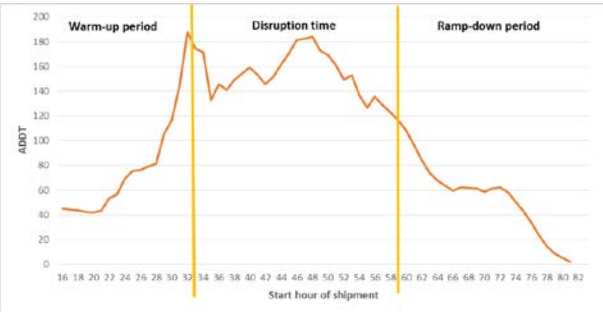

Figure 3: Development of the ADDT of all shipments started in the stated hour considering a 24-hour disruption of the Brenner Pass.

The results show that, as a consequence of the disruption, shipments are substantially delayed. Compared to a situation before or after the disruption, lead times are increased by up to 4.5 times. Additionally, even shipments, which are starting after the disruption is over, are severely affected as indicated in the first hours of the ramp-down period. As the system is overutilized as a consequence of the disruption, it takes multiple hours until the rail network restabilizes and delays are reduced.
In contrast, Figure 4 shows the development of the ADDT for a 72 hour disruption scenario.

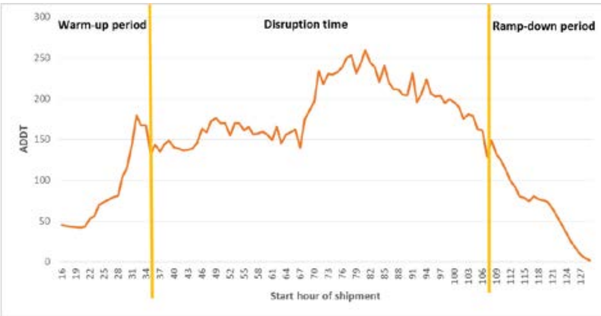

Figure 4: Development of the ADDT of all shipments started in the stated hour considering a 72-hour disruption of the Brenner Pass.

Similar to the 24-hour scenario, high delays result for shipments generated shortly before the disruption started. These shipments are travelling on the regular path and, due to the sudden disruption, required to perform costly rerouting actions. Shipments generated after the disruption occurred have more flexibility in the routing choices and can perform wide-ranging detours. Nevertheless, in case of a long disruption duration, the higher utilization at the alternative routes results in additional wait times, leading to a higher ADDT. As in the 24-hour scenario, at the end of the disruption, the system restabilizes.
In Figure 5, the impact of a disruption on the individual industrial locations in Tyrol is shown. Due to confidentially issues, all locations are anonymized.

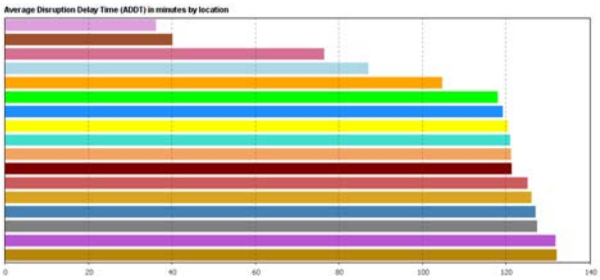

Figure 5: Impact of a 24-hour Brenner Pass disruptions for industrial locations located in Tyrol, Austria.

Depending on the geographic location as well as the individual shipping volumes, some industrial locations are more affected by a disruption. The simulation assists to identify such locations and further gives implications on the impact of various disruption scenarios.

6. DISCUSSION

Disruptions in rail networks can result in substantial delays. To quantify the impact on individual industrial locations as well as on the overall system, simulation is crucial. It allows investigating various disruption scenarios and further enables to test different policies and counter-measures. For instance, by simulating various scenarios, increased capacity as well as the impact of additional terminals or railway links can be analyzed. As a result, improved understanding on the impact of inter-regional rail disruptions is gained and preparedness can be improved.

To counteract rail disruptions, various strategies exists. Common measures to react to transport disruptions include: (i) take alternative routes, (ii) switch mode of transportation, (iii) wait for the disruption to be over or (iv) change to an alternative supplier (Georgia Tech Research Corporation, et al. 2012). While the first three options are included in the method introduced in this work, the fourth is more challenging to implement due to a lack of data and difference between individual industries. Nevertheless, as the focus is set on the critical hours and days after a sudden disruption occurs, it is unlikely that changes in suppliers, which are commonly pursued as a result of long-term disruptions, have a major impact on the shipping volumes assumed in the computational experiments.

7. CONCLUSSION

Combining openly available network data with simulation methods to investigate the impact of rail disruption allows a quick and flexible generation of different scenarios. This allows to identify critical links in the network as well as impacts of disruptions on various industrial and terminal locations in the study area. While this is an important first step to improve understanding of and preparedness to supply chain risks, future work is required to increase the potential of such methods for real-world applications. This includes the investigation of different rerouting policies or the development of optimization procedures to lower the total disruption delay time of all agents in the system.

ACKNOWLEDGMENTS

Financial support of the program KIRAS (7734010329) by the Federal Ministry for Transport, Innovation and Technology is gratefully acknowledged.

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AN INFORMATION FRACTAL FOR SUPPLY NETWORK INVENTORY OPTIMISATION

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ABSTRACT

This paper develops a new conceptual framework for an information fractal to optimise inventory across the supply network by identifying the optimum safety stock, inventory policy and cycle stock with the lowest logistics cost as well as out of stock prevention.

The proposed framework consists of two levels: top and bottom level fractals. Fractals in the bottom level analyse demand, optimise safety stock and recommend an inventory policy. Then transmit output to the top level fractal to investigate the effect of different replenishment frequencies to determine the optimum cycle stock for each fractal in the bottom level by integrating the inventory holding costs and transportation costs to minimise the logistics cost.

The proposed framework provides a systematic method through which practitioners are able to decide upon the demand analysis, safety and cycle stock optimisation.

Keywords: Fractal supply network, supply network modelling, and inventory optimization.

1. INTRODUCTION

In today's competitive world, increased competitiveness in the global business environment and improvements in manufacturing technology mean that traditional production management methods that have failed to improve the integrity of their processes have lost their effectiveness; companies need to create systematic integration in all production processes from supplier to the final consumer. Supply chain management as an integrated approach has the ability to meet these requirements to manage the flow of raw materials and final products, information and funds. Supply chain integration allows companies and their suppliers to act together, leading to performance improvement through the chain (Kannan & Tan, 2002). The major responsibilities within the industrial units are planning and inventory control. Despite the costs associated with inventory holding, having an inventory is inevitable for supply chain members because inventory shortages can lead to irrecoverable losses including stopped production, loss of sales opportunities, damage to the reputation of the organisation and so on. Inventory control strategies in the supply chain management are classified as either centralised inventory control (Gross, 1963; Zheng & Zipkin, 1990; Marklund, 2002) or decentralised inventory control (Andersson & Marklund, 2000; Jemai & Karaesmen, 2007; Hall & Zhong, 2002). In terms of centralised inventory control, decisions in the supply chain can be made by a centralised decision maker who has access to all the necessary information to improve system performance; this situation is possible when the whole supply chain is under the control of a centralised decision maker who has a high level of coordination and communication with other members in the supply chain. None of the members (e.g. supplier or retailer) can control the entire supply chain and each of them has their own goals and priorities to optimise their individual performance. Therefore, each member controls and manages their inventory position and places orders to their resources based on their own priorities; in such cases, the inventory control strategy is categorised as decentralised. In this study, an information system based on fractal features is developed which is a combination of both centralised and decentralised inventory control. Each member in the supply chain has a responsibility to analyse the demand of its downstream members, determine its safety stock, inventory reorder point and inventory policy, and share with the information centre in the chain. This in turn must determine the optimum cycle stock for each member to minimise the logistics costs in the supply chain by integrating both inventory holding costs and transportation costs.

Among all areas of potential improvement in supply chain management, information sharing is of greatest interest. When a company uses information from other companies in the supply chain, the negative effects of uncertainty in the modern business environment such as high inventory levels, wrong demand forecasts and defective orders can be reduced. To have the greatest improvement in organisational performance and increase their competitive advantage, firms can take advantage of information technology to develop information sharing and knowledge capabilities throughout the whole supply chain (Wagner & Buko, 2005). It has been noticed that there was few reported research articles tried to show the benefit of information sharing in supply chain inventory management although most of the models that were introduced were relatively simple and developed in a two- or three-stage supply chain. Gavirneni, Kapuscinski, & Tayur (1999) investigated and analysed the benefits of information sharing in a two-echelon supply chain by considering one supplier and one retailer with several levels of information sharing, including when there is no demand for information flow to the supplier except historical data, when the supplier has information regarding the type of inventory control policy and demand distribution of the retailer and, in the third level, when the supplier has full access to the retailer's daily inventory position. Lau, Huang, & Mak (2004) analysed the effect of information sharing on inventory replenishment in three-stage supply chains with one manufacturer, distribution centres and retailers. They investigated four types of information sharing among nodes, including order information sharing among nodes, demand, safety factors and inventory information sharing from retailers to their distribution centres, sharing retailers' order information with manufacturers from distribution and order information sharing from retailers to distribution centres and from distribution centres to manufacturers. Lee, So, & Tang (2000) developed a simple two-stage supply chain with manufacturer and retailer and indicated how the manufacturer can achieve benefits from information sharing by decreasing the inventory and saving costs directly.

In this case, a conceptual information fractal framework is developed by considering multiple retailers, distribution hubs, manufacturers, supplier facilities and information chain centres which are also considered as fractals separately. Each fractal has its own structure but with the same inputs and outputs, the ability to choose and use appropriate methods to optimise itself and divide large problems into small ones, and perform a goal-formation process to generate their own goals by coordinating processes with the participating fractals, modifying goals if necessary. Finally, each fractal has the ability to adapt to the dynamically changing environment.

2. THE PROPOSED FRAMEWORK FOR THE INFORMATION FRACTAL SUPPLY NETWORK (IFSN)

Figure 1 displays the new proposed framework of an IFSN with two levels including an information fractal chain centre as a top level fractal and an information fractal supplier's facility, information fractal manufacturer, information fractal distribution hub and information fractal retailer as bottom level fractals. In this paper, the information fractal structure for each fractal consists of five functional models including observer, analyser, resolver, organiser and reporter as a basic fractal unit (BFU) (Ryu, Moon, Oh, & Jung, 2013).

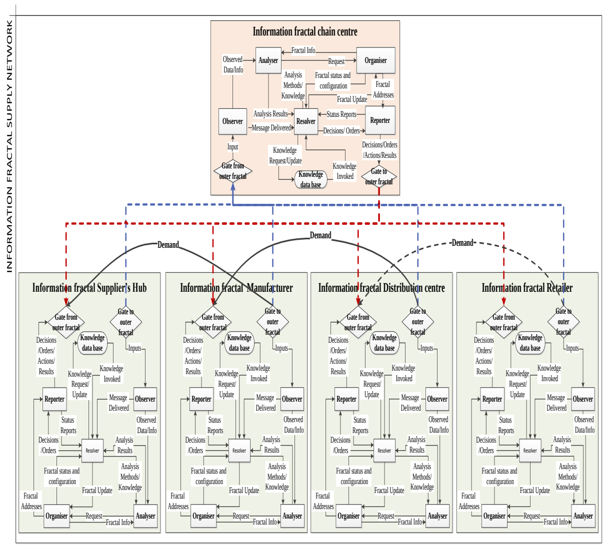

Figure 1: The proposed framework for an Information Fractal Supply Network (IFSN)

In the bottom level fractal, observers as an input gate of each fractal must monitor, trace and receive data and messages (e.g. demand) from outer fractals (e.g. retailer, distribution hub, manufacturer) and the environment (e.g. customer). Observers in the sourcing fractals trace and receive the demand from destination fractals, transmit the demand data to analysers and notify resolvers receiving the demand.

Analysers use an appropriate method to analyse current demand based on a set of demand statistics to determine demand class and then transmit it to resolvers. The demand class enables resolvers to recognise different types of demand and allocate an appropriate method to calculate safety stock. Resolvers determine the expected safety stock, recommending inventory policy and inventory policy parameters as part of the safety stock optimisation. Organisers in all the fractals, including top and bottom level fractals, observe, control and manage the fractal structure to adapt to the continuous change in the environment. Reporters as an output gate have a responsibility to report fractal outputs to outer fractals. In the bottom level fractal, reporters report resolvers' decisions regarding expected safety stock, inventory policy and associated parameters to the fractals in the top level.

In the top level fractal, observers trace and receive decisions which are made by each fractal in the bottom level (e.g. safety stock, inventory policy and so on.), transmit them to analysers and notify resolvers. Analysers investigate and analyse the different amounts of cycle stock on both transportation costs and inventory holding costs based on replenishment frequencies for each fractal in the bottom level. Resolvers integrate inventory holding costs and transportation costs based on analysers' reports to achieve an optimum amount of cycle stock with the lowest logistics cost for each non-production fractal and also determine the optimum production frequency for the production fractals. In the top level fractal, reporters report resolvers' decisions regarding optimum cycle stock, production and replenishment frequencies to the fractals in the bottom level. This paper concentrates on two main functions, analyser and resolver, to optimise both safety stock and cycle stock in the supply network.

2.1. Bottom level fractal

It is important to determine how much inventory must be held against the variability in both demand and lead times. Therefore, understanding the demand variability is essential to calculate safety stock. Analysers in the bottom level fractal use an appropriate method to analyse demand based on a set of demand statistics. During the demand analysis process, demand is aggregated, outliers are recognised and a set of demand statistics is provided. Analysers use demand statistics and demand classification threshold values to determine the demand classification (e.g. Slow, Lumpy, Erratic and Smooth).

Analysers perform the following steps to analyse current demand:

- Step 1: Determine aggregate demand for the specified aggregation period which can be based on daily, weekly and monthly demand.
- Step 2: Provide a set of demand statistics to classify the demand.
- Step 3: Classify demand based on demand statistics which are provided in step 2.

To set up a demand class, analysers use set demand classification thresholds that affect how demand is classified and how analysers determine the appropriate approach for safety stock calculation. Demand classification thresholds include demand frequency, intermittency and dispersion which determine by non-zero demand count (M_{NZ}), inter-demand interval mean (p) and squared coefficient of variation of non- zero demand (CV^2_{NZ}), respectively. Outlier, variability and clumpiness are specified by non-zero demand standard division (σ_{NZ}). Demand classification threshold values are determined based on the firm's conditions (see Figure 2).

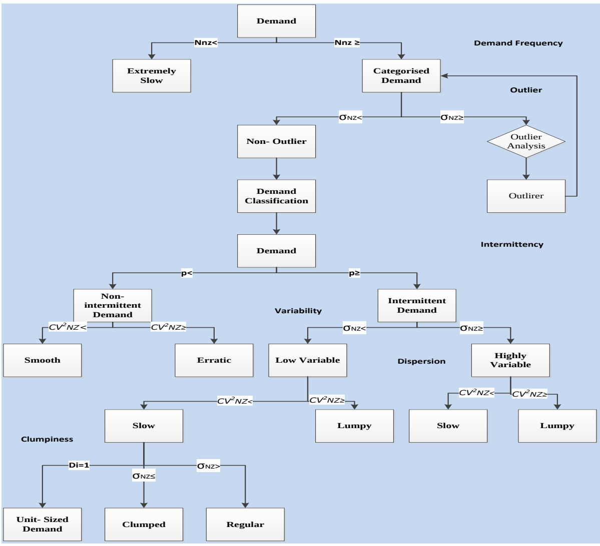

Figure 2: Demand classification diagram

An extremely slow class will occur when the demand count is lower than the demand count adjusted in the demand classification thresholds. This class has a large inter-demand interval mean.

Analysers recognise outliers based on non-zero demand standard division and non-zero demand mean values during the demand classification process:

- If (σ_{NZ}) is less than the default number in the demand classification threshold, analysers ignore the outlier recognising process and continue to demand classification.
- If (σ_{NZ}) is greater or equal to the default number in the demand classification threshold, the outlier recognising process is started. Analysers consider the aggregation period with the largest demand size and determine it as an outlier if it is greater or equal to (σ_{NZ}) in the demand classification threshold *(μ_{NZ}) from the rest of the demand.

There are two options for analysers for handling the outliers:

- Outliers are considered in the demand statistics where they were recognised.
- Replace outliers with the demand mean of the rest of the demands which are smaller than the outlier and recalculate the non-zero demand standard deviation and return to the first step of the process.

Intermittency specifies how frequently demand occurs, based on the average time between adjacent demands.

- If the average time between the demands is lower than the intermittency threshold, it is known as non-intermittent demand. It means that demand happens regularly with few exceptions during the demand period. If (CV^2_{NZ}) is greater than the default number in the threshold, this demand is classified as erratic and if (CV^2_{NZ}) is less, the demand is classified as smooth.
- If the average time between the demands is greater than the intermittency threshold, it is known as intermittent demand. It means that there is irregularity of when demand happens during the demand period. Intermittent demand can be considered as a low or high variable, and is slow or lumpy. Low variable demand has a lower (σ_{NZ}) in comparison to highly variable demand, and slow demand has a lower (CV^2_{NZ}) in comparison to lumpy demand.

Clumpiness shows how demand points are close to each other and has a reasonably fixed demand with variability close to zero. The demand size for unit-sized demand is always one, and there is no variability for this demand class.

Once analysers have finished the demand analysis, resolvers start to specify the required safety stock by considering demand and lead-time variability. Resolvers use a target service level to calculate optimum safety stock. Service level is a measure to indicate a fractal's ability to provide products to downstream fractals.

There are different types of service level which are used in industry including type 1 (probability of not stocking out), type 2 (fill rate) and type 3 (ready rate). In this research paper, service level type 1 is used. Resolvers in the bottom level fractal determine the safety stock level, inventory policy and reorder point as part of the safety stock optimisation.
There are three models to calculate safety stock and reorder point which may happen during the demand period (Heizer & Render, 2014):
The following notation is adopted:

- SS =Safety stock
- σ_{dLT} = Standard division of demand during the lead time
- σ_d= Standard deviation of demand per day
- LT=Lead time
- Z= Service level
- ROP= Reorder point
- μ_{dLT}= Demand mean during the lead time
- μ_d= Average daily demand
- d_D= Daily demand
- σ_{LT}= Standard deviation of lead time in days
- μ_{LT}= Average lead time

2.1.1. Demand is variable and lead time is constant

$$SS=Z\times\sigma_{dLT} \quad (1)$$

where:

$$\sigma_{dLT}=\sigma_d\times\sqrt{LT} \quad (2)$$

and

$$ROP=\mu_{dLT}+Z\sigma_{dLT} \quad (3)$$

where:

$$\mu_{dLT}=\mu_d\times LT \quad (4)$$

2.1.2. Lead time is variable and demand is constant

$$SS=Z\times d_D\times\sigma_{LT} \quad (5)$$

and

$$ROP=(d_D\times\mu_{LT})+Z\times\sigma_{LT} \quad (6)$$

2.1.3. Both lead time and demand are variable

$$SS=Z\times\sigma_{dLT} \quad (7)$$

where:

$$\sigma_{dLT}=\sqrt{\left(\mu_{LT}\times\sigma_d^2\right)+(\mu_d)^2\times\sigma_{LT}^2} \quad (8)$$

and

$$ROP=(\mu_d\times\mu_{LT})+Z\times\sigma_{LT} \quad (9)$$

As part of the safety stock optimisation, resolvers define the demand series and lead time demand distribution parameters; they specify a lead time demand distribution and determine an inventory policy. Resolvers use demand class and lead time demand distribution which is determined based on the lead time demand distribution parameters (lead time demand and lead time demand standard deviation) in order to recommend inventory policies (see Table 1).

Table1: Inventory policy recommendation based on demand class lead time demand distribution

Demand Class Details	Lead-Time Demand Distribution	Policy
Extremely Slow	None	Make-to-Order
Smooth	Normal	R,Q
Erratic	Mixture of Distributions	s, S
Slow-Low Variable	Poisson/Mixture of Distributions	Base Stock
Slow-Highly Variable	Poisson/Mixture of Distributions	s, S
Lumpy	Negative Binomial	T,S

2.2. Top level fractal

As part of the cycle stock optimisation in the supply network (Saad and Bahadori, 2015), analysers of the fractals in the top level have to measure the replenishment cycle stock of both finished products and components, inventory holding costs and transportation costs by investigating different days between replenishment during the demand period. Therefore, mathematical equations governing the problem of cycle stock replenishment, inventory holding costs and transportation costs are presented in the following sections:

- To calculate replenishment cycle stock in a supply network, analysers consider the days between replenishment; period time and the flow quantity per period from source fractal to destination fractal, which is the sum of the total demand and safety stock (see equation 10 and 11).

$$RCS=DBR\times\left(\frac{q_{i\to r}}{2T}\right) \quad (10)$$

where:

- RCS= replenishment cycle stock
- DBR = days between replenishment
- q = flow quantity per period
- i= the index for source fractal
- r= the index for destination fractal

- T= period time

where:

$$q_{i\rightarrow r} = TD + SS \quad (11)$$

where:

- TD= total demand.

➢ The inventory holding cost of components in each fractal in the upstream stage can be calculated using total components inventory which is the sum of the safety stock, replenishment cycle stock and the in-transit component inventory where the in-transit component inventory comprises components that are on order but have not arrived, component value, time period and inventory carrying cost (see equations 12, 13 and 14). The inventory holding cost in each fractal in the downstream stage can be calculated using total finished products which is the sum of the safety stock, cycle stock and in-transit finished products inventory where the in-transit component inventory comprises finished products that are on order but have not arrived, product value, time period and inventory carrying cost (see equations 15, 16 and 17).

$$IHC_{(C)} = T_{(CI)} \times C_{(v)} \times \frac{T}{365} \times I_{(cc)} \quad (12)$$

where:

- $IHC_{(C)}$ = inventory holding cost of components
- $T_{(CI)}$ = total components inventory
- $I_{(cc)}$ =Inventory carrying cost

where:

$$T_{(CI)} = SS + RCS + IT_{(CI)} \quad (13)$$

where:

- $IT_{(CI)}$ = in-transit component inventory

$$IT_{(CI)} = \frac{q_{i\rightarrow r} \times t}{T} \quad (14)$$

where:

- t= Transportation time

$$IHC_{(Pr)} = T_{(Pr)} \times Pr_{(v)} \times \frac{T}{365} \times I_{(cc)} \quad (15)$$

where:

- $IHC_{(Pr)}$ = inventory holding cost of finished products
- $T_{(Pr)}$ = total finished products inventory

where:

$$T_{(pr)} = SS + RCS + IT_{(PrI)} \quad (16)$$

where:

- $IT_{(PrI)}$ = in-transit finished products inventory

where:

$$IT_{(PrI)} = \frac{q_{i\rightarrow r} \times t}{T} \quad (17)$$

➢ To calculate transportation cost, analysers determine the number of shipments during the demand period between the source fractal and destination fractal by dividing the flow quantity per period from source fractal to destination fractal to the replenishment quantity (see equations 18 and 19).

$$NOS = \frac{q_{i\rightarrow r}}{RQ} \quad (18)$$

where:

- NOS = numbers of shipment
- RQ= replenishment quantity

where:

$$RQ = DBR \times \mu_d \quad (19)$$

As one of the fractal units, analysers use the number of shipments to specify total travel distance from source fractal to destination fractal (see equation 20).

$$T_{td} = td \times NOS \quad (20)$$

where:

- T_{td} = total travel distance
- td=travel distance

Finally, transportation costs from source fractal to destination fractal are calculated using equation 21:

$$T_{(c)\, i\rightarrow r} = T_{td} \times A_{(C)} \quad (21)$$

where:

- $T_{(c)\, i\rightarrow r}$ = transportation cost from source fractal to destination fractal
- A(c) = average transportation cost per mile.

Since different numbers of days between replenishments were investigated among fractals by analysers, resolvers integrate both inventory holding costs and transportation costs to choose the best match and find the optimum amount of cycle stock to achieve lower total logistics cost among fractals. Moreover, resolvers determine the optimum production frequencies for the production fractals based on logistics cost optimisation results.

3. CONCLUSION

In this paper, a new proposed framework for the information fractal with two levels named top and bottom level fractals was proposed to manage and optimise inventory in the supply network. Fractals In the bottom level traced observed and analysed its downstream fractal demand and determined optimum safety stock and inventory policy which in turn shared with fractal information centres in the top level fractal. Based on these information, information fractal chain centres of the top level fractal achieved the lowest total logistics cost among fractals of the bottom level fractal by integrating both inventory holding costs and transportation costs and determined and shared optimum cycle stock for each fractal. It is expected that one of the benefits of the proposed framework is the increase of both collaboration and integration through the supply network. Moreover, it will provide a systematic method through which practitioners should be able to decide upon the demand analysis, optimisation of both safety stock and cycle stock.

Examining the proposed framework to explore its benefits was reported for future work through which it will be applied on real supply network utilising simulation software, mathematical programming and full experimental design techniques to consider all the combinations with a full statistical analysis in order to have a comprehensive set of results, which may lead to possible generalisation. This work has been commenced and will be reported in different research paper in near very future.

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ASSESSING SERVICE QUALITY IMPROVEMENT THROUGH HORIZONTAL COOPERATION IN LAST-MILE DISTRIBUTION

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ABSTRACT
Horizontal cooperation is a relevant strategy that logistic service providers can follow in order to achieve greater efficiency. While literature has mainly focused on economic benefits, this article discusses the impact of horizontal cooperation on service quality in last-mile distribution. An agent-based simulation model is introduced to assess savings in lead times due to various horizontal cooperation agreements under consideration of trust related factors. Results of computational experiments show that cooperation enables companies to reduce lead times substantially, which increases service quality and competitiveness.

Keywords: Horizontal Cooperation, Coalition, Service Quality, Simulation, Last-mile Distribution

1. INTRODUCTION

Companies are facing significant challenges in their logistics activities. Growing competition due to globalization as well as increasing customer expectations on service quality require firms to be more efficient and competitive in the management of distribution operations. These issues are especially important for small and medium-sized enterprises (SME) that usually do not have the economic, human and technical resources needed to solve complex mathematical models related to logistics optimization. Additionally, in Europe, the logistics service providers (LSP) sector is often highly diverse, being mainly made of small companies, which are often family-owned (Cruijssen et al. 2007). Thus, unlike large companies, SME can only take limit advantage of economies of scale and, therefore, require innovative concepts in order to stay competitive.

In order to facilitate competitiveness, SME can follow cooperation strategies with other companies. Interfirm agreements imply, on the one hand, maintaining an independent legal personality and, on the other hand, the establishment of processes, protocols, or frameworks that enable the cooperation in business-related projects such as logistics activities. When cooperation takes place between companies that belong to the same echelon of the supply chain, it is commonly denoted as horizontal cooperation (e.g., Lambert et al. 1996, European Union 2001, Cruijssen et al. 2007). Therefore, horizontal cooperation is a particular typology of interfirm collaboration, in contrast to vertical collaboration where agreements take place among different stages of the supply chain, i.e., between suppliers, manufacturers and retailers. Supply Chain Management (SCM) aims to efficiently integrate the actors that are active within a particular supply chain in order to provide products in the right quantity as well as at the right time and location in such a way that total costs of all actors are minimized and service level is satisfied (Chopra and Meindl 2016). While numerous work on SCM is found in the literature, horizontal cooperation is still in its early stages (Leitner et al. 2011).

Concerning horizontal cooperation, last-mile distribution, the link between the supply chain and the final destination, is of particular interest as it is responsible for up to 28% of total logistics costs (Roca-Riu et al. 2012). This delivery often takes place in urban environments, in which case it is commonly denoted as urban freight distribution. Even though urban distribution has a key role in the economic development of cities, it has many challenges to cope with (Taniguchi et al. 2016) as urban areas are growing rapidly. According to the United Nations (2014), 54 % of the world's population was living in urban areas in 2014 and 66 % are expected to do so by 2050. Additionally, the rapid development of information and communication technologies have led to new sales channels such as e-commerce (Deloto and Chen-Burger 2015), further increasing urban freight distribution. Thus, efficiency in urban distribution, i.e. enabling higher frequency in deliveries and shorter times, is a key factor for the competitiveness of urban LSPs.

To support last-mile distribution and to investigate the impact of horizontal cooperation, this article evaluates benefits derived from the implementation of various horizontal cooperation agreements from a customer point of view. Therefore, the objective is to reduce lead times and the focus is set on a medium-term time frame of up to 90 days. To consider agents behavior and interdependencies between various actors, an agent-based simulation is presented. Therefore, the contribution of this work is two-fold: it introduces a methodology to model horizontal cooperation in last-mile distribution and discusses potentials and impacts on service quality. The remainder of this paper is structured as follows: Section 2 introduces related literature. The agent-based simulation is presented in Section 3 and results of the computational experiments are presented and discussed in Section 4. Concluding remarks are given in Section 5.

2. LITERATURE REVIEW

In literature, different definitions of horizontal cooperation exist. Lambert et al. (1996) define horizontal cooperation as a tailored relationship that it is based on trust and openness with the aim of obtaining a competitive advantage in such a way that conjoint performance is greater than the one that the individual actors would achieve individually. In contrast, the European Union (2001) defines horizontal cooperation as concerted practices between companies that operate at the same level in the market. In Cruijssen et al. (2007), it is seen as an interesting approach to decrease costs, improve service quality or protect market positions. Moreover, Bahinipati et al. (2009) denote horizontal collaboration as a business agreement between two or more firms at the same level in the supply chain in order to achieve a common goal.

As shown by the definition above, the main focus is on sharing activities or information in order to reduce costs. Therefore, the key is that through sharing information, it is possible to take advance of greater economies of scale by optimizing the overall systems instead of each partner individually. Nevertheless, sharing data and information requires a high degree of trust, which is, commonly, a major obstacle in corporate collaboration (Zeng et al., 2015). Expanding on these definitions, the following integrated definition of horizontal collaboration is considered in this work:

Horizontal cooperation is an agreement, tacit or not, which involves more than one company without vertical relationship between them (i.e. no supplier-customer relationship) based on trust and mutual commitment to identify and exploit win-win situations with the goal of sharing benefits (or risks) that would be higher (or lower) than each company would obtain if they acted completely independently.

Difficulties to ensure relationships, to find suitable partners and to allocate profits/risks as well as complexity resulting from information sharing are, among others, the major barriers to implementation of horizontal agreements (Cruijssen et al. 2007). A taxonomy to classify horizontal cooperation agreements in three different types depending on the degree of trust is presented in Lambert et al. (1999). Therefore, a 'Type I' cooperation denotes agreements in which the involved companies coordinate their activities on a limited basis for a very short time. A 'Type II' relationship, in contrast, indicates medium term agreements for an entire project duration and a greater level of coordination, while under a 'Type III' cooperation, organizations have a high level of integration for an unlimited duration. Within the simulation presented in this work, these different types of horizontal cooperation are implemented based on a modelled trust parameter.

In last-mile distribution, horizontal cooperation may occur from two perspectives: (1) unrelated, but horizontal, companies that aim to cooperate in their logistics processes and (2) LSPs cooperate to carry out joint activities. Therefore, reducing transportation cost is primarily the key enabler to start a coalition (Lehoux et al. 2014), while other factors receive little attention in the literature (Cruijssen et al. 2010; Schmoltzi and Wallenburg 2011). Nevertheless, some work focuses on the reduction of emissions. In Perez-Bernabeu et al. (2015) a reduction of about 20 % in emission costs as result of horizontal cooperation is recorded, while Schulte et al. (2015) lower emissions by reducing empty trips. The impact on service quality is rarely investigated. Ghaderi et al. (2016) study the impact on lead times of cooperation agreements. Therefore, the authors collected real-world data of various cooperations over a 14-month period. Results show significant reductions of 30.8 % in lead times as well as in the variance. In contrast to our work, no simulation is employed and the impact of trust is not investigated.

Additionally, the creation of business coalitions may be supported by game theory (Guajardo and Rönnqvist 2015). Being part of a coalition must imply the value of the coalition is at least as good as the sum of the values of its members individually, e.g., a coalition is not formed if not beneficial. Furthermore, in practice, many additional reasons might exist against forming a coalition. These reasons usually have to do with managerial complexity or legal issues that make the alliance difficult to coordinate and costly (Lozano et al. 2013). Additionally, according to the Treaty on the Functioning of the EU (European Commission 2007), anticompetitive behavior is forbidden in the cases of agreements and business practices which restrict competition and/or abuse dominant positions; however, some exemptions apply in rail, road and inland waterway transportation, e.g., if agreements look for technical improvements or to achieve technical cooperation (European Commission 2009).

3. METHOD

An agent-based simulation was developed using the software package Anylogic 7.3 (AnyLogic 2016) to study the introduced problem settings. Therefore, wholesalers, stores, i.e. customers, orders and vehicles are individually modelled as agents in geographic space. Wholesalers are the agents that may cooperate in order to improve service quality for their customers. In the initial scenario, a pure competitive setting is assumed in which no horizontal cooperation exists, i.e. no information or customers are shared. Each wholesaler has its own customer base that is served if a product is requested.

Store agents are small shops in the study area with almost no stock- (micro enterprises). This kind of shops are typical in the urban environment and usually do not have access to complete information about the wholesaler market. In the simulation, stores are assumed to employ an (s,S) inventory policy (Arrow et al. 1951). Therefore, when the inventory level falls below a minimum value, denoted by ‘s’, the store will generate a request for a replenishment order that will restore the inventory to a target value, denoted by ‘S’. This is triggered by an event in the simulation. To initialize the simulation, each store is set up with a random value for both ‘s’ and ‘S’. Using a demand function constant in quantity but randomized in ordering time, inventory levels decrease during the day to simulate sales.

Transportation of products from wholesaler locations to store locations is performed by vehicle agents. Therefore, each wholesaler has its own and homogeneous vehicle fleet.

Vehicle motion is reflected in the Figure 1. Due to last-mile distribution and stores’ characteristics, it is assumed that once an order occurs, it must be delivered as soon as possible. Starting at the wholesaler warehouse, each time a replenishment at a store is requested, an order is generated. These agent orders are processed in the wholesaler management office. Consequently, the products are loaded in the vehicles and moved to the costumer site. After unloading, vehicles return to the wholesaler location. Concerning information, we are using real data in roads and driving times because vehicles travel on the shortest path calculated with network data taken from OpenStreetMap (OpenStreetMap, 2016).

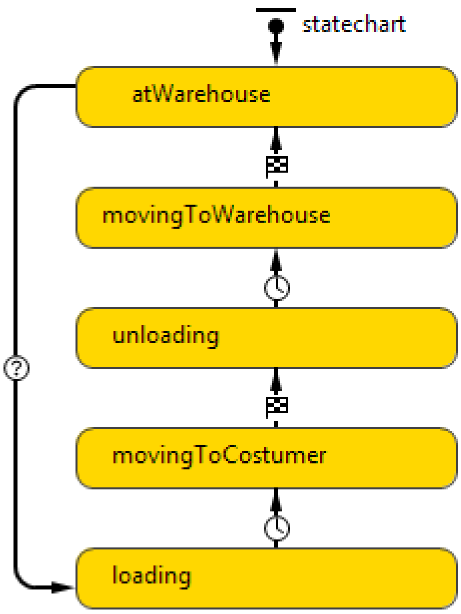

Figure 1: Vehicles motion

3.1. Assumptions

The agent-based simulation model is based on various assumptions in order to allow modeling the problem setting. Therefore, wholesalers have identical cost structures and they provide their logistics service at a given and competitive price that cannot be changed in the short run. As a result, service quality (measured by lead-times) is the only determinant for a store to choose its wholesaler. A 3-month time-horizon is selected to simulate the coalition behavior in the medium time frame. This time period is simulated in which the small wholesalers engage in forming a coalition based on types I and II cooperations. Moreover, in the long run some stores may open or disappear and the coalition may evolve to more formal agreements. Likewise, new wholesalers may enter in the market or existing agents may exit from it or change their cost structures. While this factor can be easily added to the simulation, based on the medium-term focus of the simulation, such factors are not considered in the computational experiments.

3.2. Cooperative Behavior

Each time an order arrives, the store served evaluates the shipment concerning the achieved service quality, measured by the lead time. Therefore, a threshold value is implemented to consider the expected lead time of the store. This threshold is calculated by the best potential lead time considering the closest wholesaler and no shipping delay multiplied with a tolerance parameter. If products are delivered before this threshold, a positive performance point is given to that wholesaler, otherwise, a negative performance point. Additionally, an extra point is given if the current shipment was shorter than the average lead time, otherwise, a negative performance point. At the end of the working day, the wholesaler with the least performance points (the wholesaler with the weakest performance, namely wholesaler A) starts a coalition with another wholesaler in order to stay competitive. Nevertheless, wholesaler A will take some time to choose a partner to make the coalition. The partner eventually chosen (namely wholesaler B) will be someone that also has a motivation to make the coalition due to negative customer evaluations (least performance points). After this contact, A and B start a type I cooperation to improve the respective service levels. In this context, type I cooperation implies limited information sharing about their customers in such a way that A and B maintain the same shipping volume respectively, but potentially swap customers in order to improve service levels. After another evaluation period, the coalition is assessed with two potential outcomes:

1. Service quality improved as a result of the coalition.
2. Service quality did not improve as a result of the coalition.

If (1), trust in the coalition will increase, and, therefore, the likelihood of raising the degree of cooperation and/or enlarging the coalition with new members will increase as well. If (2), trust in the coalition will decrease, and therefore, the likelihood of raising the degree of cooperation and/or enlarging the coalition with new members will decrease as well. Based on the coalition trust achieved over time, a coalition potentially upgrades to a type II cooperation. In the type II cooperation, wholesalers share not only information about their customers but also orders. This implies that a coalition acts as a whole firm pooling all the customers and assigning them to the most appropriate wholesaler. Thus, the total profit will increase; however, the distribution among the members of the coalition may differ. Therefore, as the trust in the coalition is high, it is assumed that this factor will be offset by profit-sharing agreements. Additionally, if the coalition service quality improves, other wholesalers may be interested in joining the coalition. In such a case, a type I cooperation with the coalition is started and again evaluated based on the performance.

4. RESULTS AND DISCUSSIONS

The model was tested with 26 wholesalers and 273 stores, which interact in a geographic space based on spatial data originating from Vienna, Austria. An overview of the problem setting is shown in Figure 2, with stores indicated in green and wholesalers indicated in red (if currently not in a coalition) and gold (if currently in a coalition). The graphical user interface further shows customer orders, plots routes of vehicles performing the last-mile distribution and further gives various statistics and results to the model user.

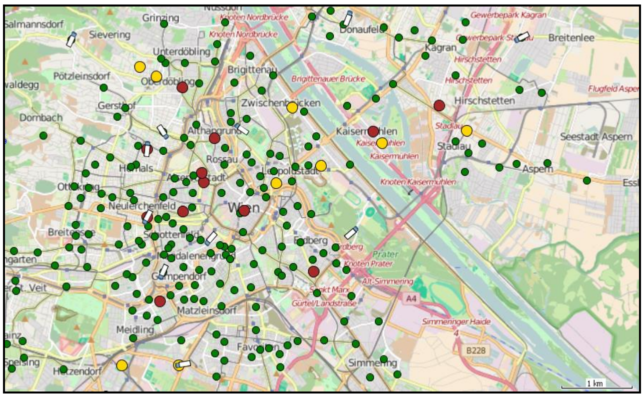

Figure 2: Simulation user interface

Table 1 shows the savings in lead times compared to a non-cooperative scenario based on 100 replications of the simulation experiments for each setting. On average, cooperation improves lead times by 24 %, indicated by the 'System' row, ranging from a minimum of 14 % to a maximum value of 39 %. 'Customers' and 'Wholesalers' saving rows are computed only for the setting where cooperation is enabled. In those cases, savings are calculated comparing lead times before cooperation started and after the wholesaler joined the coalition. When cooperation is enabled, degree of cooperation, i.e. type I and II, may evolve within the members of the coalition. Depending on the individual store, average savings range from 18 % to 45 %. From the wholesaler's point of view, its lead times decrease on average between 15 % and 48 %.

Figure 3 shows the distribution of average lead times (vertical axis) allowing cooperation (cooperation= 1) and without allowing it (cooperation= 0). Fluctuations in the individual replications are larger when cooperation does not take place. As a result, cooperation reduces not only lead times but also uncertainty in delivery lead times.

Table 1: Savings in Lead-Times vs No Cooperation

	Min	Max	Average
System	-14%	-39%	-24%
Customers	-18%	-45%	-30%
Wholesalers	-15%	-48%	-30%

The system's behavior (i.e. taking into account all wholesalers) is illustrated in Figure 4, where the vertical axis corresponds to performance points and the horizontal axis corresponds to time. The negative performance at the beginning of the simulation horizon indicates that, on average, wholesalers are not fulfilling store requirements in terms of lead time. After some time, coalitions start to form as wholesalers start cooperating. As a result, the wholesalers' performance improves considerably.

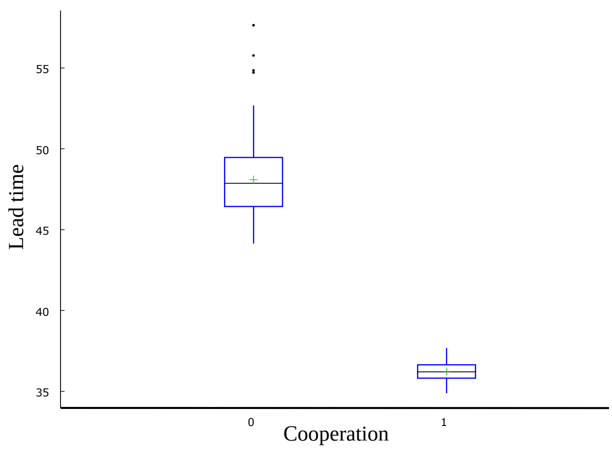

Figure 3: Distribution of times by cooperation

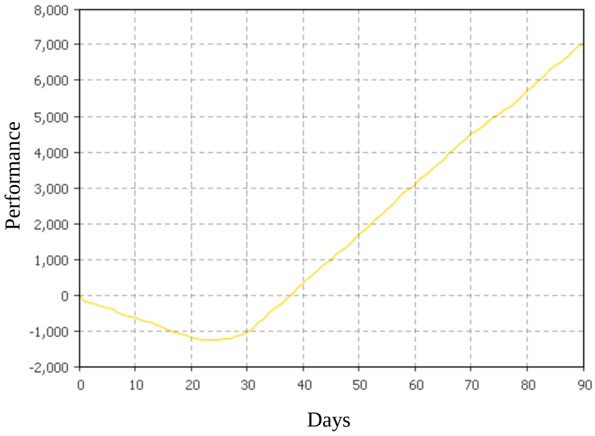

Figure 4: Wholesalers' performance in a single run

Nevertheless, considering the particular performance of individual wholesalers, four different outcomes can be identified. These are shown in Figure 5. The most common behavior is the one on the top in which cooperation helps the wholesaler to improve the performance. In Figure 5.1, the wholesaler is performing poorly and forced to start the coalition in order to stay competitive. In Figure 5.2, in contrast, is the case in which a running coalition enabled a wholesaler to improve the performance by joining at a later time. Less common cases are depicted at the bottom of Figure 5 in which cooperation does not result in a real improvement, eventually bringing candidates to leave the coalition. For instance, Figure 5.3 describes the case of a wholesaler that started cooperating in order to improve its performance. However, as the coalition size increases, performance is unstable. The main reason is that new members have a more advantageous situation with respect to its location. Finally, the Figure 5.4 is a case in which a wholesaler does not improve its performance because of cooperation. The simulation enables one to analyze different setting and to investigate the impact of horizontal cooperation and of joining or leaving a coalition based on simulated demand behavior as well as the location of stores and wholesalers.

5. CONCLUSIONS

Horizontal cooperation is an important strategy that SMEs can adopt in order to take advantage of greater economies of scale. Regarding last-mile distribution, cooperation is a way to reduce transportation costs (Lehoux et al. 2014). This paper has addressed the topic of horizontal cooperation from a service quality point of view in the context of urban deliveries. Therefore, lead times were used as a critical indicator of service quality in last-mile distribution. An agent-based simulation model was developed to investigate the impact of horizontal cooperation on lead times under consideration of various horizontal cooperation agreements and trust-related factors.

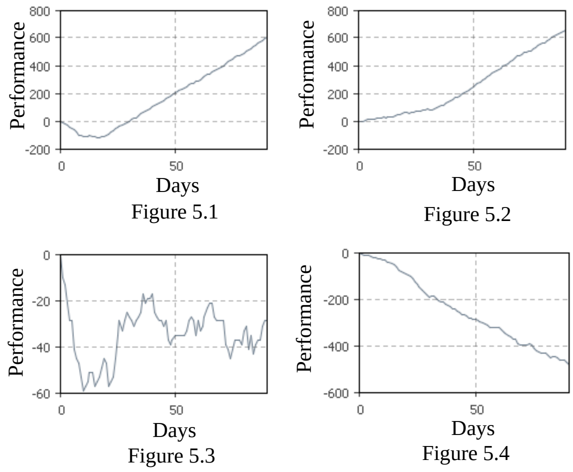

Figure 5: Performance of 4 different wholesalers in a single run

As a result, average lead time reduction reaches on average 24 % in the test setting; however, lead times can be reduced by up to 39 %. Improvements in service quality are not a trivial issue. Customer satisfaction and customer loyalty, among others, are key determinants that allow firms to improve market position and business competitiveness (Lindgreen et al. 2012).
In future work, the simulation will be extended to consider a wide range of different horizontal coordination agreements and further will be tested in different experimental settings. Therefore, employed procedures will be extended to calculate savings in travel costs and emissions. Additionally, the impact of the geographic distribution of wholesalers and customers is of high interest. Hence, investigating different geographic settings with the developed agent-based simulation enables one to analyze different influencing factors to derive implications and beneficial settings for horizontal cooperation requirements under consideration of service quality and trust-related issues.

ACKNOWLEDGMENTS

This work has been partially supported by the Spanish Ministry of Economy and Competitiveness (TRA2013-48180-C3-P and TRA2015-71883-REDT), and the Ibero-American Program for Science and Technology for Development (CYTED2014-515RT0489). Likewise, we want to acknowledge the support received by CAN Foundation in Navarre, Spain (Grant CAN2015-70473) and the financial support of the program iv2splus (project number 845 348) by the Austrian Federal Ministry for Transport, Innovation and Technology.

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MULTIMODAL FREIGHT TRANSPORT MODEL FOR INFRASTRUCTURE ANALYSIS

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ABSTRACT
Nowadays the improvement in transport infrastructures involves big projects with important investments. If a correct analysis of this new infrastructure is not made, the return on these investments will be affected and a significant increase in costs may occur. In this paper a complete conceptual model is proposed in order to analyse a new service or infrastructure and to establish the conditions to make it profitable. This model allows to obtain the use that the freight flows do of a transport system, taking into account different levels of resolution, like long and short distance travels. The variables of the model allow to make the analysis of the system from different points of view: flows, times, costs, etc. The model also takes into account the multimodality of the system, due to the importance that this characteristic has in the development of new infrastructures.

Keywords: Transportation, Modelling, Simulation, Freight, Multimodal

1. INTRODUCTION

Transportation is one of the most important activities that takes place every day and has great importance in the economy of a region. Taking into account the data of the Spanish Development Ministry (Fomento 2014), the transportation represents an average value of the 4% of the GDP (for 2000 to 2009). And in the case of the United States (US-DOT, 2015) this value increases a 10% (on average from 1980 to 2013). So improvements in the transportation system will have important effects in the economy.

But the construction of new infrastructure is also more important when we are talking about developing countries, not only by the great investments but also for the high number of existing initiatives because of the lack of them or bad conditions of the transport system. So any initiative that helps the governments to analyse a new infrastructure or prioritize the investments in order to make a better use of the available budget, will be of great value.

An important tool for transport system analysis is simulation based transport modelling. A transport model is a tool for planning a transportation system from different points of view. It is a representation of the real transport system, taking into account the geographical scale of the model and the level of resolution that this scale needs to be faithful with the reality. Using the transport model to simulate different scenarios we can forecast the future situations of the services and infrastructures.

In most of the cases a transport model is developed using the classical four step model (Ortúzar and Willumsen 2011). This steps are:

1. Trip generation: It gives the generated and demanded freight in the different zones considered in the model.
2. Trip distribution: Gives the freight flows between origin-destination pairs in base of the data of the previous step. It gives the origin destination (OD) matrices of freight flows.
3. Mode choice: It shares the OD flows between the transport alternatives of the model, giving a OD flow matrix for each one of the alternatives.
4. Network assignment: Obtain the use of the network, giving the route of each one of the OD flows.

These steps allow to obtain, for the present and the future, the generated and demanded freight of different zones and how these flows are distributed between these zones. These values provide the use of the different transport modes and the freight volumes of each arc and node of the system, or the vehicle flows.

Taking this theoretical definition as a base, a complete transport model for freight transport will be presented in this paper. But some special characteristics have to be taken into account. The first one is the geographical level of the model. The model has to be capable to consider different freight flows; that is, flows of different nature like the importation/exportation flows or the flows related to the internal consume. For this reason, the model should be able to manage a high distance variability.

Another characteristic of the transport system that the model has to consider is the transport multimodality. This is because most initiatives in the development of new infrastructures and transport policies establish that the multimodality is the main characteristic a sustainable transport system should have in the long term. For example the White Paper (European Transport Commission 2011) indicates that the main characteristics of a quality service are: attractive frequencies, easy

access, reliability of the transport and the integration of the ***intermodality***. Another example of the importance that governments give to intermodal transport is the Intermodal Transportation Infrastructure Strategic Plan of Colombia (Ministry of Transport of Colombia & EPYPSA, 2013). It indicates that the government has to guide the transportation sector towards intermodal models of higher efficiency and sustainability in the middle and long term. In the case of Spain some studies for intermodal terminals or logistic platforms are cofounded by the European Commission (European Transport Commission 2015). In South America the Inter-American Development Bank promotes some projects to develop the transport modes that are an alternative to road transport, using intermodal routes. An example is the Central Bioceanic Railway Corridor (IIRSA, 2015). This railway corridor will cross South America from an Atlantic port (Santos) to a Pacific port (Ilo, Arica…).
In this paper, a complete transportation model is presented. The architecture of this model is flexible and configurable, because not all the steps defined in the model have to be used in all the cases. It depends on the geographical level and the objectives of the project. First, and introduction of previous European models will be presented. After that, the complete model will be showed. In section 4 some cases of study will be presented. The paper finishes with some conclusions and future lines.

2. PREVIOUS TRANSPORT MODEL IN EUROPE.

A significant number of transportation models were developed in Europe in the last years. Some of them are showed in Table **1**.

Table 1: European transportation models (de Jong et al. 2013)

Model	Area	Step	Modes
SMILE +	Holland	1,2,3,4	a-f
MODEV	France	1,2,4	a,b,c
BVWP	Germany	1,2,4	a-e
Transtools	Europe	1,2,3,4	a,b,c,d
Worldnet	Europe (focusing on traffic with no European countries)		a-e
Norway	Norway	1,2,4	a,b,d,e
Samgods	Sweden	1,2,4	a,b,d,e
Mobility Masterplan Flanders	Flanders and Brussels	1,2,4	a-e
LOGIS	France	1,2,4	a,b,c
Basgoed	Holland	1,2,4	a,b,c

(1) Generation and Distribution.
(2) Mode Choice
(3) Logistics.
(4) Assignment.

(a) Road.
(b) Railway.
(c) Internal waterway.
(d) Sea.
(e) Air.
(f) Ducts.

As it can be seen, all of them use the theoretical basis of the four step model. So it could be considered a good basis for the development of a complete transportation model, but taking into account the limitations encountered in the previous models. The four step model has been developed for transport of passengers: this explains why there are a high number of papers in this field. There are also some works that use these steps to develop freight transport models, but taking into account some changes regarding to the characteristics of the freight transport. These particular characteristics are:

- Freight transport has a high number of decision agent compared with the passengers one. In the second case is the passenger the one that choose between a set of options, but in freight transport shippers, carriers… can have different decisions for a service or a route.
- The number of transport alternatives usually is higher in freight transport (road, train, maritime… and different vehicles in each one of the alternatives).
- Also there is more variability in the unit of transport or size of the shipment in freight transport.

The development of the complete conceptual model for freight transport has to consider all these elements. But there are also other elements that have to be taken into account, derivate from the study of some previous works. For the Distribution step, most of the previous works use the Gravitational model (Tavasszy 1994) (Fosgerau 1996), regardless of the geographical level considered in the model. When the model considers different types of flows this model could not work in a good way. For example, if the model considers importation/exportation flows between countries with very different economic systems, the calibration of the gravitational model is very complicated.
In the case of the Mode Choice step, the most used methods are the Logit ones (ETIS 2014). These models are robust, and provide good solutions not only in transport model but in other areas as marketing or social sciences. A limitation of the previous works is the number of variables considered in the model (de Jong et al. 2013). The introduction of new variables represents a good opportunity to consider in the development of the model.
Holguín-Veras (2011) identified that the mode choice depends on the shipment; this is an element that most of the projects does not take into account. It is very important to introduce this interaction as a new step in the model.
Another limitation of these kind of models, is the way in which congestion is considered. As SteadieSeifi et al (2014) found, the importance of congestion for freight transport is in the nodes of the network, especially of long distance. Special nodes as Customs, tolls, train terminals, ports… are important elements capable to increase the travel times because of their congestion. The

congestion is related with their capacities and the flows that can make use of them. Most of the studies uses queuing models to consider the delay due to the congestion in nodes, (Tan et al. 2015), but they do not consider the interaction between the transport mode (that calculate the freight flows) and the delays in the node.
All of this leads to set out a complete transportation model, for multimodal freight transport, that allows the assessment of infrastructures and services. This model takes into account different geographical levels, and different freight flows. It is configurable and flexible, because not all the problems need the same steps or calculations. The model considers more variables and it lets to introduce new ones depending on the problem to solve. It also takes into account the limitations in the consideration of congestion and the relation between the freight flows and the size of the shipment

3. MULTI-STEP TRANSPORT MODEL.

The great investments that a new infrastructure needs gives importance to all the tools that makes easier or give support to the decision maker. These decisions could be about infrastructure or the services that will use this infrastructure. Even these tools help in the development of transportation policy design.
A transportation system is a complex network with complicated relationship between the different elements of the system. The process for planning usually is a hierarchical process (Bussieck el al, 1997).
The network that support all these infrastructures have to be perfectly defined. Horn (2003) identified that most of the studies follow the next steps to define a complete and characterized network:

a) Identify the most important nodes, as origin, destinations, intermodal nodes etc.
b) Establish the transportation modes of the systems and the arcs and nodes of the network that each mode can use. Also if some services have fixed routes or arcs.
c) The time and cost are two important variables of the system. For a service this values are established, for other routes it is necessary to build or identify a time and cost chain.
d) Time and cost are not only important on the arcs of the system. Some of the nodes of the system are intermodal nodes, so it is necessary to identify the penalties in terms of cost and time in transfer processes.
e) Limitations of the system like arcs that cannot be used by some modes. And requirements and preferences.

The transportation system belongs to an environment, and it is not isolated of it, there are relationships between them and changes in one of them affect to the other and vice versa. For example, the changes in the socioeconomic characteristics have influence in the demand and therefore in the transport flows. In the other direction changes in the network could affect the economic and social environment, improving the communication of some areas and helping the development of these areas. It also can improve the external or internal trade of the country because of the improving of the transport routes.
Taking all these things into account and the uses searched, a methodology for the construction of freight transportation models will be presented in the paper.
The characteristics of the methodology are:

- Adaptable to the data available, the geographic level and the objectives of the analysis.
- Oriented to the national and international levels, not regional.
- Take into account the congestions on the nodes.
- Influence of the shipping size.

The projects analysed before showed that theoretical basis of the Four Step Model (Ortúzar and Willumsen 2011) is useful for transportation planning models, so it will be the basis of this conceptual model.
Figure **1** represents all the steps and methods considered in the multimodal freight transport model that will be presented in the paper. As it was said before, it follows the Classical four step model theoretical basis, but taking into account that is a freight model, that have to consider high variability in the distance of the shipments, and also the limitations funded in previous studies.

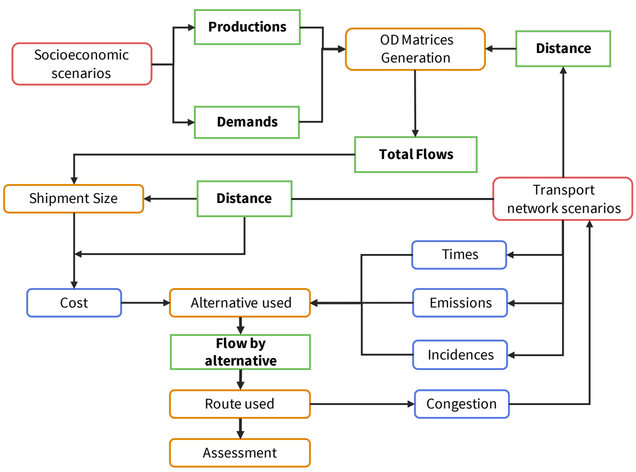

Figure 1: Complete conceptual transport model.

3.1. General elements of the model.

The model developed with the methodology must be useful for systems with high variability in the distance, for different types of cargo and different periods of analysis (not all of them with the same length). So there a set of elements which must be established or defined, depending on the problem to solve.
First of all, the **objectives** of the study must be set. They let us identify the results that the model searches and establish the steps and calculations of the model that must be used. Another of the elements are the **zones** of the study (Traffic analysis zones, TAZ). All the possible

origin and destination nodes of freight flows. These define the geographical level of the model and transport system. The relationship between transport system and environment make necessary to know the **socioeconomic characteristics** and they present and forecasted value. They are the basis of the econometric models that give the production and consumption flows, origin of the freight flows. Also these values are useful to estimate another variables or parameters of the model. The transport system has two main elements: **transport alternatives** and **transport network**. First one is all the modes or modes combination available in the system. The second one are the physical infrastructure or routes that the modes use in their trips. Both have to be characterized in the present but also in the future, because of possible changes in infrastructures or services. All these things allow to define the model to obtain the main result that is the **freight flows** over the network. Joining the freight flows the model gives another skimming results, like travel cost, travel time, distance, etc. So some parts of the complete model must be the **assessment components**, that are oriented to the different wanted analysis like emissions, economic, profitability, social, etc.

3.2. Steps of the model.

The methodology to define the transport model is based in the classical Four Step Model, but with the adaptations that the freight transport requires. This methodology is widely used for passenger transport, but there are less studies for freight transport. In these studies, the analysts use the four step model but with adaptations. It is due to the differences between both cases. In freight case there are a great number of decision maker (carrier, shipping company, user…) compared with passengers (passenger). Other difference is that freight transport usually has a high number of transport alternatives. And also there is more variability in the shipping size.

The study of previous model gives some limitations, explained in section 2:

- Use of the gravity model for distribution, independently of the geographic level.
- Logit model in most of the cases for mode choice. These models usually use time and cost as variables of the model, so it is important take into account more variables.
- The interaction between mode and route choice and shipping size is note taking into account in most of them.
- For freight transport the effects of the congestion are more important in nodes that in links, where is taking into account in most of the cases.

The steps of the model take all the characteristics and limitations in order to give answer to the requirements of the analysts.

The model presented is a model for freight transportation using multimodal systems, in order to assess infrastructures or design transport policies. The model is flexible and configurable, it means, not all the steps of the model have to be used in all the cases. The steps used depend on the geographical level of the problem, the results that the model searches, or the data available. Some characteristics of the model related with the limitations of previous models are that the model considers the congestion in the intermodal nodes, it considers a high number of variables and takes into account the shipment size and its relation with the mode choice and network assignment.

Figure **1** represents in a general way all the steps of the model. As we use as basis of the methodology the four step model, it has the four main steps of the model, but also the steps that allow to take into account the limitations or opportunities identified in the previous studies.

The model has some requirements. First one are the socioeconomic aspects. They have influence in the transport system and vice versa. Another one is the network that represents all the infrastructure that the transport modes uses. Not only physical infrastructure but routes as maritime routes. Also all the transportation modes which make use of the network must be established.

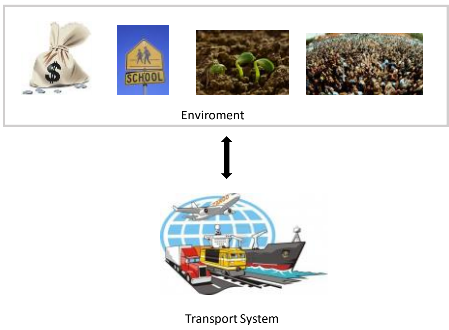

Figure 2: Bidirectional relationship between transport system and environment

Some restrictions in terms of links of the network (for some alternatives) or regulations must be considered in order to define the real network for each alternatives or the value of the parameters or variables used in the model.

It is also important establish the aims of the study and the geographical area, because they define some of the steps that must be used, or not.

The main results of the model are how the freight choose among the transport alternatives in the system, the freight flows over the network and another supporting results as travel cost or travel time. All of them allow to make differ analysis under diverse points of view (economic, environment, GHG emissions…).

The construction of the model begins obtaining **freight production and consumptions**, in the origin and destination nodes. When the methodology is used to build a transport model, we have to choose the points that generate or consume freight. These are the origin and destination nodes. Econometric models give the total amount of freight by means of the social and economic variables of the environment. Usually regression and time series methods are used, but also input-output methods could be used.

Once the total amount of freight is defined, it is necessary to share it into **Origin-Destination (OD) pairs**. It means, share the productions and consumptions in the nodes making OD freight flows. In the methodology explained in this paper, the variability of the travel distances in the model is considered. Trade relationships between countries or regions have different nature. For example, the importation and exportation relations are very different taking into account an origin country and all the possible destination countries, and it is usually related with long distance. By other way the trade relations between regions in the same economic area are more stable.

It means that the model has to consider methods to share these freight flows which take into account this different nature of the trade relationships. For example, a system that share the production and consumptions using partition coefficients estimated using historical data, works in a good way to build the OD matrices when there are very different relationships among the areas of the study. In other way the gravity model works better when these relations are more stables. Depending of the model and its geographic level could be necessary apply one of the models or both of them.

Once the total OD matrices of freight flows are obtained is necessary to know the way these flows use the different transport alternatives existing in the model, it means **freight flows for each alternative.** In most of the cases logit models are used. But there is a limitation in most of the studies and it is that the relation between the size of the shipment and the mode choice it is not presented. The solution presented in this paper is the following. The cost of a travel usually is one of the parameters that some user takes into account to decide which alternative should be used for a shipment and assess its viability (Kreutzberger 2008). So the methodology implements a step to do that. In this step the size of the shipment is calculated, using formulas of economic order quantity, regression models, etc. The **size of the shipment** allows to obtain in a more accurate way the real cost of the travel, because it makes possible to define the vehicle and to handle the cost of the shipment.

As it was said before, the cost is one of the most important parameters for mode choice, so the cost is the element that **relates the shipment size and the mode choice**, that is one of the limitations detected in previous studies.

The choice between alternatives using mode choice models gives the OD freight flows for each transportation alternative in the model. Logit models are widely used, but there is another method like minimize a generalized cost. In previous studies, it could be seen that the number of variables used to make the choice are minimal. The proposal methodology takes into account an important number of parameters, which could be used or not, like travel cost and time, distance, GHG emissions or incident probabilities. The higher the number of well-defined explanatory variables, the better the establishment of mode choice.

Last main step is **assign the freight flows to the network**. The way that the route for each OD pair is calculated depends on the result searches: generalized cost minimization, short path methods…An improvement of the classical studies is that the congestion is taken into account in the nodes of the system, not in the links. Due to the capacity of the nodes (ports, train terminals, customs…) and the freight flow that try to use it, it is possible that delays may occur in those nodes.

This model is useful for macro models, where long distances and high periods of time are evaluated. It makes that travel times can be of days or weeks compared with travel times of hours in meso and micro models. So the problems that a model for urban transport or pick and delivery transport have with the congestions of roads and streets are not representative in the macro models. Nevertheless, the **congestion in the intermodal nodes**, as a congested port or a custom with waiting times of weeks, has important effects on the total travel time. This is the reason why it is important the node congestion. In most of the studies of delay times in intermodal node the time is obtained by queueing theory, so in function of the freight and the capacity of the nodes, the total time could be obtained.

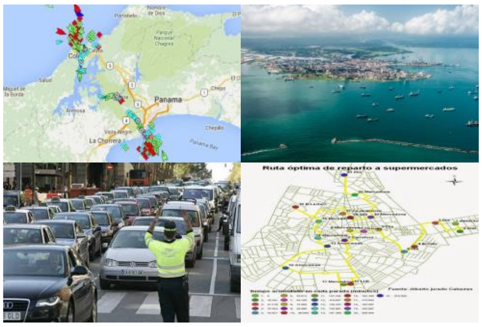

Figure 3: Congestion: Nodes vs Links.

3.3. Model results for infrastructure analysis.

The main results of the model are the freight flows in arcs and nodes of the network. They are obtained using simulation of some scenarios and they allow to know the future use of the infrastructure under different conditions. It means, if a new infrastructure will be used, if an infrastructure could have congestion problems, define the characteristics of this infrastructure, the operational service conditions, etc.

But the model gives another results like travel times, travel cost or travel emissions. They allow analysis the infrastructure for another points of view, like economic assessment, GHG emissions or logistics times.

The mode choice gives the total among of freight for each transportation mode, so it gives a measure of the rate of use of all the modes in the system.

As the model uses the support of a SIG system, where information about population, regions, etc, is present, the model gives some secondary results as the population affected by an infrastructure or services or distances to the infrastructure.

4. CASES OF STUDY.

The methodology described in the paper was used in two real projects. Both projects are developed in countries of South America: Bolivia and Brazil. They search different aims. The case of Bolivia searched the assessment of a new railway infrastructure that cross the continent from the port of Santos in Brazil to the Ilo port in Peru. The model of Brazil allows to prioritize a set of projects related with logistics and transportation infrastructures.
The aims of both projects and the data available makes that each one of the models uses different steps of the methodology.

4.1. Bolivia Transportation Model.

An international model to assess a railway corridor between Pacific and Atlantic coasts was developed. The aim of the study was establishing if the railway corridor will be profitable, under which condition it is profitable and also the characteristics of the infrastructure. The purpose of the model was obtaining the freight flows in each link and node of the transport system. It also allows to obtain another secondary results as travel cost and time.

The steps of the methodology used in the model are showed in Figure **4**.

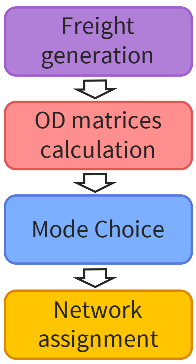

Figure 4: Steps of the Bolivian Model.

The productions and demands of each one of the origin and destination nodes considered was build using socioeconomic data, importations and exportation and some more sources.
The OD matrices were built using two methods. For import export flows, a method that share the productions and demands using coefficients based on historical data. Inside the country, gravity methods were used. The use of both methods allows to take into account the different nature of the trade relationships.
Once the OD matrices were built the step to obtain the size of shipment is not necessary, because the units that the analysts need are physic units. The mode choice model, a logit model, was calibrated using cost and time variables, based on physical units.

The mode choice gave the total freight flow that will use each one of the transportation modes. An all or nothing assignment was made to see the total freight that use each link and node.
As the model was built for simulation, some scenarios of speed, cost and times in nodes were evaluated to obtain the optimal characteristics of the system.
So the methodology allows to assess the new infrastructure.

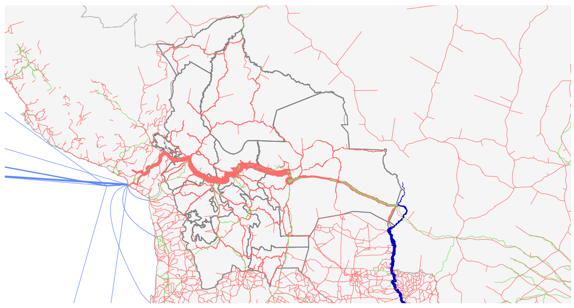

Figure 5: Network assignment, flows results.

In the case of Brazil, the aim of the study was to prioritize a set of projects (logistics and transportation projects). To do that, a multi-criterion matrix was built, where some of the variables used are results of the transportation model.

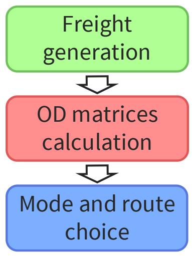

Figure 6: Steps of the Brazilian Model.

In this case the geographical area of the model was the north east region of Brazil.
The OD matrices come from input-output data of the Institute of Statistics of Brazil, using as in the case of Bolivia a mixed system of coefficients and gravity model to transform these data in the OD matrices. In this case a joining choice of mode and route was made. To do that, a generalized cost build with the travel cost and the cost of the travel time, was minimized. The congestion was considered as penalized time in the nodes.
The results of the model were the flows in links and nodes, and also another elements as affected population or saving transport time and cost.
All these elements are part of the multi-criterion matrix, that in function of the points given to each project for the variables prioritize them.
The methodology was useful to establish transport and investment policies.

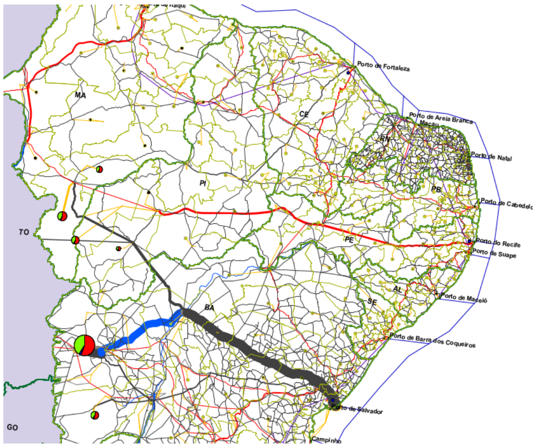

Figure 7: Flows in the system.

5. CONCLUSIONS.

This methodology allows to build complete models to assess infrastructure and services and define policies in terms of transportation or investments.

It is highly configurable, only is necessary use the step that are consistent with the data available and the aims of the model.

The methodology takes into account the variability of the trade relations between zones, and it propose a mixed model (coefficients and gravity model). Also implement the relation between shipment size and mode choice by the step of size shipment calculation and the calculation of the cost of the travel.

The congestion in the nodes is taking into account and is related with the mode choice.

As it was explained the methodology was used to develop the transport model for two real projects. It allows to verify the utility of the model. In the case of Boliva, the assessment of a new infrastructure and in the case of Brazil, it was a tool decision support to choose better investments.

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COMPARISON BETWEEN A MACRO AND A DES APPROACH TO THE TRANSPORT MODE CHOICE PROBLEM

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ABSTRACT

One of the main problems in the freight transport is the congestion that can occur in multi-modal nodes and how this may affect the use that the load makes the entire transport system. Aggregate transport models take into account congestion in a simplified way, which may introduce bias in the estimation. Discrete events simulation provides a better tool for explaining the mechanisms that lead to congestion. This paper presents a comparison between an aggregate transport model and a model of discrete events that takes into account the delays caused by congestion at the nodes and how they affect modal choice. The goal is to assess the bias caused by the aggregated approach and whether it compromises the validity of the modal split estimation.

Keywords: transport model, discrete event simulation, multimodal, mode choice

1. INTRODUCTION

The development of transport infrastructure involves the disbursement of large investments. Errors in the initial studies of a project may cause deviations in the budget or lead to underutilized and unprofitable infrastructure. Thus, it is of the uttermost importance to employ appropriate modelling tools in order to obtain accurate estimations of the attractiveness of a project for its potential users.

Several initiatives in the last years have focused in promoting Multimodal transport as a means for achieving a sustainable and efficient transport network (European Transport Commission 2011, Ministry of transport of Colombia and EPYPSA 2013, Geerts and Jourquin 2001, SteadieSeifi et al. 2014). Providing a fast and reliable connection among all the transport modes (maritime, rail, air, road, waterways and ducts) allows to minimize costs and environmental and social impacts; as well as giving greater accessibility and improving the mobility of passengers and cargo. Improving multimodal networks requires acting on both the links and the nodes of the system. Without railways and roads in good conditions a complete multimodal network is unfeasible. However, often, the nodes of the transport system are the actual constraints to the growth of multimodality. For instance, even if the rail transport is expected to be more efficient in terms of cost and environmental impact for medium distance shipments, in countries such as Spain it only reaches a small market share due to inefficiencies at the terminals and other managerial factors.

Nodes are key elements of a transport network since they can greatly increase inventory costs and delays in a supply chain. Hence, modelling methodologies must take into account the delays and costs caused by them. Particularly, when the terminals are highly congested, long delays may occur that reduce the attractiveness of the intermodal alternatives. Any model that intends to represent a multimodal transport network in a reliable way must account for the delays at the terminals.

A transport model is used to predict the traffic flows and the behavior of a transport system under different conditions. The most common approach for evaluating infrastructure projects is to develop an aggregate macro-model, following the classical Four Step Model (Ortúzar and Willumsen 2011). These kind of models use aggregated data, representing the flow of cargo as a continuous variable given by its expected value.

Micro-simulation models are used for detailed evaluation of congestion in road transport, such as crossings or urban networks. They describe the behavior of system's entities and interactions between them (Kumar et al. 2014). For example, considering an intermodal node as a train terminal, an aggregate model would use the average time at the terminal to estimate the total travel time while a micro model would take into account the times of all the operations at the terminal as well as the operational rules.

For evaluating multimodal networks, one of the most critical steps of a transport model is the "mode choice". This component of a model determines the distribution of the flow of cargo from a given origin to a given destination among a set of competing alternative modes (Habibi 2010, García-Menéndez and Feo-Valero 2009). The mode choice step forecasts how many shipments choose each mode so it determines the accuracy of the results (Crespo-Pereira, Rios-Prado, and De Gregorio-Vicente 2014) . Thus, many previous authors have addressed this issue considering how different factors such as the characteristics of the trip maker, the journey and the transport facilities affect the decision.

The most used mathematical models in this step are the logit models, as we can see in the some of the transport models developed in Europe: MODEV model (de Jong et al. 2013), WORLDNET (Sean Newton 2008), NORWAY (Kleven 2011) or SAMGODS (de Jong and Ben-Akiva 2007), among others. This kind of models are based on utility functions of each alternative, it means, how attractive is an alternative for each trip. Kreutzberger (2008) states that the distance and the time, along with the cost, are the main variables that make competitive a transport alternative so they are used as the factors to predict a decision.

Aggregate models deal with this issue in a *static* way, since they estimate the expected modal distribution in stationary conditions. Congestion is dealt with in this way, since the existing methods for traffic assignment with congestion seek to obtain an "equilibrium" solution on which no user obtains a benefit from changing his decision (Matsoukis 1986, Rajagopalan and Yu 2001, Benedek and Rilett 1998). Dynamic effects such as transitory effects and adaptive behavior are not naturally covered by this approach.

Four steps models usually take into account the congestion in the arcs of the system, using speed-flow or cost flow functions. However, for multimodal freight transport this is not usually the main source of delays. For example, for long distance transport the travel times by ship are usually in the order of several weeks while the delays due to road congestion would amount only to a few hours. However, the delays at the maritime ports could be of several days and even weeks due to ship queues for unloading, material handling or delays in customs inspections.

Taking as an example the movement of goods between the south of Europe and China, the road link could have some delays due to congestion of some minutes or hours compared with a travel time of weeks. However, if the port is congested, the vessel can wait days for a berth and that is not a negligible time.

Due to this reasons, including the effects of the congestion at the nodes of a multimodal transport system is one of the ways to improve the model accuracy, mainly with respects to the modal choice problem but also for a reliable estimation of travel times. This paper presents a comparison between a macro and a micro transport model in order to stablish the differences in the results and how these differences may affect the conclusions of a simulation study. A macro model based on the four steps methodology is compared to a discrete events simulation model.

The case study used for the simulation experiment is based on the real case of the "Central Bioceanic Railway Corridor" in South America (Rios Prado et al. 2013, Crespo-Pereira et al. 2014, Rios Prado et al. 2013). The real data from the study is not used due to confidentiality issues, but the scenario analyzed contains a similar but simplified network, similar transport costs and travel times and a realistic distribution of freight.

The section 2 presents an introduction about logit models and the consideration of congestion in nodes. Section 3 describes the macro and micro models. Section 4 contains the experimentation and results and, finally, section 5 presents the conclusions.

2. MODE CHOICE.

Mode choice is the step of a transport model that divides the freight flow among the alternatives in the system. It allows to:

- Assess the competitiveness of transport infrastructure and stablish investment policies.
- Analyze the attractiveness of a multimodal transport service.
- Perform "what if" analysis varying the characteristics of the infrastructure or the transport service.
- Stablish transport policies.

There are two main types of models for modal split: deterministic or probabilistic. Deterministic models assume that the decision of a shipper is completely determined by a set of decision factors such as the time and cost while probabilistic models assume that there always exist a set of *hidden* or circumstantial factors which make each individual choice possibly differ from the optimal choice in terms of cost and time. In general, probabilistic models are preferred for large scale transport systems because they better reflect the diversity of decision criteria among shippers.

Some different methodologies employed for modelling the modal split are logistic regression, Bayesian networks or neural networks.

As it was said previously in the paper, the most popular are the logit models. The main logistical models are Multinomial Logit Model, Binary Logit Model and Nested Logit Model, these discrete choice models are based on random utility theory. Linear regression models are discarded because the assumptions of ordinary least squares are violated (John H. Aldrich; Forrest D. Nelson. 2014).

The bases of the discrete choice model (Ortúzar and Willumsen 2011) are that there is a homogenous population of individuals who know the characteristics of a set of available transport alternatives. Each transport alternative has a net utility for each individual. The utility is then assumed to be the sum of two components, a measurable function of certain factors that affect the transport choice (V_{jp}) and a random component which reflects the idiosyncrasies and particular tastes of each individual as well as measurement and observational errors (ε_{jp}) ($U_{jp} = V_{jp} + \varepsilon_{jp}$).

The Multinomial Logit Model (MNL) is a very popular one in practice due to its simple assumptions and robustness (Domencich and McFadden 1975). It relies on the assumption that the random errors are Gumbel IID distributed, which leads to the well-known equation of a MNL for calculating the share of k^{th} alternative (P_k):

$$P_k = \frac{e^{V_k}}{\sum_j e^{V_j}} \qquad (1)$$

Due to all these reasons, this is the type of model used in the paper for the simulation experiment. The variables of the utility function are the cost and the time of the travel. Congestion at the nodes affect the travel times so it influences the modal distribution accordingly.
Most of the studies that consider delays at the nodes deal with the delays at the ports terminals. There are different modelling approaches to estimate the influence of waiting times. Fan, Wilson, and Dahl (2012) stated that the capacity of the port is assessed in a practical manner by using a model based on queuing theory. Leachman and Jula (2012) developed a model based on queuing theory to obtain the total time for different supply chain strategies. The model calculates changes in the times caused by changes in the flows that use a common channel. The model estimates the value of the waiting time and, iteratively, this new value affects the estimation of the total time when it is calculated again. This new value feeds the ***mode choice*** giving the new modes share. All this process has to be repeated until it converges.

3. CASE STUDY.

To create the macro and the micro models, the network shown in Figure 1 is used. The network has two ports in the extremes and three intermediate points of demand and production of freight. Each trip has two alternatives: only road or multimodal road-train. The distances between each pair of nodes are the same for road and for train, so the modal choice is only affected by differences in price, velocity and delays at the terminals.
The arcs of the system are characterized by a speed (both road and train) and a price *per* kilometer. The units of cargo are assumed to be only containers in order to simplify the model and focus the analysis on the modal choice.

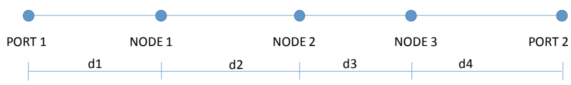

Figure 1: Transport model network.

The values that complete the characterization of the system for the macro model are the capacity of the nodes and the waiting time at these nodes.
As the multimodal alternative considered is train-road the nodes that will be modeled in the micro model are the train terminals. The micro model reflects a simplified but realistic characterization of the processes that take place at the terminals which may cause congestion. The following characteristics are specified:

- Train capacity in containers.
- Entry time of a truck in the terminal.
- Delay at the gates and gates capacity.
- Upload time of a truck. Capacity of the handling equipment.
- Load time of a train. Capacity of the handling equipment.
- Load time of a truck. Capacity of the handling equipment.
- Unload time of a train. Capacity of the handling equipment.
- The number of train platforms.
- The travel times and capacity of the internal transport system.
- Maneuver times at arrival and departure.

3.1. Macro model description

Most of the aggregated transportation models at national or regional levels are based on the Four Steps methodology. This methodology begins with the estimation of productions and consumptions of all the origin and destination nodes of the system; this is the Generation step. These values are used to build the origin-destination matrices (ODM) in the distribution step. This paper is focused on the mode choice step so the ODM are kept fixed. The ODM is the same for both the micro and the macro models. The appendix A shows the data used for this scenario.
The next step of the model is the mode choice. Two options are available: train and truck. The logit model uses utility functions to predict the share between transport alternatives. The logit model was proposed by the researchers (based on realistic values from the experience withdrawn from real projects whose results were confidential). The utility functions used for this simulation experiment were:

$$U_{ij}^{Train} = -0.0476 \times Time_{ij}^{Train} - 0.006493 \times Cost_{ij}^{Train} \quad (2)$$

$$U_{ij}^{Truck} = -0.0476 \times Time_{ij}^{Truck} - 0.006493 \times Cost_{ij}^{Truck}$$

With this functions the probability of chose each one of the transport alternatives is:

$$P_{ij}^{Train} = \frac{e^{U_{ij}^{Train}}}{e^{U_{ij}^{Train}} + e^{U_{ij}^{Truck}}} = \frac{1}{1+e^{U_{ij}^{Truck} - U_{ij}^{Train}}} \quad (3)$$

The probability of truck is:

$$P_{ij}^{Truck} = 1 - P_{ij}^{Train} \quad (4)$$

Three matrices were used to obtain these probabilities. First one is a OD matrix of distances. These distances are the same that in the micro model. Other matrix is the OD matrix of cost. As in the other model a cost by TEU and kilometer is defined, using this cost and the matrix of distances, a OD matrix of costs is build. The travel time between an origin and a destination is obtained using the speed and distance of each travel plus the time at the terminals. The time at the terminals is estimated adding the mean times for each operation.
The model is implemented in an Excel spreadsheet.

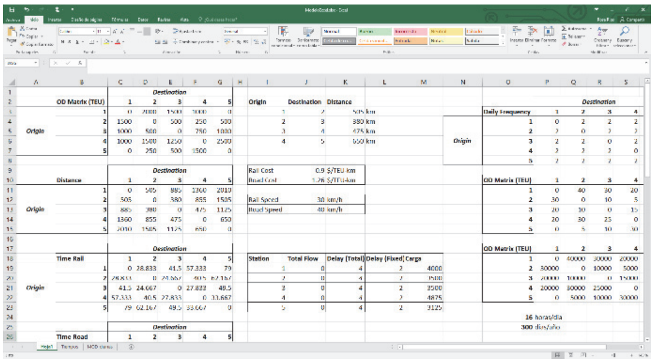

Figure 2: Macro model in Excel Spreadsheet.

3.2. Micro model description

The micro model was developed using the discrete events simulation software ExtendSim. The main elements simulated are the ones shown in Figure 3:

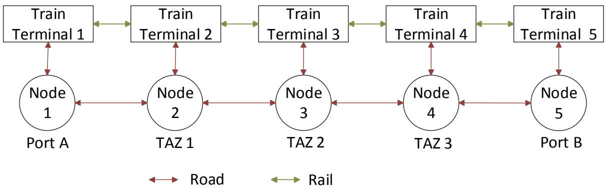

Figure 3: Micro model diagram.

This model represents the transport network of Figure 1. Node 1 and 5 represents the ports of the system, and node 2, 3 and 4 represents the cities that also generate and consume freight.

The transport options considered to move freight between an origin and a destination are road or railroad. The three nodes as well as the ports generate random shipments with a random destination. The "Create" blocks that generate the shipments from each origin to each destination employ an exponential distribution for the time between arrivals (TBA). The mean time between arrivals is calculated from the annual flow defined in the OD matrixes of the macro model.

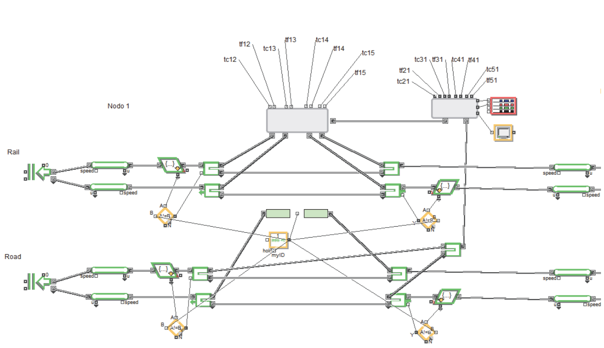

Figure 4: Representation of a node and its transport options in ExtendSim.

Each time a shipment is generated, the first element of the model is a logic decision for selecting which mode to use. The selection is performed using a random model. The probability of each transport mode is calculated according to a Multinomial Logit Model that uses the cost and the time as decision factors. This corresponds to the underlying assumptions of a discrete choice model: each decision maker selects the transport mode depending on a set of measurable factors (cost and time) as well as a set of subjective or hidden factors that cause the observed randomness. The MNL model employed is the same as in the macro model. However, there is a key difference in how the decision is taken. In both models, the modal split is made according to the price difference between modes and the time difference. But the time difference between the modes is calculated differently. In the macro model, the time at the terminal is estimated from the mean times of each operation plus the travel times through the network. In the DES model, the time differences are calculated during the simulation and are affected by the congestion in the system. Thus the DES model takes into account the expected adaptive behavior of shippers who may change their decisions depending on the delays observed through each alternative.

The road transport is defined by the distance, the speed in each link and the cost per kilometer of each container (Twenty-foot equivalent unit, TEU). Trucks are assumed in the model to be readily available so the effect of a possible delay due to truck fleet constraints is not considered.

Five train terminals were modelled. The behavior of the terminal is the following. The trucks arrive to the terminal through a gate where there is a reception process. Then, material handling equipment is used to unload the containers (for instance, it could be assumed that the equipment are reach stackers). The containers are then transported to the yard where they are stored in the first available position. In order to simplify this aspect of the model, detailed operations at the yard are omitted. The yard is represented by a queue and a random load, unload and transport time. When a train arrives, it reserves a platform and the containers which are going to be loaded in the train. Transport orders are sent to the load terminal to move the reserved TEUs to the platform.

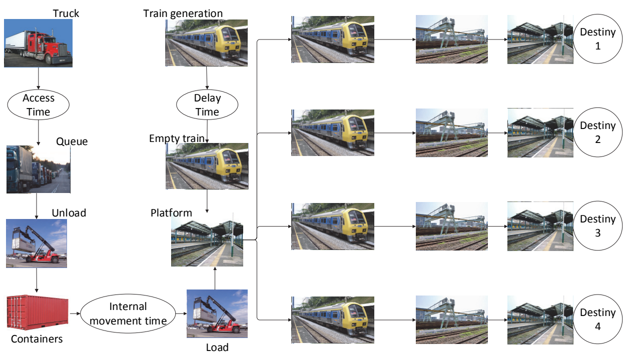

Figure 5: Terminal performance.

Once the TEUs are in the platform, they are loaded in the train, using cranes and internal transports such as reach stackers.

This leads to the establishment of operation times for all the process on the terminal:

- Truck access time (4 mins).
- Truck unload time (3 mins).

- Train arrival and maneuvering time (30 mins).
- Internal movement time and yard storage (15 mins).
- Train load time (5 mins per container).
- Train departure and maneuvering time (30 mins).

All these times were defined for this simulation experiment based on realistic values. Exponential probability distributions were assumed in order to evaluate the performance of the system introducing variability.

4. EXPERIMENTATION AND RESULTS.

Both models were configured with the same data, so differences between the results can only be explained by three reasons:

- In the aggregated model the times at the terminals are assumed fixed while in the micro model the times depend on the congestion level and the delays at the terminal queues.
- In the aggregated model, the effect of the delay caused by the train service frequency is introduced by increase the travel time by the half of the time between train departures. However, in the DES model the travel times for the train are dynamically calculated depending on the train schedule. Thus, if a train departs into 3 hours, the model takes this into account.
- The shipments are generated randomly in the DES model. However, due to the length of the simulation runs, this source of variability is heavily damped so its effect on the results is insignificant. The small confidence intervals of the response variables are proof that the conclusions are not sensitive to this source of variability.

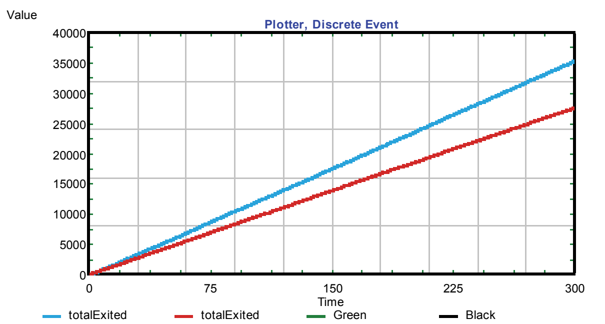

Figure 6: Number of containers arrived by rail (red) and by road (blue) to a node.

Table 1 presents a comparison between both models in terms of percentage of use of the train, for each destination. In general, the election of train is lower in the DES model. This can be explained considering that the DES model reproduces congestion effects in a realistic way.
The differences between the DES and the macro models are significant for all the nodes of the network at the 95% confidence level. The largest differences observed occurred at the nodes 1, 4 and 5.
The Table 2 and Table 3 show the occupation of the maximum train system in both models.

Table 1: Train share percentage.

	Train % (5 runs)			
Node	Macro Model	DES Model	Confidence Interval (95%)	Difference
1	46,98%	42,62%	0,40%	4,36%
2	44,11%	42,84%	0,21%	1,28%
3	42,29%	41,86%	0,14%	0,44%
4	45,39%	39,82%	0,30%	5,57%
5	47,91%	43,67%	0,09%	4,24%

Table 2: Train occupation, macro-model.

		Destination				
		1	2	3	4	5
Origin	1		75.06%	100%	80.48%	
	2	56.30%		32.72%	18.16%	41.37%
	3	40.49%	32.72%		50.14%	42.37%
	4	44.20%	60.38%	46.62%		66.62%
	5		20.69%	38.41%	57.99%	

Table 3: Train occupation, DES model.

		Destination				
		1	2	3	4	5
Origin	1		67,46%	95,80%	55,97%	0,00%
	2	48,98%		34,19%	17,69%	34,51%
	3	36,32%	32,62%		49,88%	35,84%
	4	41,00%	57,10%	46,52%		61,89%
	5	0,00%	20,98%	37,20%	53,65%	

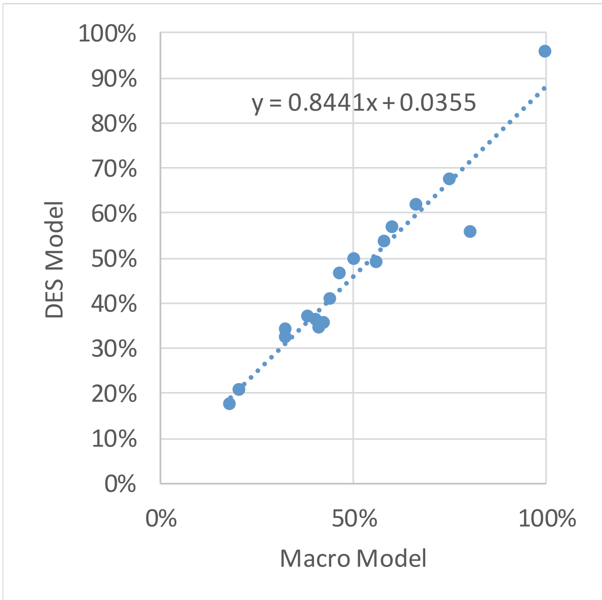

Figure 7: Relation between the train occupation estimated by the macro model and the DES model.

Figure 7 shows a scatter plot of the train occupation values estimated for the macro model and the DES model. Each point of this graphs correspond to one of the Origin-Destination pairs and the values of the X and Y coordinates are the train occupations estimated by the macro and the DES models. The plot shows that the results are consistent between the models in the sense that there is a strong correlation between them.

However, the slope of the regression line is negative, which indicates that as the occupation of a train increases, the DES model forecasts a relatively lower usage of the train.
This result is consistent with the previous observation that the congestion effects estimated by the DES model lead to a lower estimation of the train share.

5. CONCLUSION

A simulation experiment based on a realistic scenario has been shown that compares the estimations of the modal split between road and train given by a conventional aggregated transport model and a discrete events simulation DES model. The simulation results highlight the utility of DES for estimating the modal split when congestion happens at the nodes of the multimodal network. Common practices for assessing infrastructures often omit this congestion effects or consider them in a simplified way by queuing theory methods. However, queuing theory methods provide simple approximations that do not capture the real behavior of a terminal.
The results of this simulation experiment show significant differences between both approaches. The differences correlate with the level of occupation of the transport services and thus indicate that this is a source of error in aggregated models.
The practical consequence of the results is that, although the observed differences are not drastic, a macro model may overestimate the competitiveness of a multimodal transport. Further research is required to evaluate the potential impact of this bias in other type of cases.

APPENDIX A

Table 4: Origin-Destination matrix used in the scenario. The units are TEUs.

		Destination				
		1	2	3	4	5
Origin	1	0	40,000	30,000	20,000	0
	2	30,000	0	10,000	5,000	10,000
	3	20,000	10,000	0	15,000	20,000
	4	20,000	30,000	25,000	0	50,000
	5	0	5,000	10,000	30,000	0

Table 5: Origin-Destination matrix of distances in kilometers.

		Destination				
		1	2	3	4	5
Origin	1	0	505	885	1,360	2,010
	2	505	0	380	855	1,505
	3	885	380	0	475	1,125
	4	1,360	855	475	0	650
	5	2,010	1,505	1,125	650	0

Table 6: Unit costs and speed assumptions adopted in the simulation experiment.

Rail Cost	1.08	$/TEU-km
Road Cost	1.26	$/TEU-km
Rail Speed	30	km/h
Road Speed	60	km/h

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SIMULATION FRAMEWORK FOR TESTING PERFORMANCE OF MULTI-UAV MISSIONS

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ABSTRACT

In this paper, we present a Software-in-the-Loop simulation framework for multi-UAV systems which allows test the implementation of cooperation algorithms, sense & avoid algorithms, etc., without taking any risk. In our proposed framework, we can test the correct execution of algorithms, and since our setup is inherently multi-UAV, we can also test the communication flow among the vehicles. The simulation framework has been developed as a functional extension of Mission Planner, open source software aimed to plan, control and analyze data from missions of a single UAV driven by Ardupilot flight controllers.

Keywords: SIL, multi-UAV, Mission Planner, Simulation Framework

1. INTRODUCTION

In recent years the research in the field of multi-UAV systems has received increased attention, due to that this option allows to perform missions set with greater efficiency. This new technologies offer many potential applications in multiple fields such as infrastructure inspection, monitoring coastal zones, traffic and disaster management, agriculture and forestry among others. The coordination of a team of autonomous vehicles allows accomplish missions that no individual autonomous vehicles can accomplish on its own when certain time constraints have to be satisfied. Team members can exchange sensor information, collaborate to track and identify targets, perform detection and monitoring activities (Ollero and Maza 2007), or even actuate cooperatively in tasks such as the transportation of loads.

However, multi-UAV missions are much more complex. The development of algorithms for multi-UAV systems requires performing tests which implies a high level of risk for UAVs. Hardware-in-the-Loop (HiL) and Software-in-the-Loop (SiL) simulations are a good way to test these aspects without a need of real UAV experiments.

Hardware-in-the-Loop is a well established methodology for testing of automotive software under simulated conditions. One advantage of HiL simulation is that the validation of control results is very straightforward. In industrial control, hardware-in-the-loop simulation techniques can significantly reduce the time required to design controllers and can increase the reliability of the systems (Xue and Chen 2013). However, it requires the software to run on an electronic control unit (ECU), and the vehicle components (e.g. sensors and loads) to be either available physically or simulated accurately. The tests based on HiL simulation are limited: occurs relatively late, it is expensive, has slow turn around times, limited scalability, and provides in practice only quite limited coverage. On the other hand, the Software-in-the-Loop methodology has emerged as an alternative approach to embedded software testing. A SiL system of simulation requires no physical hardware and can reduce the time and costs of new software development considerably.

In this paper we present a Software-in-the-Loop simulation framework for multi-UAV systems, which consists of two main parts. The first one is formed by a group of virtual machines that simulate the fleet of UAV Software-in-the-Loop. And the second one is the open source Ground *Control* Station (*GCS*) software *Mission Planner* for planning and executing UAV missions. The source code of Mission Planner is modified to handle multi-UAV systems.

2. BACKGROUND

One of the main research topics involved in the study of multi-UAV systems focuses on modeling the problem as a multi-agent system. Therefore, most multi-UAV simulators are used only as testbeds for cooperative models and algorithms.

The commercially available X-Plane flight simulator, together with MATLAB, are used by Garcia and Barnes (2009) to create a simulator framework for studying multi-UAV control algorithms. Pujol, Cerquides, and Meseguer (2014), proposed a multi-agent simulation environment to investigate decentralized coordination for teams of UAVs. Odelga, Stegagno, and Ahmad (2015) present a setup for HIL multi-UAV simulations which is based on Gazebo, a popular open source ROS-enabled.

Other research lines around the field of multi-UAV simulations include the study of the best interface or set of interfaces for the operator to monitor the status of all UAVs. Related to this, the company Silicon Valley Simulation, specialized in real time visual simulation since 1996, has developed MUSIM (Multiple UAV Simulation) [30]), a flexible and modular UAV simulation environment used for research into the operator interface.

3. ARCHITECTURE FRAMEWORK

This section provides a brief overview of the configurations of the architecture framework *proposed in this paper*. A block diagram of the simulation framework is depicted in figure 1.

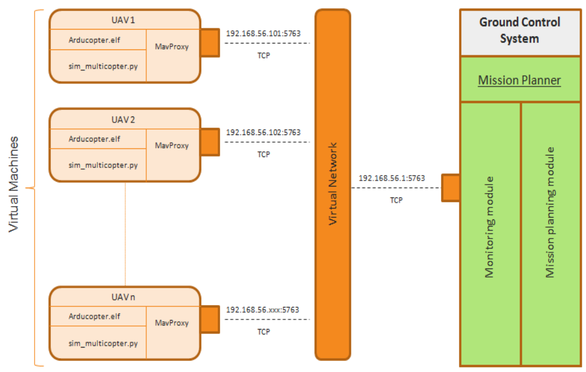

Figure 1: Scheme of the Software-in-the-Loop simulation framework for multi-UAV

3.1. Simulated UAVs

The fleet of UAVs is created from virtual machines that run the software-in-the-loop simulation. The SiL simulator used was developed by the community of APM as a tool for analysis of APM firmware: Copter and other variants. It allows execution of source code without connecting hardware, emulating all modules involved (low-level drivers of different sensors) [see figure 2]. In addition, it works by performing a compilation of the complete code, which runs in conjunction with a simulation of the physics of the ship.

The source code is compiled into an executable file ArduCopter.elf, which is invoked in conjunction with the sim_multicopter.py simulator that is written in Python language. These two programs interact with data packets sent through the UDP ports 5501-5502. On the other hand, the main program also interacts through the communication protocol Mavlink, with MAVProxy program. MAVProxy is a powerful command-line based "developer" ground station software and is responsible for establishing communication between the simulated UAVs and GCS software, using the TCP / UDP protocol [see figure 3].

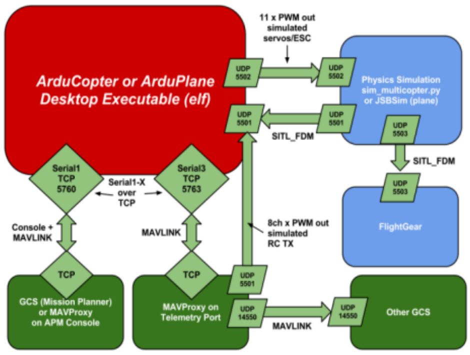

Figure 2: Architecture of the SiL simulator

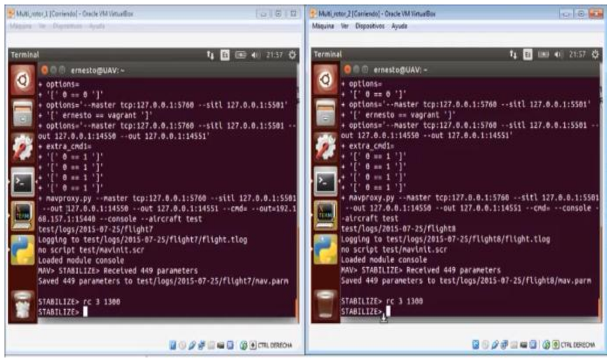

Figure 3: *MAVProxy running* under Ubuntu Virtual Machines

3.2. The Ground Control Station (GCS)

On the other hand, we have selected the open source software Mission Planner to perform the functions of control, planning and monitoring. This package software is, by far, the most used open source software for configuring and planning autonomous missions. This results in a large online community with many resources for developing an autonomous vehicle.

Mission Planner, created by Michael Oborne, is a software package that allows us to configure the APM's settings for our particular airframe setup, so we can achieve the best stability and control for manned and unmanned flights. This software package also supports calibration of the compass and our accelerometers. Mission Planner also allows us to test our motors as well as our sensors such as the sonar module. Mission Planner allows us to plan missions with waypoints planned using a Google Maps interface within the software. Mission Planner makes this very easy with point-and-click waypoint entry. We also have the possibility to download mission log files for analysis after our missions are completed and the copters have safely returned. This Ground Control Station software can be used as a configuration utility or as a dynamic control supplement for your autonomous vehicle.

As this software is designed to operate with a single UAV, we have modified your source code for providing it with the ability to control multiple UAVs. We have created a multiple connection module, which allows simultaneous communication with several UAVs using TCP / UDP and Serial protocols.

To establish the connection between the Mission Planner and each UAV, this module performs the following steps [see figure 4]:

1. Receives the connection request.
2. Identifies the communication protocol used.
3. A MAVLink interface for this UAV is created (this interface allows you to interact with the UAV using the MAVLink protocol). For identification a name according to the order of connection, UAVi, is assigned.
4. The interface is stored in a list called "Comports".
5. All Mission Planner modules (Monitoring, control and planning) point to the "Comports" list to interact with each of the stored MAVLink Interfaces.

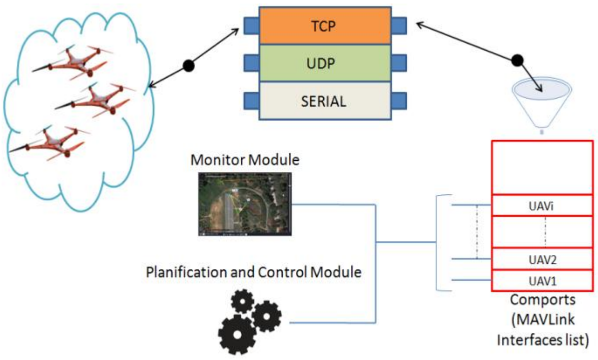

Figure 4: Multiple connection scheme

In figure 5 the graphical user interface of the Multiple Connection module is shown.

A great advantage of using the Mission Planner software in this simulation framework is that all the implemented algorithms can be easily tested in real missions with only replacing virtual machines by real UAVs.

3.3. Communication

To establish communication between simulated UAVs and the GCS we used the VirtualBox Manager to make a Virtual Network. VirtualBox provides several virtual PCI Ethernet cards for each virtual machine. For each card, you can individually select the hardware that will be virtualized as well as the virtualization mode that the virtual card will be operating in, with respect to your physical networking hardware on the host.

Figure 5: Graphical user interface of the Multiple Connection module

In our case, we selected the Intel PRO/1000 MT Desktop adapter and the Host-Only networking mode for each simulated UAV, as shown in figure 6.

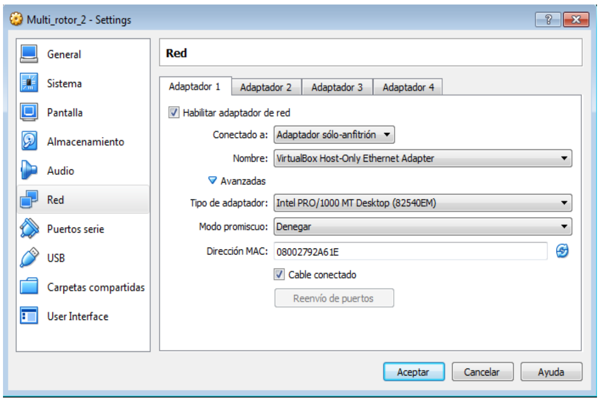

Figure 6: Virtual PCI Ethernet card setting

This configuration is particularly useful for preconfigured virtual applications, where multiple virtual machines are shipped together and designed to cooperate. Instead, a virtual network interface (similar to a loopback interface) is created on the host, providing connectivity among virtual machines and the host [see figure 7].

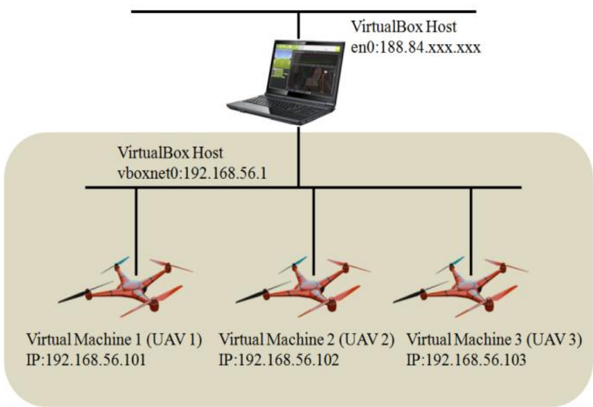

Figure 7: Software in The Loop Simulation Network

4. APPLICATIONS

The proposed framework has been used to assess the feasibility and performance of some flight missions for multi-UAV systems.

Also, this simulation framework has proven useful in the development and implementation of various types of algorithms for multi-UAV systems. As it is based on open source software, it is possible to access each of the features of the environment and modify existing features or create new ones. A simple way to implement algorithms for multi-UAV systems is by using Python scripts directly in Mission Planner.

One of the algorithms implemented using this framework has been a Sense & Avoid algorithm for multirotor UAVs based on TCAS II (traffic collision avoidance system II). For this implementation, we have relied on the TCAS-II Resolution Advisory Detection Algorithm presented in Munoz and Chamberlain 2013 [see figure 8].

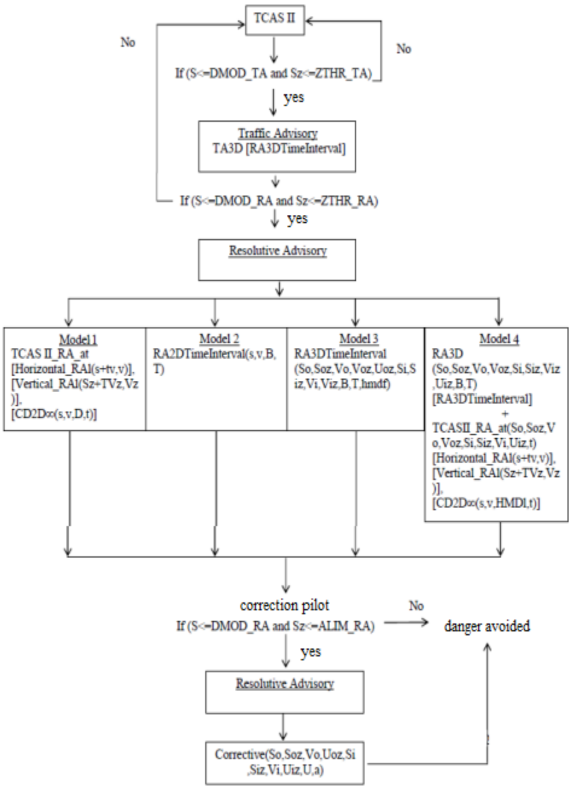

Figure 8: Flowchart of the TCAS-II Resolution Advisory Detection Algorithm

The TCAS II system provides that in the case of a potential collision, a sounding alert is emitted by the “Traffic Advisory” (TA). This system warns the pilot about every intruder aircraft by a "traffic, traffic" vocal announcement. It does not provide any suggestion avoidance maneuver. Whenever the conflict situation gets worst after a TA alert and the collision seems impending, an audio message and a visual alert are generated by the “Resolution Advisory” (RA). This alert indicates the concerned airplane and suggests an avoidance action to be immediately executed by the pilot.

To implement the TCAS II in UAVs we need to modify those processes involving interaction with the pilot. This is due to the fact that the UAV does not require notice to the pilot to perform evasive action. The aircraft itself can perform the maneuver after receiving the alert. Also, the ranges have been modified for TA and RA alerts due to low speed of multirotors UAVs.

The TA will have a horizontal range of 150 meters and 70 meters for the RA. On the other hand, the minimum vertical separation will not be taken into account for the TA, while for the RA will 5m.

In the case of vertical separation of less than 10 meters the avoidance maneuver is a displacement of 60 meters in the horizontal plane and a descent or ascent of 10 meters.

Figure 9 shows a scenario of conflict implemented in our simulation framework. In this case there is a vertical separation of 2 meters between the two UAVs. In figure 10 the avoidance maneuver is shown. More details about the algorithm can obtained in Sánchez (2016).

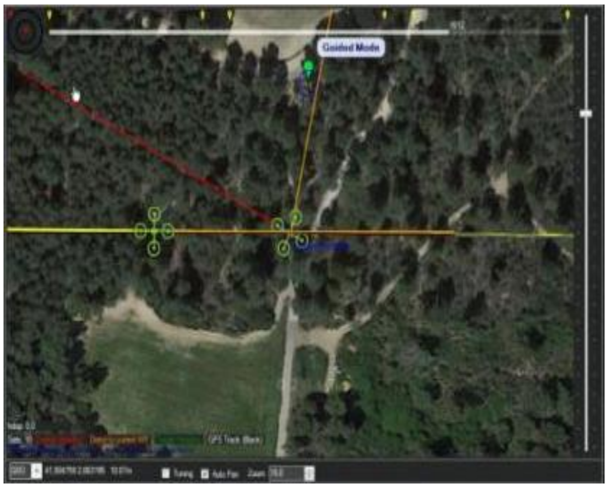

Figure 9: Vertical separation of less than 10 meters

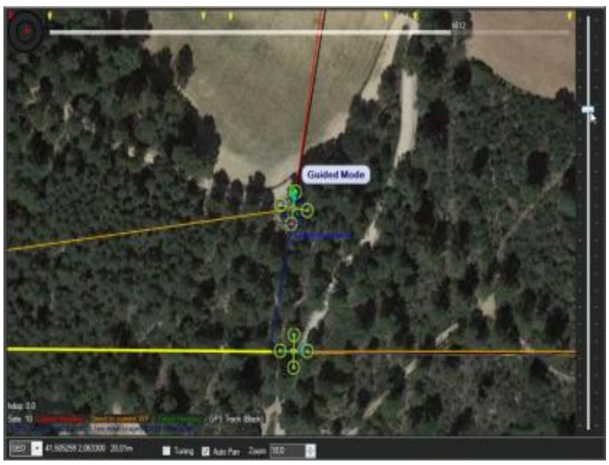

Figure 10: Avoidance maneuver

In addition to this, we have test the simulation framework in other applications. One of them consists in developing and implementing a multi-UAV routing for area coverage in the shortest time possible [see figure 11].

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Figure 11: Multi-UAV Routing for area coverage with minimum time

This algorithm has been especially designed for applications where it is necessary to cover an area in the shortest time possible, such as to look for hot spots after a fire. The target area is subdivided into subregions it. Each subregion is allocated to a UAV following a strategy that minimizes the overall time of the mission. The algorithms discussed above were programmed directly into the source code of "Mission Planner" code.

Currently we are developing some cooperative algorithms for multi-UAV systems where the simulation framework is also showing its usefulness.

CONCLUSIONS

In this paper, a Software in The Loop Simulation Framework has been presented which allows testing performance of missions and developing different types of algorithms for multi-UAV systems. Additionally, this framework allows implement the communication among UAVs for developing cooperation algorithms.

The proposal has been successfully used for simulating several flight tests including basic flight motions, full-envelope flight and multiple UAV formation flight. Results obtained show that the constructed software-in-the-loop simulation framework is highly effective and useful. This implementation has allowed us to make significant progress in the development and study of task allocation algorithms, sense & avoid algorithms and cooperative algorithms.

FUNDING

This work was supported by the Ministry of Economy and Competitivity in the project ‘‘Fire Guided Unmanned Aircrafts and Resources Distribution - 2 (FireGUARD-2)’’, CICYT Spanish program (TIN2014-56919-C3-1-R)

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A SOCIO-TECHNOLOGICAL APPROACH TO IMPROVE THE PERFORMANCE OF THE AIRCRAFT BOARDING PROCESS

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ABSTRACT

Airports are critical transport infrastructures supporting different tight interdependent operations that must be properly coordinated to avoid delays on the departures. A sustainable air transport system requires that the strategic planned departures could be preserved at operational time, to avoid downstream overcapacity problems at the airside. In this paper it is introduced some of the perturbations that affects the aircraft turnaround time and the importance to improve the robustness of those operations, which are more sensible to uncertainties generating departure delays. A new boarding MAS algorithm based on a socio-technological system approach is presented, removing some barriers in its deployment.

Keywords: security screening, slot assignment, queuing, capacity demand balances

1. INTRODUCTION

Air transport system requires the implementation of new processes, procedures and techniques to tackle the growth in air travel demand, which now a days saturates present Air Traffic Management (ATM) resources both at airside and at landside [5,6], resulting in poor KPI's during certain time peak periods.

In the service sector, it is well accepted that resource-saturation usually is the cause of delays that affects drastically different quality indicators. Furthermore, a tight interdependency between a service-chain allows the free propagation of a delay through the different processes provoking idleness and saturation dynamics.

At the airport landside, delays can be generated due to a saturation of airport infrastructure or a poor coordination of the different services that should be provided to the aircraft during the turnaround process.

Turnaround is defined as the period of time the aircraft is on the ramp between an inbound and outbound flight, and different ground- handling operations are performed. Ground handling comprises the activities, operations procedures, equipment requirements, and personnel necessary to prepare an aircraft for the next flight. Many aircraft delays can be attributed to overlong turnarounds due to a lack of planning integration of the different activities and an inefficient use of resources. In addition, the ground tasks are very interdependent. Each operation is a potential source of delays that could be easily propagated to other ground operations and other airport sub-processes [3].

Despite several efforts to improve the robustness of the turnaround processes to avoid the generation and propagation of delays through other aeronautical processes, now a days, turnaround is still considered the weak cornerstone in the airport due to the tight interdependencies between the tasks to be executed in an operational context characterized by uncertainties and decision making tasks fragmented between different stakeholders.

Most relevant stakeholders that participates in the decision making process during turnaround operations are:

- Airport: Manages the required infrastructures to support turnaround tasks. Some decisions, which can drastically affect the turnaround scheduling, is the parking and door assignment. Thus, a remote position can require some extra tasks (ie. transport of passengers to the parking position, stairs, etc) while some others can be avoided (pushback on autonomous positions).
- Airlines: Are the responsible to extend the turnaround time to tackle unpredicted disturbances (ie. a non-shown passenger) and accept or not late baggage.
- Handling Companies: They must coordinate most of ground operations considering the precedence spatio-temporal constraints.

Additionally, all the stakeholders use their own resource management systems and resource optimization systems to satisfy their particular business goals. The different criteria used for each stakeholder may lead to solutions incoherent with the rest of the stakeholder's needs, leading to inefficiencies. In order to fill this gap, the Airport-CDM concept arose [2], aiming to improve the overall efficiency of operations at an airport through collaborative planning and information sharing among stakeholders, with particular focus on the aircraft turn-round and pre-departure sequencing processes.

Figure 1: Independent Process Oriented Turnaround

The INTERACTION Project proposes to improve the efficiency of airport processes through the integration of the 4 independent turnaround sub processes (Figure 1) by considering the different interdependencies and providing new processes to mitigate the propagation of disturbances.

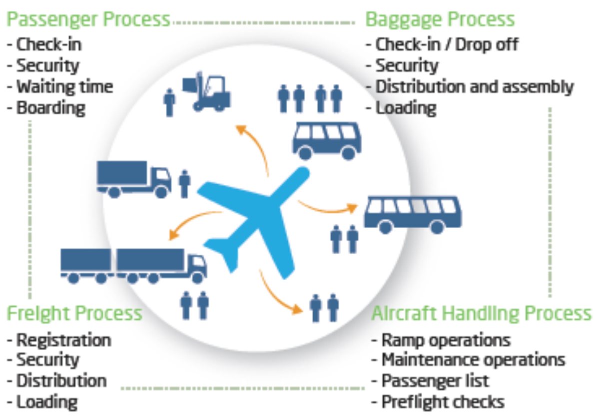

Figure 2: Interaction : Turnaround as a whole

In Figure 2 it is represented the new approach developed in INTERACTION project in which a central information system has been implemented to support the proper monitoring of the different tasks and turnaround milestones and enhance a coordinated decision in case of deviations with respect to scheduled actions.

As it can be observed in Figure 3 the reduced space located around the aircraft which is shared between all the ramp handling equipment is a source of tight spatial interdependencies. On the other hand, logical precedence requirements such as passenger disembarking precedence to cleaning and to the embarking process are a source of tight temporal interdependencies. Thus, tight spatio-temporal interdependencies between the turnaround tasks that should be finalized in a short period of time deals with a complex system in which decision making must consider all downstream consequences.

In INTERACTION it has been developed a causal model using Coloured Petri Net (CPN) formalism to analyze all the physical and temporal interdependencies and some control mechanisms to mitigate the propagation of perturbations between turnaround processes that are placed in the critical chain. Among the turnaround operations with a non-deterministic duration time, there are 3 ground tasks that provides a higher level of uncertainty:

- Boarding: The boarding process is very sensible to the boarding sequence and the characteristics of the passenger, providing as average an increment of 7 minutes with respect to scheduled time.
- Bulk Loading: It can impact on an increment of 12 minutes with respect to scheduled time
- PRM arrival: Passenger with Reduced Mobility can impact with an increment of 8 minutes with respect to scheduled time.

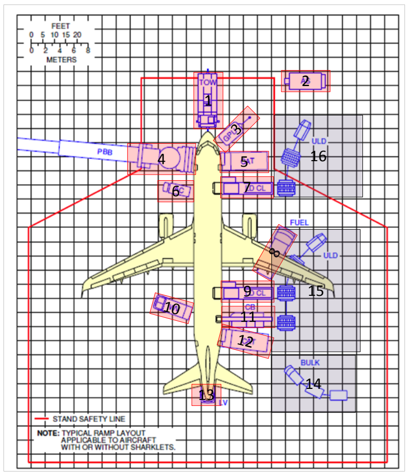

Figure 3: turnaround ramp handling tasks

Among these 3 turnaround operations with highest stochastic duration time, only the Boarding process is always in the critical chain. In this paper it is presented a description of the main disturbances that affects the boarding process and a Multi Agent System model that has been implemented in Netlogo to mitigate the effects of disturbances and improve the robustness of the boarding process.

2.- THE BOARDING PROCESS

During the boarding process, passengers use to compete in the terminal area to get inside the aircraft through a Boarding Pass control.

Inside the aircraft, the space in the aisle is quite reduced generating flow conflicts and interferences between passengers that can block the boarding flow. The main conflicts, which can affect the boarding speed, are:

- Placing a luggage in the overhead compartment: In case there is room in the overhead compartment this time can be modelled as a stochastic process, however when overhead compartments are nearby saturation (ie. the lasts boarding passengers), the time required to find an overhead compartment with enough room to place the luggage is tightly dependent on the amount of passengers in the aisle.

- Placing a coat in the overhead compartment: Specially, in winter time and old people, to remove the wearing coat in a reduced space and placing the coat in the overhead compartment avoiding to loose the objects (coins, keys, mobile,…) from their pocket, usually impact on the boarding time.
- Latent Aisle capacity: Distance between passengers waiting in the aisle is 2 or 3 time bigger in the embarking that at disembarking. It is easy to see how passengers take profit of any space in the aisle when preparing the disembarking while the door is still closed.
- Taking a seat: The time it takes a passenger to leave the aisle after having arrived at his or her seat's row and having stored the luggage, depends on the seat location in the row and if another passenger is seated in the row and need to leave their seats in order for the current passenger to sit down.

There are several algorithms reported in the literature that try to maximize the boarding speed considering somehow the above-mentioned conflicts, among them, the most relevant are mentioned bellow with some new insights obtained using the MAS model developed :

Random Boarding: There is no pre-established sequence of passengers boarding the aircraft. Some authors claims that random boarding provides the best boarding time because passengers are spread through the aircraft seats.

According to simulations results obtained using the MAS model developed and an analysis of passenger interdependencies, one of the main causes of these good boarding time achieved using Random policy is because the passengers with the most carry-on bags try to in the first positions of the boarding queue since they are afraid about lack of room in overhead compartments, while passengers without bags prefer more to spend their time in the commercial area instead of queuing long time before the embarking. In [1] it is shown how the "passengers with the most luggage board first" policy provides good results in terms of the total time for all passengers to board. Furthermore, the sooner it is detected that overhead compartments are saturated the better, since airlines companies can ask earlier passengers to leave the baggage outside the aircraft to be loaded in the bellies providing indirect benefits in the turnaround time.

Back-to-Front: Passengers are grouped according to their assigned row and embarking is performed by groups of passengers with rows assigned in a descending order. The most popular implementation is to split passengers in just two groups (passengers from rows 16 to 23 and from1 to 15). Smaller groups could also be implemented but experimental results are worst that the Random policy.

One of the reasons that justify these results is because the amount of aisle conflicts increases considerably when passengers are concentrated in the same area, and lack of interaction between passenger's together with random sequence inside the group leads to situations in which passengers are seated in the sequence C B A (see Figure 4) increasing the "Taking a seat" time which will be additive to the placement of baggage.

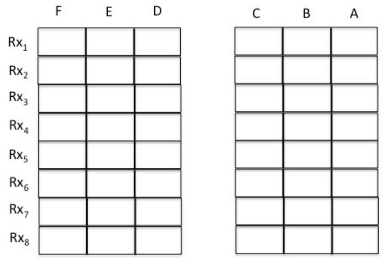

Figure 4: Seat distribution

Front-to-back
This policy is quite similar to the previous embarking policy (back-to-front) but groups of passengers seated at the front of the aircraft will embark before than passengers at the back.

According to experimental results, this policy provides the worst embarking times, which is justified because aisle blockages compute multiplicatively (few concurrent aisle blockages) instead of additively (several blockages takes place in the same time).

WILMA Algorithm
Passengers are assigned to 3 groups: passengers with a window seat (group 1), passengers with a middle seat (group 2) and passengers with aisle seat (group 3). Boarding is organized using the same order of the groups.

Experimental results confirm that "Taking a seat" blockages are minimum.

Reverse Pyramid
Some authors consider this policy as a combination of back-to-front and Wilma embarking policies, since passengers are sequenced providing priority to windows seats at the back of the aircraft.

The experimental blockages observed provides a good trade-off between "Taking a seat" and "placement of baggage" with a good rate of concurrent blockages.

Steffen
For an aircraft with 20 rows and 120 seats, passengers are split in 12 different groups each one with 10 passengers. First passenger is seated in the window of

the last row and the next passengers are seated in the window of two rows ahead of its predecessor. This sequence is repeated for the passengers with a window seat located at the other side of the aisle. Once odd windows are occupied the next passengers are seated in even windows repeating the same procedure. Once all windows are full, the next passengers are seated according to previous steps but in the middle seat, and once all middle seats are full passengers are seated at the aisle according to the same sequence used in window seats [7].

Assuming that baggage is randomly distributed through passengers, blockages due to aisle latent capacity and “taking a seat” time are minimum while the concurrency of blockage due to placement of baggage is maximized. In Figure 5 it is represented the aisle blockage results applying Steffen boarding algorithm with a row-to-row deterministic time of 2 seconds and 7 seconds for taking a seat and placing 1 baggage with a configuration of 7 rows. In the Y axis B is used for aisle Blockage and F for aisle Flow. As it can be observed, the 7 seat windows (F) are first assigned and then the other seat windows at the other side of the aisle (A) are assigned alternatively.

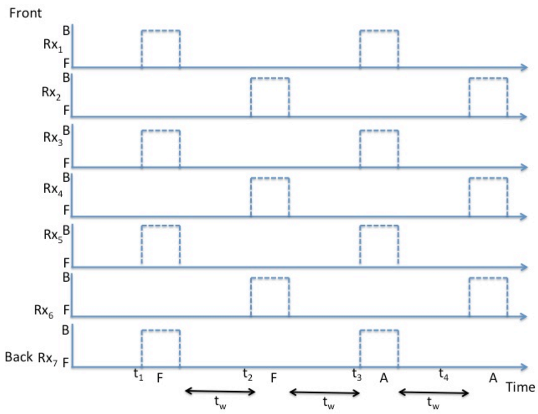

Figure 5: Aisle blockage concurrency

Aisle blockages at the different rows takes place at the same time which allows longer time periods in which the aisle is free of blockages improving the averge speed boarding flow. These excellent results can only be obtained if deterministic times are considered for the “row-to-row”, “time to seat” and “placement of hand baggage”. However, saturation of overhead compartments impact negatively on boarding performance, with more sensitivity effects in the front seats. In Figure 6 it is shown how extra time to store a luggage affects the aisle blockage times and in consequence the accessibility of passengers to reach their seats. The time to store a luggage is computed according to the next equation described in [1]

$$T_{sl} = \left(\frac{n_{bin} + n_p}{n_p}\right) \times n_p \times t_{row-to-row}$$

In which

- T_{sl} : The estimated time to store a luggage in the overhead compartment.
- n_{bin}: The number of luggage already in the overhead compartment
- n_p : The number of luggage the passenger must store
- $t_{row-to-row}$: Time to move from one row to the next

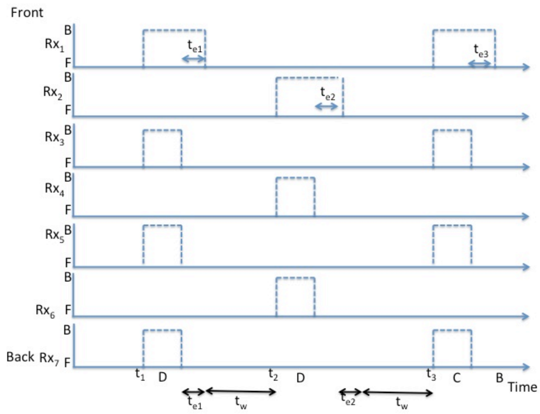

Figure 6: Increment of blockage time due to extra time for storing luggage

3.- SOCIO TECHNOLOGICAL BOARDING APPROACH

Despite the excellent robust results that can be achieved using Steffen algorithm if overhead saturation problems are not considered, it is recognized that the acceptability of the algorithm is really low for passengers since it requires to split a group (ie. family with kids should embark at different times) and also generates pre-embarking problems since sometimes the right passenger is not located in the gate at the time required by the Steffen algorithm.

A socio technical approach to the boarding problem has been considered in which the developed MAS model considers not only the control variables but also the influence variables. Thus, agents can interact between them in a local context to minimize conflicts while maximizing benefits. In INTERACTION it has been assumed the use of reward mechanisms (such as extra miles, a free drink consumption, etc) to enhance the cooperation between passengers.

Cooperation between passengers to achieve a short boarding can be represented by means of influence variables in which the passengers located at a neighbourhood of 2 -3 ahead or 2 – 3 back in the lane (preferably at finger) can be influenced for a local re-sequencing satisfying window – middle – aisle if they are seated in the same row.

A MAS model has been implemented in Netlogo in which the main influence variable to achieve a re-sequencing in the lane considers the next 3 factors:

- Age: Young people are more aware of airline reward mechanisms, willing to obtain always extra miles or any other advantage provided by the airline.
- Location: Passengers in a window seat assigned will be much more pro-active to check with the neighbourhoods passengers if they have a middle or aisle seat in order to swap in case are in the same row.
- Willingness: The main barrier for the acceptability of a swap are: the language problems, reduced mobility passenger problems, and fear about overhead compartment saturation.

Different weights are assigned to the 3 influence factors to succeed with a sequence swapping meanwhile passengers are still waiting to reach the aircraft door (pre-embarking area or finger). As extreme scenarios for validation purposes it is considered that in a group of 6 passengers with 3 or more young people, the re-sequencing is guaranteed. In case there are not PMR's with only 2 young people it is also guaranteed. On the other hand, it is considered that a group of 6 elderly tourists with 2-hand baggage per passenger at the latest stages of embarking wouldn't accept easily a swapping due to fear about lack of room in the overhead compartment to store their luggage.

In order to remove some barriers of the Steffen algorithm in which group of people (ie. families, friends, etc) should embark at different times, it has been developed a model in which passengers embark according to a pre-established sequence of rows which has been formulated considering the occupancy factor and the latent aisle capacity. Thus, for an aircraft with 100% occupancy with 20 rows the sequence of rows proposed is:

20 15 10 5 19 14 9 4 18 13 8 3 17 12 7 2 16 11 6 1

This sequence somehow tries to combine the benefits of back-to-front with Steffen and WILMA algorithms. Thus, first row to embark is the row at the back (ie row 20) in which the 6 passengers are re-sequenced (as :

F A E B D C

The next row is located 5 rows ahead (ie. row 15) since the aisle space between row 15 and row 20 is used by the passengers with seat at row 20 meanwhile they are storing their luggage in the overhead compartments. Note that the storage of the baggage is performed by the passengers at the same time, thus the aisle is blocked by the 6 passengers of the row at the same time and it doesn't affects the movement of passengers in the aisle to reach row 15. Furthermore, the local re-sequence achieved through the use of reward mechanisms minimizes the time-to-seat in the row.

In Figure 7 it is represented the simulation of the sequence at different time intervals in which the blue colour represents the aisle of the aircraft and the brown colour the seats. Thus, Figure 7 (a) illustrates the seat occupied by the first 4 rows of the sequence (ie. 20, 25 10 and 5). In part b) it is visualized the boarding until row 4, in part c) it is visualized the boarding until row 3 and in part d) until row 2. As it can be observed in part c) the 6 passengers at the top part of the aisle are moving without any aisle blockage until row 17.

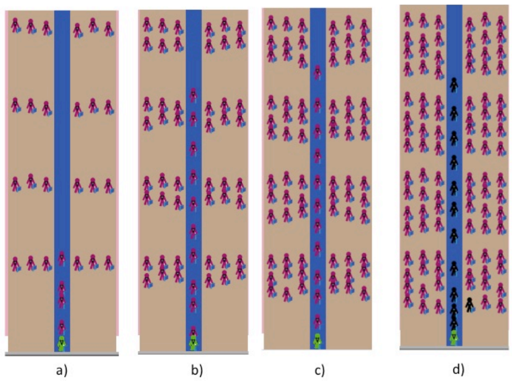

Figure 7: Boarding by rows

Using the proposed sequence, the boarding speed flow is interrupted only 4 times when passengers of rows 5, 4 3 and 2 stores their bags in the overhead compartments. In fact, the boarding flow it is interrupted according to:

20 15 10 5
19 14 9 4
18 13 8 3
17 12 7 2
16 11 6 1

In the top side of Figure 8 it is represented the amount of people generating a blockage in the aisle. As it can be observed, the passenger of seat F in each row blocks the aisle during the T_{sl} time which is used also by the other passengers of the same row to store their bags in the overhead compartment. Time between 4 consecutive blockage correspond to the time required by passengers to reach their row. At the bottom part of the same figure it is represented the amount of passengers that are blocked in the aisle. Some of the reported blockages are due to the speed differences of passengers walking thorough the aisle and the latent capacity generated by trolleys.

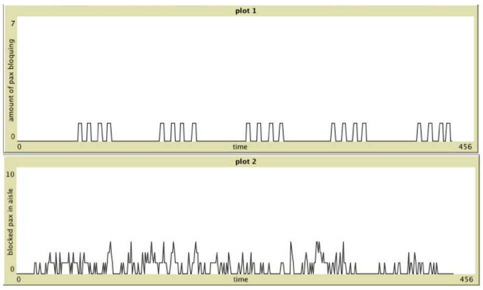

Figure 8: Boarding results using proposed sequence

4.- SIMULATION RESULTS

The proposed algorithm tries to minimize both the severity and the amount of aisle blockages, by combining the benefits that can be obtained by the Back-to-Front boarding algorithm, the Steffen algorithm and WILMA algorithm.

In Table 1 it is summarized the boarding times obtained with similar passenger profiles and amount of hand baggage to compare the benefits of the proposed embarking sequences with respect to Steffen sequence [4]. As it can be observed, Steffen provides better boarding times in those flights in which hand baggage is minimum (ie. business flights). A possible reason that justify this small difference is that the first 2 passengers in the row (ie. seats A and F) shares the same aisle area to reach their seats while this situation doesn't appears in the Steffen algorithm.

With a random low amount of well distributed hand baggage both algorithms provides similar boarding times, however the proposed algorithm is much robust and provides better boarding times when the amount of hand baggage is nearby saturation.

New Algorithm		Steffen Algorithm	
Boarding Time	Amount of Hand Baggage	Boarding Time	Amount of Hand Baggage
6' 50''	0	6' 37 ''	0
7' 3''	54	7' 3''	57
7' 13''	98	7' 21''	102
7' 24''	95*	9' 29''	96*

Table 1: Boarding time simulation results

Last experiment reported in the table (last row marked with *) consists of an scenario in which passengers at the front of the aircraft have at least 1 hand luggage (maximum 2) that must be placed in the overhead compartment. As it can be observed, Steffen algorithm performance is affected since the aisle is blocked at consecutive times, while the new algorithm is much more robust because passengers of the same row stores the baggage at the same time (ie. task performed in parallel).

In Figure 9 it is represented the amount of passenger blocking the aisle (upper side) and the amount of passengers blocked (lower side) in the scenario requiring 9' 29'' to complete the boarding.

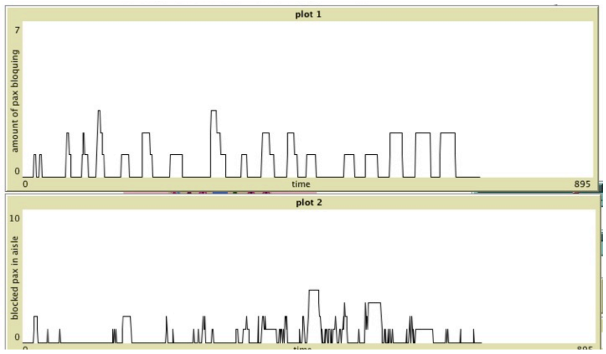

Figure 9: Steffen Boarding results with passengers with 1 or 2 baggage at the front

4.- CONCLUSSIONS

A new boarding algorithm has been designed to improve the robustness of present algorithms which usually do not consider the disturbances of overhead compartment and its saturation.
The implementation of reward mechanisms can be easily designed together with the airlines to enhance passengers to facilitate a local re-sequence while waiting at finger. The results obtained at simulation opens new opportunities to airlines to exploit the seat assignment considering passenger willingness to benefit from rewards.

ACKNOWLEDGMENTS
This work is partially funded by FP7 INTERACTION project, and MINECO project "Fire Guided Unmanned Aircrafts and Resources Distribution (TIN2014-56919-C3-1-R).

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URBAN LOGISTICS: THE ROLE OF URBAN CONSOLIDATION CENTRE FOR THE SUSTAINABILITY OF TRANSPORTATION SYSTEMS

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ABSTRACT
In the paper urban consolidation centres (UCCs) are considered as solution for the urban freight transportation. After a short related research concerning UCCs, a case study about a medium Italian city is considered. Static simulation is used to evaluate the environmental benefits of UCC due to freight consolidations and electric vehicles. Results show that the environmental effectiveness of UCCs depends on the level of cargo consolidation. Considering for instance cargo consolidation of 80%, a saving of 30% of emissions is possible.

Keywords: urban consolidation centre, freight consolidation, urban transportation simulation, logistics simulations

1. INTRODUCTION

Urban consolidation centres (UCCs) could play an important role in the future sustainability of the cities. Up to now, the studies of urban consolidation centres show that they could be effective in reducing the urban traffic but the economic viability is always under discussion. This mainly because UCCs could increase logistics costs. Several possible solutions are studied. It is anyway interesting to plan the possibility to introduce UCC, also in medium-small cities in Italy. Thanks to IT technologies and to improvements in alternative fuels such as electric cars, UCCs will become more attractive in the future.

In the paper a study concerning a possible UCC in a medium city in Umbria is considered. In particular a simulation model based on Cube software shows the potential benefit of the introduction of UCC.

In Section 2 a related research concerning UCC is shown. In Section 3 the case considered is depicted and results of different UCC scenarios are shown. In Section 4 conclusions are drawn.

2. RELATED RESEARCH

Modeling and Simulation can support UCCs design like any other logistics facility. In Bruzzone et al. (2015), for instance, a simulation tool for the design of harbor terminal is considered. UCCs have many common aspects with harbor terminal even if they are usually smaller: flows management, loading and unloading and housekeeping operations etc. But for other aspects they differ a lot. In harbor terminal the goods flows concern mainly containers, while in UCCs goods are mainly parcels.

In Van Duin, Quak and Muñuzuri (2010) the important factors for the success and failures of UCC are identified: Number of Users, Organization, Subsides, Type of Vehicle, Location and Accompanying Measures. Authors investigate several UCCs projects and they found that one of the main problems is the cooperation between transportation companies using the UCCs. For transportation companies phases like picking and delivery of goods to the clients are part of their core business. It is not so simple, then, to outsource those activities. Furthermore they should share very sensitive information with other competitors. A feasibility study of an UCC is considered and several scenarios are discussed. Evaluations are based only on average statistical data about goods and deliveries without any traffic measurements.

In Paddeu et al. (2014), an analysis of an existing UCC (Bristol-Bath) is shown, based on a database of goods and deliveries data for a period of 17 months. A Multiple Linear Regression model is developed to correlate the number and the type of heavy goods vehicles delivering to the UCC with the number of deliveries. The regression is good and could be useful in the planning of the UCC. Also Environmental Emissions reductions are estimated. The UCC is successful, but since the take-up was slower than forecasted, emissions reduction at the time of the paper were limited.

In Leonardi et al. (2014) a best practice methodology for UCC is considered. A Multi Criteria Analysis based on 4 criteria is shown: Innovation and Technical and Economic Feasibility, Strength of External impact, Accessibility of Information, Transferability of Best Practices. 15 cases chosen from 93 are analyzed. Results are interesting but they need more cases to be validated scientifically.

Janjevic and Ndiaye (2014) concerns the very interesting subject of Micro Consolidation Schemes, logistics platforms within urban area. They represent something different from UCC which are usually located outside the city centre. It is some sort of UCC downscaling. Micro consolidation schemes are then similar to the UCC considered in this paper, because is thought for a small Italian city. There are 6 main typologies of Micro-Consolidation Centres. While there are many project developing Micro-Consolidation initiatives, main issue is about the transferability. Transferability means the possibility to transfer a micro-consolidation centre successful solution to another place. Authors propose a framework for such transferability. They apply the framework to the City of Brussels where they show the feasibility of a micro-consolidation solution and they find the best location within the city. Nevertheless the paper does not cover in detail the issue of the volume and flows of traffic within the urban area.

Moeinaddinia et al. (2015) introduces an Urban Mobility Index, UMI, for the evaluation of transportation in cities. First of all at macro-level the urban structure variables correlated with the percentage of daily trips are investigated. They found 18 variables with significant correlations: Urban population density, Length of road per thousand of inhabitants etc. On the basis of correlation results the UMI, with range from 0 to 100, is evaluated. In this manner it is possible to evaluate if the mobility is sustainable (high values) or no (low values). UMI seems to be effective for a quick evaluation about a city, even if is based on macro-level variable and there is not distinction between transportation of goods or people. In Anderson et al. (2005) it is underlined that urban freight transport impacts the economy, the sociality, the environment. They used collected data from 120 vehicle rounds and 2286 collections and deliveries from 3 different cities.

In this manner the impact of 4 policies measures (Low Emissions Zones, Congestion Charging, Weight Restrictions, Time Restrictions) is evaluated. Even if in the paper there are interesting suggestions and insights the benefits of the 4 policies, measures are not completely quantified. Furthermore paper does not consider the possibility to reduce traffic via an urban consolidation centre.

In de Oliveria et al. (2012) a preference technique and adoption theory based model for retailer and carrier is considered. Thanks to this model it is possible to identify for a particular city what are the more important attributes an urban distribution centre (UDC) must address. Application of the model to 2 Brazilian cities shows that for carriers the more important attribute is parking while for retailers costs attribute are contrary to the UDC schemes.

In Browne et al. (2011) an interesting micro consolidation centre trial in London is depicted. The trial shows that it is possible to reduce the emissions by using electric vehicle even if the kilometers travelled within the city increases. This because of the reduced capacity in weight and volume of the electric vehicles. Operating costs does not increase with the micro consolidation centre. In more detail the increase of costs concern the distribution centre operating costs (because of the micro consolidation centre) and driver costs. The decrease of costs concern vehicle capital, insurance, maintenance and fuel costs.

Cherrett et al. (2012) analyses 30 surveys about urban freight activity in UK searching correlated factors.

They estimated the average number of deliveries per week to establishments; the mean number of goods delivery by business and other interesting factors. They make a distinction between goods deliveries to establishment and service visits to establishments. Those factors can be useful for understanding the freight activities and also for the design of facilities like UCCs. They refer only to the UK context and factors provided, averaged data, are useful only at the very first stage of the analysis.

In Allen et al. (2012) UCC benefits are: reduce goods vehicle traffic, vehicle related greenhouse gas emissions and local air pollution.

UCCs are logistics facilities for transshipping and consolidating goods. In this manner vehicles can reach high load factors for the final delivery in the urban area.

Electric goods and alternatively powered vehicle can further reduce the environmental impact. Another important distinction is that there are several types of UCC: serving all or part of an urban areas, UCC serving large site with a single landlord and UCC consolidating construction materials. Only the second type, with single landlord (airport, big hospitals, etc.) can reach easily an economic feasibility. For UCC of type one success depends on several factors above all the number of retailers participating to the initiative.

It is important in the UCC analysis to consider the kind of good transported. In the present paper mainly non fresh food is considered. For fresh food, in Bruzzone and Longo (2014) there is an interesting application methodology for the logistics and transportation in the fresh food supply chain.

3. CASE CONSIDERED

The case study concerns the urban logistics of a medium Italian city. Starting from the actual scenario of goods distribution, several scenarios are analysed with the aim of reducing the number of vehicles and the quantity of emissions. The study focus on the city centre, where local environmental and traffic problems are more noticeable.

To obtain data about the actual goods distribution system, a data collection was made in the limit traffic zone (LTZ) area. After a preliminary analysis of the LTZ input gates, four gates are considered for the vehicles counting.

For 10 days, from 7.00 a.m. to 11.00 a.m., all the vehicles entering the city centre through the 4 input gates are counted. Table 1 shows the daily averaged collected data. The commercial vehicles are classified in these categories:

- Mini – Van
- Van
- Light trucks (< 3.5 tons)

- Trucks (> 3.5 tons)

Some light trucks and trucks are not used for commercial activities but for other services like the vehicles of cleaning companies or construction firms. These vehicles are classified separately from the others and they are indicated with "services".
From 7.00 a.m. to 11.00 a.m. 2593 vehicles enter the city centre. Of these 283 are commercial vehicles.
The peak hour is from 07.45 to 08.45 a.m.: 88 commercial vehicles on a total of 915 vehicles.

Table 1: Collected Data

	Cars, taxi	Motorcycles	Mini-van	Van	Light Trucks	Trucks	Bus	Light trucks (services)	Trucks (services)	Total
07:00	39	3	2	4	3	1	6	0	0	58
07:15	52	3	4	2	4	0	13	1	0	79
07:30	117	24	9	6	2	0	10	0	0	168
07:45	212	39	18	13	6	0	11	1	0	300
08:00	187	18	7	5	3	0	10	1	1	232
08:15	153	20	15	5	0	0	10	1	0	204
08:30	133	22	10	3	3	0	7	1	0	179
08:45	115	34	11	2	2	2	9	2	1	178
09:00	142	21	15	4	0	1	15	0	0	198
09:15	117	19	8	2	3	1	11	3	0	164
09:30	104	20	11	5	1	1	9	0	0	151
09:45	102	19	17	2	5	1	12	0	0	158
10:00	80	21	9	3	1	0	6	1	1	122
10:15	87	19	6	2	3	1	11	3	0	132
10:30	94	12	11	5	8	0	9	0	0	139
10:45	89	12	8	5	2	0	11	4	0	131
Total	1823	306	161	68	46	8	160	18	3	2593

To simulate the actual and other scenarios, the Cube software (Cube 6.0, Citilabs Inc.) is used. The version used allows the modelling of the distribution of vehicles on the road network of the city. The city is divided into different traffic zones and then an O/D matrix is built to represent the movements between those zones. Each (*i*,*j*) element of the matrix represents the number of vehicles having the zone *i* as the origin and the *j* zone as destination. The model treats the road network as a graph, which consists of arcs and nodes. To each arc is assigned a vehicular load on the basis of a mathematical law, the choice of which depends on the type of network and the type of mobility that characterizes the area. However, the user can choose the most cost-effective route, taking into account rational behaviour and user needs. In the case study, the assignment is made on the basis of actual traffic flows counted in the input gates of LTZ.
In the case study, 8 zones are detected:

- Zone 1: the city centre, the destination of all the vehicles;
- Zone 2: a freight village, a possible origin zone for alternative scenarios;
- Zones 3-8: the main access routes to the city.

To simulate the traffic, the software needs of the weighted sum of the vehicles, where the weight is relative to the size. For motorcycles the weight is 0.5; for cars, mini-vans and vans the weight is 1; for light trucks the weight is 1.5 and for trucks and buses is 2.5.
Regarding the peak hour and only the commercial vehicles, the total commercial equivalent vehicles are 94.

3.1. Actual Scenario

Figure 1 shows the actual schematization of the city centre (1) with the four gates (a, b, c and d) and the main access route (3-8). The freight village (zone 2) is not used. The numbers next to the arrows refer to equivalent vehicles passing between the origin and destination linked by the arrow. Table 2 is the O/D matrix for the actual scenario. The showed flow of vehicles is assumed.

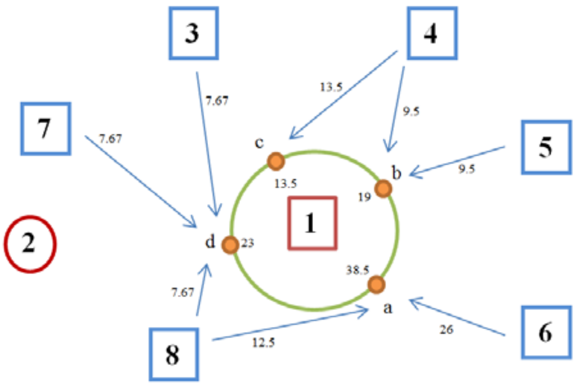

Figure 1: Actual Scenario

Table 2: O/D matrix for the actual scenario

Origin	Destination				
	a	b	c	d	Total
3	0.00	0.00	0.00	7.67	7.67
4	0.00	9.50	13.50	0.00	23.00
5	0.00	9.50	0.00	0.00	9.50
6	26	0.00	0.00	0.00	26.95
7	0.00	0.00	0.00	7.67	7.67
8	12.5	0.00	0.00	7.67	19.22
Total	38.50	19.00	13.50	23.00	94

3.2. UCC Scenarios

The study aims to use the UCC in the distribution of goods in the city centre. Different scenarios which include the UCC are analyzed. A first scenario called "UCC scenario" is taken as the basis for the comparison with the other scenarios.
Figure 2 shows the UCC scenario where the urban consolidation centre is used in the freight delivery system of the city. The UCC is denoted in the figure by zone 2. Knowing the data collected, the following assumptions are made to trace the number of vehicles traveling:

- Only about 65% of the total vehicles diverts to the UCC. So on the average 61.1 vehicles travels from UCC to the city centre.
- All the vehicles originating from zone 3 are shifted to UCC.
- Only 60% of the vehicles originating from zone 4 are shifted to UCC.
- Only 40% of the vehicles originating from zone 5 are shifted to UCC.
- Only 30% of the vehicles originating from zone 6 are shifted to UCC.
- All the vehicles originating from zone 7 are shifted to UCC.
- All the vehicles originating from zone 8 are shifted to UCC.

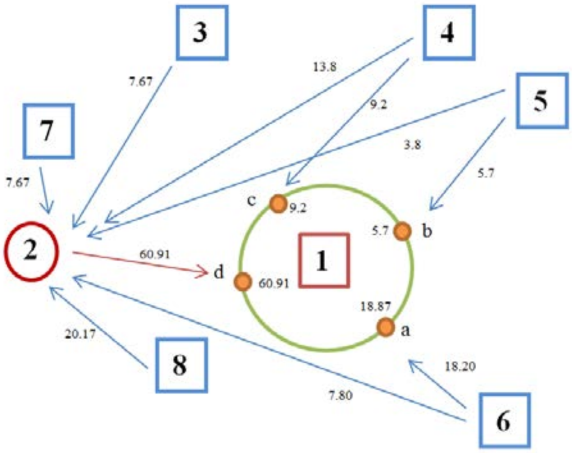

Figure 2: UCC Scenario

Considering all these assumptions, in Figure 2 the numbers next to the arrows refer to equivalent vehicles passing between the origin and destination linked by the arrow.
The O/D matrix in Table 3 refers to the movements from the different zones to the city centre for the UCC scenarios.

Table 3: O/D matrix for UCC Scenario

Origin	Destination				
	2	a	b	c	d
2	-	0.00	0.00	0.00	60.91
3	7.67	0.00	0.00	0.00	0.00
4	13.80	0.00	0.00	9.20	0.00
5	3.80	0.00	5.70	0.00	0.00
6	7.80	18.20	0.00	0.00	0.00
7	7.67	0.00	0.00	0.00	0.00
8	20.17	0.00	0.00	0.00	0.00

For the other scenarios involving the UCC, assumptions about the type of vehicles used and on the load consolidation are made.
Regarding the type of vehicles, Electric Scenario involves the use of electric vehicles from the UCC.
The assumptions on load consolidation, consider three scenarios. In the Optimistic Scenario the vehicles are filled to 80%, in the Intermediate Scenario they are filled to 50% and in the Pessimistic Scenario the vehicles are filled to 20%. The UCC Scenario considers a load consolidation of 30%.
To compare the UCC Scenario with the alternative ones, EMISMOB, an integrated module of Cube software, is used. EMISMOB aimed at quantifying the consumption and emissions of pollutants, it is possible to know the amount of fuel consumed by passing vehicles, and the amount of emissions (NO_x: oxides of nitrogen and their mixtures, CO: carbon monoxide, PM10: Particulate Matter, SPM: suspended particulate matter, CO_2: carbon dioxide, N_2O: nitrogen monoxide, CH_4: methane). Table 4 shows fuel consumptions and emission for the UCC scenario.

Table 4: Fuel Consumptions and Emission for the UCC Scenario

UCC Scenario				
	Zone 1-8		Zone 1	
Fuel Consumption	35,585.66	g/h	4,278.01	g/h
NO_x	664.33	g/h	79.86	g/h
CO	437.81	g/h	52.63	g/h
PM10	62.59	g/h	7.52	g/h
SPM	70.82	g/h	8.52	g/h
CO_2	111,798.99	g/h	13,440.16	g/h
N_2O	1.91	g/h	0.23	g/h
CH_4	2.69	g/h	0.32	g/h

3.2.1. Electric Scenario

The Electric Scenario uses electric vehicles to deliver the goods from the UCC (zone 2) to city centre (access point *d*). All other deliveries are made with diesel vehicles. The electric vehicles produce no emissions or fuel consumption. Fuel consumption and emissions for this scenario are due to the diesel trucks (see Table 5).

Table 5: Electric Scenario

Electric Scenario					
	Zone 1-8		Zone 1		Reduction
Fuel Consumption	33,293.95	g/h	1,378.54	g/h	68%
NO_x	621.43	g/h	25.72	g/h	68%
CO	409.65	g/h	16.97	g/h	68%
PM10	58.56	g/h	2.42	g/h	68%
SPM	66.25	g/h	2.74	g/h	68%
CO_2	104,599.15	g/h	4,330.95	g/h	68%
N_2O	1.79	g/h	0.07	g/h	70%
CH_4	2.52	g/h	0.11	g/h	66%

The comparison with the UCC Scenario is reported in terms of percentage reduction.

3.2.2. Optimistic Scenario

The Optimistic Scenario uses traditional vehicles to deliver the goods from the UCC (zone 2) to city centre (access point *d*). The assumption on the consolidation load of 80%, implies that on the average 22.84 vehicles leave the UCC towards the city centre (the number of vehicles decreases of 62.5%). Fuel consumption and emissions for this scenario are due to the diesel trucks (see Table 6).

Table 6: Optimistic Scenario

Optimistic Scenario					
	Zone 1-8		Zone 1		Reduction
Fuel Consumption	45,968.,20	g/h	2,962.83	g/h	31%
NO_x	858.08	g/h	55.31	g/h	31%
CO	565.56	g/h	36.45	g/h	31%
PM10	80.85	g/h	5.21	g/h	31%
SPM	91.48	g/h	5.90	g/h	31%
CO_2	144,417.69	g/h	9,308.27	g/h	31%
N_2O	2.47	g/h	0.16	g/h	30%
CH_4	3.48	g/h	0.23	g/h	28%

The comparison with the UCC Scenario is reported in terms of percentage reduction.

3.2.3. Intermediate Scenario

The Intermediate Scenario uses traditional vehicles to deliver the goods from the UCC (zone 2) to city centre (access point *d*). The assumption on the consolidation load of 50%, implies that on the average 36.55 vehicles leave the UCC towards the city centre (the number of vehicles decreases of 39.9%). Fuel consumption and emissions for this scenario are due to the diesel trucks (see Table 7).

Table 7: Intermediate Scenario

Intermediate Scenario					
	Zone 1-8		Zone 1		Reduction
Fuel Consumption	53,566.22	g/h	3,912.58	g/h	9%
NO_x	999.84	g/h	73.03	g/h	9%
CO	659.07	g/h	48,14	g/h	9%
PM10	94.21	g/h	6.88	g/h	9%
SPM	106.59	g/h	7.79	g/h	9%
CO_2	168,288.27	g/h	12,292.09	g/h	9%
N_2O	2.87	g/h	0.21	g/h	9%
CH_4	4.06	g/h	0.30	g/h	6%

The comparison with the UCC Scenario is reported in terms of percentage reduction.

3.2.4. Pessimistic Scenario

The Pessimistic Scenario uses traditional vehicles to deliver the goods from the UCC (zone 2) to city centre (access point *d*). The assumption on the consolidation load of 20%, implies that on the average 91.36 vehicles leave the UCC towards the city centre (the number of vehicles increases of 49.9%). In this Scenario the number of vehicles increases due to a worse consolidation load. Fuel consumption and emissions for this scenario are due to the diesel trucks (see Table 8).

Table 8: Pessimistic Scenario

Pessimistic Scenario					
	Zone 1-8		Zone 1		Increase
Fuel Consumption	83,974.62	g/h	7,713.63	g/h	80%
NO_x	1,567.45	g/h	143.98	g/h	80%
CO	1,033.20	g/h	94.91	g/h	80%
PM10	147.69	g/h	13.57	g/h	80%
SPM	167.11	g/h	15.35	g/h	80%
CO_2	263,821.96	g/h	24,233.80	g/h	80%
N_2O	4.51	g/h	0.42	g/h	83%
CH_4	6.36	g/h	0.59	g/h	84%

The comparison with the UCC Scenario is reported in terms of percentage increase.

3.3. Annual Savings

The fuel consumptions and the emissions for several scenarios are compared.
Tables 9-12 show the annual savings that are achieved with the scenario considered (Electric, Optimistic, Intermediate and Pessimistic) compared to UCC Scenario.
First, the whole day emissions are calculated by multiplying the peak hour' results by a factor of 11.
Then the number of working days per year is assumed according to the following cases:

- I: 288 working days per year
- II: 264 working days per year
- III: 240 working days per year

The whole day results are multiplied per the working days per year to get the annual fuel consumptions and emissions of the different scenarios.
To obtain the annual savings achieved through the Electric Scenario, Optimistic Scenario, Pessimistic Scenario, and Intermediate Scenario, their annual values are compared with the annual values of UCC Scenario.
Table 9 shows the very high savings achieved with the Electric Scenario due to the large use of electric vehicles.

Table 9: Annual Saving with Electric Scenario

	Annual Savings (Electric Scenario)		
	I [ton]	II [ton]	III [ton]
Fuel Consumption	9.1855	8.4201	7.6546
NO_x	0.1715	0.1572	0.1429
CO	0.1130	0.1036	0.0941
PM10	0.0162	0.0148	0.0135
SPM	0.0183	0.0168	0.0153
CO_2	28.8580	26.4531	24.0483
N_2O	0.0005	0.0005	0.0004
CH_4	0.0007	0.0006	0.0006

Table 10 shows the high savings achieved with the Optimistic Scenario due to the high level of cargo consolidation (80%).

Table 10: Annual Saving with Optimistic Scenario

	Annual Savings (Optimistic Scenario)		
	I [ton]	II [ton]	III [ton]
Fuel Consumption	4.1665	3.8193	3.4721
NO_x	0.0778	0.0713	0.0648
CO	0.0513	0.0470	0.0427

PM10	0.0073	0.0067	0.0061
SPM	0.0083	0.0076	0.0069
CO_2	13.0898	11.9990	10.9082
N_2O	0.0002	0.0002	0.0002
CH_4	0.0003	0.0003	0.0002

Table 11 shows the good savings achieved with the Intermediate Scenario due to the slightly better cargo consolidation (50%).

Table 11: Annual Saving with Intermediate Scenario

	Annual Savings (Intermediate Scenario)		
	I [ton]	II [ton]	III [ton]
Fuel Consumption	1.1577	1.0612	0.9647
NO_x	0.0216	0.0198	0.0180
CO	0.0142	0.0130	0.0119
PM10	0.0020	0.0019	0.0017
SPM	0.0023	0.0021	0.0019
CO_2	3.6371	3.3340	3.0309
N_2O	0.0001	0.0001	0.0001
CH_4	0.0001	0.0001	0.0001

Table 12 shows the increase of emissions and fuel consumption with the Pessimistic Scenario due to the worse cargo consolidation (20%).

Table 12: Annual Saving with Pessimistic Scenario

	Annual Savings (Pessimistic Scenario)		
	I [ton]	II [ton]	III [ton]
Fuel Consumption	-10.884	-9.977	-9.070
NO_x	-0.203	-0.186	-0.169
CO	-0.134	-0.123	-0.112
PM10	-0.019	-0.018	-0.016
SPM	-0.022	-0.020	-0.018
CO_2	-34.194	-31.345	-28.495
N_2O	-0.001	-0.001	-0.001
CH_4	-0.001	-0.001	-0.001

4. CONCLUSIONS

In the paper an UCC for a medium Italian city is analyzed via simulation.

Simulated scenarios show the environmental benefits of the UCC: lower number of vehicles and a lower quantity of emissions thanks to a better load consolidation.

The success of UCC depends on the percentage of load consolidation that it is possible to reach. In the Optimistic Scenario, for instance, emissions reductions are around 30% as shown in Table 6. While in the Pessimistic Scenario, the environmental emissions increase respect the base UCC Scenario.

It could be interesting to simulate also several policies (Congestion Charging, Weight Restrictions and Time Restrictions) to evaluate their impact on the UCC use. To do this it would be necessary to model and validate the behavior of UCC users (transporters and retailers). On the economic point of view, the UCCs can be viable only in the Optimistic Scenario, otherwise they need some public supports.

In future studies it could be interesting to make online measurements of traffic level within the city by using connectivity. In this manner it could be possible to implement more feasible policies to regulate the freight traffic within the city. Simulation could support such studies on how to optimize online the traffic and the freight distribution.

ACKNOWLEDGMENTS

Authors want to acknowledge the student Riccardo Berti Nulli for his precious contribution in data collection.

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PEDESTRIAN SOCIAL GROUPS MODELING & SIMULATION: A STATE OF THE ART

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ABSTRACT
The paper focuses on pedestrian social groups. A social group is formed by individuals that have social ties and intentionally walk together, such as friends or family members.
The percentage of people in social groups within a crowd is large. Pedestrian crowds have been studied, modeled and simulated for different purposes.
The simulation of crowds is employed to support pedestrian environment designs. It allows to elaborate "what if" scenarios and to evaluate the environment design with reference to specific criteria.
Virtual worlds, to become more lively and appealing, are populated by large number of characters. Typically, these characters should be able to navigate through the virtual environment in a human-like manner.
The study of pedestrian social groups plays a very important role also in the case these groups include mobile robots as individuals and as a robot team.

The papers presents empirical evidences of social group walking behavior. Then, briefly presents the most relevant pedestrian microscopic models, focusing on the ones that take into account social groups. A critical review of the current approaches and future developments end the paper.

Keywords: social groups, pedestrians, modeling, simulation, traffic, crowds

1. INTRODUCTION
The study of human crowd dynamics has recently found great interest in many research fields such as: the planning and design of the pedestrian environment; crowd safety during mass events; computer graphics and robot navigation.
Good pedestrian facilities promote people to walk, whilst poor ones discourage the use of area or structure where they are.This creates the necessity of measuring the performance of pedestrian facilities in order to determine quality of operations, existing deficiencies, needs for improvements, and for purposes of priority settings. Traditionally, the quality of operations of transportation facilities is assessed on the basis of the level of service (LOS) concept. These levels currently classify the level of comfort based on space available for movement and speed (and delay, in case of crosswalks). The comfort is assumed to be linked to the possibility to maintain a free space, during the motion, that every pedestrian requires around itself, and to maintain the desired speed. Therefore, assuming anhomogeneous pedestrian crowd, the LOS levelis assessed in terms of average characteristics of pedestrian flow, like average density and average speed. Guidance is provided for different area types and times of day (Sisiopiku et al. 2015).
In transportation studies attention has been paid also to walking spatial patternsand their impact on the overall traffic efficiency.Walking spatial patterns that influence crowd dynamics are related to "physics" of crowd motion such as:

- the organization around bottlenecks: the resulting zipper effect causes the capacity of the bottleneck to increase in a stepwise fashion with the width of the bottleneck (Hoogendoorn and Daamen 2005, Kretz et al. 2006),
- the segregation of opposite flows in pedestrian counterstreams: compared to a situation without counterflow the performance - in terms of passing or total times, speed, and flux - of a group of walkers is never reduced as much as one would expect from the amount of counterflow. This phenomenon can be summed up by saying that the sum of fluxes in a counterflow situation was always found to be larger than the flux in any of the no counterflow situations (Kretzet al. 2006, Moussaı¨et al. 2009, Helbing and Molnar 1995) or
- the turbulent movement in extremely dense crowds: the fundamental diagram has been reproduced for these situations and demonstrates that the average local flow is not reduced to zero at highly dense situations (Yu and Johansson 2007) .

All these studies investigated a crowd as a collection of isolated individuals, each having their own desired speed and direction of motion and social interactions among pedestrians have been largely neglected. Moussaid et al. (2010) focused on social interaction among pedestrians in crowd and investigated the spatial organization of walking pedestrian groups, in terms of average angle and distance between pedestrians, to find out whether there are any specific patterns of spatial group organization and how such patterns change with

increasing density. Crowd dynamics is not only determined by physical constraints induced by other pedestrians and the environment, but also significantly by communicative, social interactions among individuals.
One of the most relevant and at the same time most challenging problems are panic stampedes, which are a serious concern during mass events. Despite huge numbers of security forces and crowd control measures, hundreds of lives are lost in crowd disasters each year. The goal of many researches in this field is the identification of variables that are helpful for an advance warning of critical crowd conditions: these variables allow one to understand where and when crowd accidents tend to occur (Helbinget al. 2007). The identification of critical crowd conditions are important for the organization of safer mass events.
Field studies (Isobe et al. 2004, Kretz et al. 2006) have shown that in crowds, social group members do not communicate. Pedestrians follow other pedestrians without establishing a formal and steady social relationship (Fang J. et al. 2015).
Recent field work has shown that evacuees perform complex maneuvers and behave deliberately rather than in a non-cooperatively competitive manner or mindless panic. Some of these studies show that social and social-psychological factors significantly influence pedestrians' movement (Aguirre et al. 2011).
Algorithms that, based on surveillance trajectory data and informed by social psychological models of collective behavior, automatically discover small groups of individuals traveling together in a crowd have been proposed (Ge et al. 2012, Sochman et al. 2011). These algorithms could be used by police during public mass events to discover pathways or monitor for abnormal events and therefore to plan their intervention: rather than seeing an irrational homogeneous crowd, police should be looking at small groups, only a few of which might merit coercion.
In *computer graphics*the target is to create virtual worlds. Virtual worlds are ubiquitous in video games, training applications and animation films. Such worlds, to become more lively and appealing, are populated by large number of characters. Typically, these characters should be able to navigate through the virtual environment in a human-like manner. (Rojas et al.2016,Karamouzas and Overmars 2012)
Although state-of-the-art computer graphics enables a virtual reconstruction of the built environment with impressive geometric and photometric detail, it should enable the automated animation of the environment's human occupants (Badler et al. 1993). Human animation should be visual plausible rather than correct. The addition of groups can improve the plausibility of crowd scenarios (Peters et al. 2008).
Robot navigation should be smooth and safe in dynamic environments. If the obstacle is an intelligent agent, such as a human or another robot, this problem is complicated by the difficulty in predicting the agent's reaction to the robot's own movements. Dynamic obstacle avoidance is contingent on two separate capabilities. First, the robot must be able to predict the future trajectory of a dynamic obstacle passing through the robot's environment. Secondly, the robot must define a control strategy that is both optimized for the predicted trajectory and safe in any other outcome. Many approaches, inspired by human navigation in crowded pedestrian environments, draw from the sociology literature on pedestrian interaction (Knepper and Rus 2012). In navigating through personal spaces, humans make frequent, minor corrections to their trajectory in response to the predicted motions of other people. In so doing, we follow a social convention, or pedestrian bargain, designed to distribute responsibility for altering one's trajectory in recognition of another's intentions. Wolfinger (Wolfinger 1995) describes the pedestrian bargain as comprising two rules: "(1) people must behave like competent pedestrians, and (2) people must trust copresent others to behave like competent pedestrians". Algorithms for robot local navigation try to implement the same heuristics for mutual avoidance adopted by humans. In doing so, the resulting trajectories are human-friendly, because they can intuitively be predicted and interpreted by humans and the algorithms result suitable for the use on robots sharing navigation spaces with humans.
The paper focuses on pedestrian social groups. According to Hughes and Lee (2006), the term "group" is used here in its sociological sense: it is "a collection of individuals who have relations to one another that make them interdependent to some significant degree". A group is formed by individuals that have social ties and intentionally walk together, such as friends or family members.A social group is characterised by the duration of the interaction and the communicative setting.Social groupsrepresent an important component of urban crowds in low and medium density conditionswhilst in overcrowded environments the communication assumption between group members is not available anymore (Zhang et al. 2011).
We define temporary voluntary groups a group formed by several proximate pedestrians that voluntary walk temporary close to each otherin specific situations. There is not any social relationship between the group members. It has been observed that people are likely to follow others in front of them; they will walk on the same side of the path as other people in front of them and they will take avoidance action on the same side. This behavior leads to temporary voluntary groups

The paper breaks down as follows: the following section reports empirical evidences of social group walking behavior. Section 3 briefly presents the most relevant pedestrian microscopic models, focusing on the ones that take into account social groups. Section 4 ends the paper and includes a critical review of the current approaches and future developments.

2. EMPIRICAL KNOWLEDGE ON WALKING BEHAVIOUR OF PEDESTRIAN SOCIAL GROUPS

2.1. The frequency of social groups

Empirical studies show that in the real-world, large proportions of pedestrians are in social groups (Aveni 1977). The percentage of people in groups within a crowd ranges from 40% to 70%: the percentage changes according to different times and environment situations (Coleman and James 1961, Singh et al. 2009). Generally, more groups can be observed in leisure areas in public holidays (Moussaïd et al., 2010). According with Singhet al. (2009), in travelling environment (train station), the percentages of people in groups are about 55%; in shopping environments, the percentage is about 65%; on university campus where people study or work, the figure is about 47%. These data are reported in figure 1.

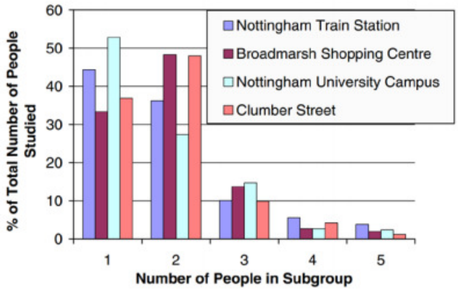

Figure 1: The sizes and proportions of subgroups within a crowd (Singh et al. 2009)

The reported % are not so far from other empirical evidences: in the data collected by Moussaı¨d et al (2010), up to 70% of observed pedestrians in a commercial street walked in group; in the data collected by Cepolina et al. in the “infinite” corridor in a building of Massachusetts Institute of Technology (Cepolina et al. 2016), about 42% walked in social groups.

Table 1:Dimensions of the observed social groups (Cepolina et al. 2016)

N. groups.	Groups of 2 ped.	Groups of 3 ped.	Groups of 4 ped.
59	83%	10 %	7 %
(132 ped)	(49 groups - 98ped)	(6 groups - 18 ped)	(4 groups - 16 ped)

As it concerns the group dimensions, the data collected in this study are reported in table 1: the 83% of the total number of pedestrians that walk in groups, belongs to a 2 member group. The 10% of the total number of pedestrians that walk in groups, belongs to a 3 membergroup and the 7% of the total number of pedestrians that walk in groups, belongs to a 4 member group. Almost 45% of the groups were composed by both the genders. Among the mono gender groups, we observed an equal number of female and male groups.

The existence of ubiquitous social groups indicates that not only the individual-level, but also the group-level behaviour needs to be included in the modelling program in order to carry out realistic pedestrian simulations in low and medium density conditions.

2.2. Effects of group size on walking speed

As observed by Moussaı¨d et al (2010), pedestrian walking speeds decrease linearly with growing group size, as shown in figure 2.

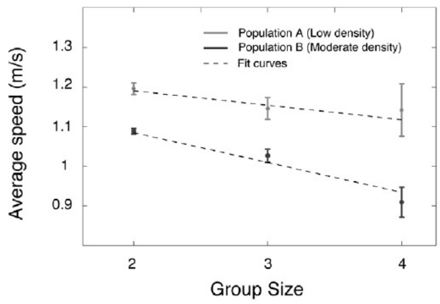

Figure 2: Effects of group size on walking speed (Moussaı¨d et al (2010))

Similar findings were discussed in the research of Schultz, et al. (2010), who recorded and analyzed the walking behavior of passengers in Dresden International Airport.

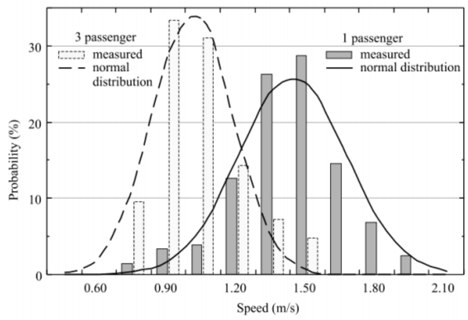

Figure 3: Group size interdependencies regarding to speed (Schultz, et al., 2010).

Figure 3 compares the differences in speed between groups with one and three members: groups with three members are clearly slower than groups that have onlyone member.

2.3. Effects of density on groups’ walking speed

The speed of pedestrians results clearly dependent on the density level. At low density, people walk faster than at higher density. This is in agreement with previous empirical and theoretical studies of pedestrian traffic (Seyfried et al. 2005).

Cepolina et al (2016) tried to find an empirical relationship between group speed and density from the data collected at the corridor at the Massachusetts Institute of Technology. For each density value, the average speed of the individuals that crossed the reference area in the given density conditions has been assessed and the resulting data are reported in figure 4 and figure 5. In figure 4, the points that refer to pedestrian walking alone have been marked with a diamond symbol whilst the points that refer to pedestrians walking in social groups have been marked with a star symbol.

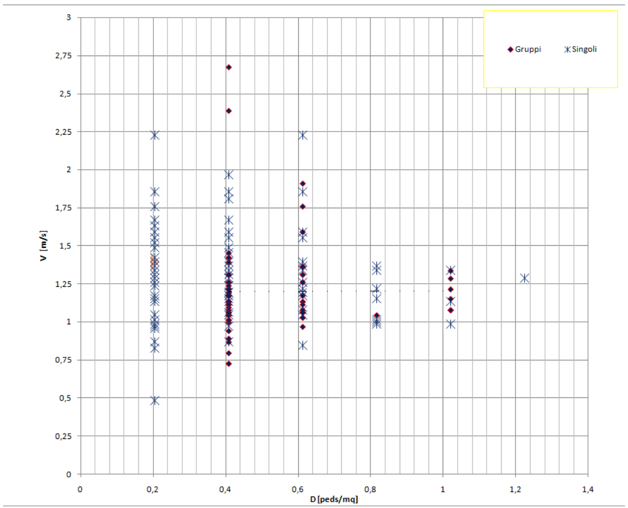

Figure 4: Pedestrian speed against density (Cepolina et al., 2016).

Figure 4 shows a large pedestrian speed variation, for each density value, for pedestrians walking alone; it is smaller for group members. According with previous studies, the speed of pedestrians walking in social group tends to be lower than speed of pedestrians walking alone at same level of density.

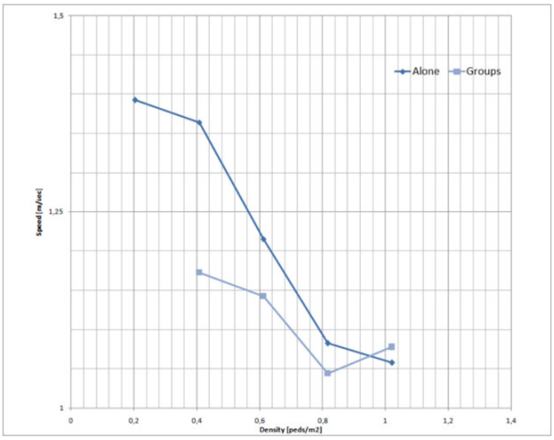

Figure 5: Average speed Vs. density for individual pedestrian and pedestrians in social groups (Cepolina et al. 2016)

Further, as shown in figure 5, the speed of pedestrians walking alone decreases faster than the one of pedestrians walking in groups as density increases. This fact makes explicit that some people walking in social groups are aware of the speed adjustments they have to cope with in order to keep walking in a group in medium density conditions.

2.4. Spatial organization of walking pedestrian social groups

Moussaïd, et al. (2010) investigated the spatial organization of walking pedestrian groups in two different population densities by analyzing the average angle and distance between group members. It has been suggested that at low density, people in the same group walk in a horizontal formation which enables them to communicate with other group members easily. While at moderate crowd density, this structure is hard to maintain without interfering with pedestrians outside the group. Therefore, the linear group structure will bend in the middle and form a 'V'-shaped formation. Moussaïd, et al. (2010) pointed out that this bending is forward in walking direction instead of backward, thus facilitates the social communication between group members (Figure 6 b). Though bending backward is a more flexible structure against the opposite pedestrian flow, it impedes the interaction within the group. Finally, at high density, the physical constraints would prevail over the social interaction, group members will walk behind each other and form a 'river-like' formation (Figure 6 c).

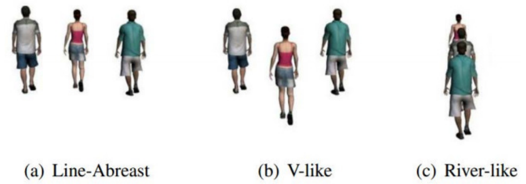

Figure 6: Group formations (Moussaid et al. 2010)

It is known that the distribution of spoken contributions among group members is not equal during a conversation: a few members speak most of the time, while the others listen (Stephan andMishler1952,Horvath 1965). Therefore, it is likely that pedestrians who talk more would end up in the middle of the group and the listeners would walk on the sides. In the same way, large groups would probably split up into subgroups around those who talk most.

2.5. Avoidance behavior of pedestrians that walk in groups

Singh, et al. (2009) filmed crowds in various locations around the University of Nottingham main campus and then analyzed the footage. The selected locations were chosen as they were long straight stretches of pathway, where it was possible to view people for a sufficient length of time to see their behavior after avoidance action had to be taken. Figure 7 shows the percentage of avoidance action taken when facing incoming pedestrians: 44% of the time, a person or subgroup will move to the right to avoid colliding with others and 34% of the time they will move to the left. The other 22% of the time, a subgroup will actually split to avoid colliding with people they are walking towards. The ratio of people moving to the left is higher than that of moving to the right:a possible explanation of this phenomenon is that the experiment was conducted in

UK, where left-hand traffic rule is applied (Cheng, 2014).

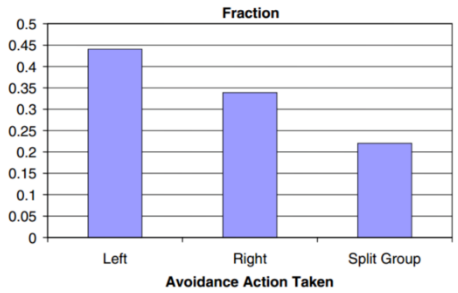

Figure 7: The avoidance action taken by people walking straight towards another (Singh et al., 2009).

The first observation by Singh, et al. (2009) is that a social group of people will usually avoid splitting if possible. This may mean that they will crowd closer together: rather than split up, the people in each social group move closer toward their companions and allow group members to enter their personal space. This therefore displays a preference of social groups to remain together.

Another finding is that an individual person is more likely to walk around a social group of people than walk through the middle of them. To avoid colliding with and splitting the group of two, an individual person not only moves aside but also steps onto a raised wall, highlighting the behavior described above.

When a social group does split, it is because there is an obstacle of something to avoid, usually another person or group. In the situation where there is more than one obstacle to avoid a social group will not regroup between them. Instead the group will remain apart and regroup only after all obstacles have been avoided.

Rastogi (Rastogi et al. 2011) observed that on sidewalks, pedestrians in large social groups (having 5 or more people) often split into smaller sub-groups in order to avoid incoming pedestrian flow. This splitting behavior decreases the group sizes, but increases the speed of pedestrian sub-groups. This phenomenon is absent on wide sidewalks and precincts because there is no restriction in space and large groups are not necessary to split into small sub-groups.

3. MICROSCOPIC MODELLING OF PEDESTRAIN SOCIAL GROUPS: DIFFERENT APPROACHES

According to Vizzari et al. (2013) we propose a schema classifying the different current approaches based on the way pedestrians are represented and managed. From this prospective, pedestrian models could be roughly classified into three main categories that respectively consider pedestrians as particles subject to forces, autonomous agents acting and interacting in the environmentor particular states of cells in which the environment is subdivided in Cellular Automata (CA) approaches

3.1. Particle based approach

Social force models are probably the most known method in the group of continuous models. Lewin and Cartwright (1952) suggested that the changes of human behaviorcan be guided by social forces or social fields. Based on this concept, Helbing and Molnár (1995) proposed the basic equation of the social force model to describe pedestrian motion:

$$\vec{F}_{\propto}=\vec{F}^{0}_{\propto} + \sum_{\beta} \vec{F}_{\propto\beta} + \sum_{B} \vec{F}_{\propto B} + \sum_{i} \vec{F}_{\propto i} \quad (1)$$

They assumed that a pedestrian's total motivation $\vec{F}_{\propto}$ can belinearly influenced by three main factors:

(1) $\vec{F}^{0}_{\propto}$ – the desire of pedestrian α to reach a certain destination or goal;

(2) $\sum_{\beta} \vec{F}_{\propto\beta}$ – the total influence from other pedestrians β such as the repulsive effect of others;

(3) $\sum_{B} \vec{F}_{\propto B}$ – the total repulsive force generated to avoid a border or an obstacle B.

In addition to the above four main effects, the social force model can be applied to demonstrate complex pedestrian behavior by adding a fluctuation term. This fluctuation term enables modelers to consider random variations of pedestrian behavior and make extension from the basic formula.

Using the social force model, several observed collective phenomena in pedestrian crowds have been successfully reproduced. This includes the lane forming behavior in crowds and the oscillatory walking pattern at a narrow exit (Helbing and Molnár1995) as well as the mechanisms in escape panic situations (Helbing et al. 2000).

In Moussaid et al.(2010) a new interaction term has been introduced in eq. 1:

(4) $\sum_{i} \vec{F}_{\propto i}$ – the attraction of other persons or objects i: it describes the response to other group members.

Moussaid et al. (2010) postulate that the observed patterns of group organization result from the desire of their respective members to communicate with each other. Therefore, individuals continuously adjust their position to facilitate verbal exchange, while trying to avoid collisions with in-group members and out-group pedestrians.

The new interaction term has been assessed taking into account three facts: 1) group members turn their gazing direction to see their partners: the authors assume that the pedestrian adjusts its position to reduce the head rotation. 2) the pedestrian keeps a certain distance to the group's center of mass: according to observations, the average to the center of mass increases with group size. 3) there is a repulsion effect so that group members do not overlap each other.

Helbing, et al. (2005) conclude that the simplicity, linearity and small number of parameters are the main advantages of the social-force-based simulation. However, some researchers suggested that it is not easy to model heterogeneity and complex behaviors using social force model (Manenti et al. 2012).

3.2. Agent-based methods

The most common way to model the locomotion of human crowds is with agent-based methods, in which each agent plans individually its own actions. In agent based models, agents follow some pre-determined rules of behavior, which allow them to execute various behaviors appropriately in the modeled system.

In such approaches, global path planning and local collision avoidance are typically decoupled.

The agent perception model specifies the area which each pedestrian can perceive.Each agent has a set of behaviors, such as random movement, obstacle avoidance and maintaining group. Each of these behaviors is a steering behavior exited by some sensory inputs. Each agent individually perceives the situation according to its own characteristics, adapts its behavior according to the situation and chooses the nature of its interactions with the others.

Based on Reynolds's Open Steer environment (Reynolds1 999), Qiu and Hu (2010) proposed an agent-based simulation system for modeling crowd behavior with group structures, in which agents can move randomly, avoid obstacles and maintain group structures. The group movement is governed by the rule that each group is assumed to have a group leader and the leader would influence the decisions of other group members. However, in real-world situations, pedestrian groups are often composed of friends and families, where it is not necessary to have a group leader.

Agent based models are generally more computationally expensive than cellular automata and social force models, thus, modeling large systems is still a challenge for agent-based models

The agent basedapproach allows to include heterogeneity in pedestrian motion that improve simulation realism (Lemercier and Auberlet 2015). Heterogeneity could be performed by: turning the agents' external parameters values (such as speed, size, perception area) or implementing the ability for an agent to behave in different ways according his perception cognitive behavior.

Zhang et al. (2011) introduce heterogeneity in their simulation model by defining a level of communication for each agent that allows the flexible formation of small groups. Level of communication specifies the tendency of a member to talk with group members, and therefore maintain a closer spatial relationship. Intuitively, the group members with higher communicationability tend to keep closer for chatting. The member with highest communication would stay in the middle of the formation, with the others on both sides. Qiu and Hu (2010) proposed a model that allows to represent the heterogeneity nature of different groups and influences among group members. Two aspects have been introduced: intra-group structure and inter-group relationship. Intra-group structure refers to the network relationship among the members inside a group: different intra-group structures give rise to different shapes of a group. Inter-group relationship refers to the relationships among different groups: this is used to model the fact that groups also influence each other. However the model does not concern how the group structure is formed and how it will be dynamically changed.

A bilevel approach has been proposed by Karamouzas and Overmars (2012). Their model considerspairs and triples of characters and uses a two-step algorithm to ensure that the groups will stay as coherent as possible while avoiding collisions with other groups, individuals and static obstacles.

At every cycle of the simulation the desired velocity of each group is provided by some higher level path planning approach. Then, in the first step of the algorithm, an avoidance maneuver for each group of agents is determined. The authors formulate this as a discrete optimization problem of finding an optimal new formation and velocity for the entire group. In the second step of their approach, the computed solution velocity and formation are used to determine the desired velocity of each group member. This velocity is then given as an input to a local collision avoidance model which returns the new velocity for the group agent.

3.3. Cellula automata

A relatively novel model called Cellular Automata (CA) uses intuitive rules that make the model easy to understand without complex mathematical equations and thus demand less computation than social force models and agent based models. In cellular automata models, space is represented by a uniform grid of cells. At each discrete time step, the values of variables in each cell are updated according to a set of local rules and the values of variables in the cells at its neighborhood.

Cellular automata has been extensively used in modelling the crowd. In regular cellular automata models, each pedestrian occupies a single cell with the size of a pedestrian body. Since the space is divided into relatively large cells, the movements of pedestrians look like the movements of pieces on a chess board. Furthermore, all pedestrians have the same body size and speed. Pedestrian transition to neighboring cells is based on simple rules. Cellular automata transition rule could be simple mathematical equations which determine the next transition cell for each pedestrian. The next cell is normally one of the adjacent cells.

In Siamak et al. (2014), a method called "fine grid cellular automata"is proposed in which smaller cells are used and pedestrian body may occupy several cells. The model allows the use of different body sizes, shapes and speeds for pedestrian.

The majority of the pedestrian movements can be described in terms of movements toward successive targets. A least effort cellular automata model uses a measure distance to the target for calculating the probability of transition into neighboring cells.The

concept of least effort (Zipf, 1949)mostly results into a shortest path straight line walking toward the target. In addition to least effort movement behavior, pedestrians show other behaviors like collision avoidance, density and congestion aversion and group formation. Siarmady et al. (2009) proposed a variation of least effort cellular automata algorithm which also considers the effect of pedestrian groups on crowd movement. The main idea behind the model is that pedestrians in a group maintain a short distance to the leader of the group or other group members.
The cellular automata models portray the interactions between pedestrians by intuitively understandable rule sets, rather than complex mathematical functions. It also provides an easier treatment of complex geometries than models with long-range interactions (Schadschneider, 2001). Therefore, one can easily implement cellular automata on computers and the computational speed is exceedingly fast compared to other microscopic pedestrian models. However, CA models have the disadvantage of dividing space into coarse cells, which may lead to larger errors than social force models in which space is not discretised (Köster et al. 2011).
Among the researchers who have used cellular automata for the simulation of pedestrian movements Dijkstra (Dijkstra, 2000), Blue and Adler (1998), Kirchner et al. (2001), Kirchner et al. (2003) and Schadschneider (2002) can be mentioned.

4. WEAKNESS OF THE CURRENT APPROACHES AND NEW POSSIBLE FUTURE DIRECTIONS

Planning and design of pedestrian environmentsis based on traffic efficiency that could be synthesized in the Level of Service, as it happens in the transport field.
The authors believe that the Level of Serviceshould be based on the individual perceived levels of service and not to average pedestrian flow characteristics. The individual perceived Level of Service should be related to the discomfort while walking in the pedestrian environment. The discomfort should be a function of: the personal space lost due to interactions with objects and other pedestrians and of reduced quality of the conversation and maybe,communication interruptions, in case of members of social groups. In assessing individual discomfort, heterogeneity in the pedestrian population is a key issue. A microscopic agent based approach seems suitable for this. As far as the authors know, no models have been developed for assessing discomfort at individual level. A first trial in this direction is the work performed by Cepolina et al. (Cepolina, Caroti et al.2015 and Cepolina, Cervia et al. 2015).
The overall traffic efficiency become relevant as density increases and become crucial in case of crowd accidents.
When density increases, crowd dynamics is characterized by spatial organization of group members, by segmentation of opposite flows in pedestrian counterstreams and by the zipper effect at bottlenecks. These emergent phenomena deeply affect the overall traffic efficiency (for instance in terms of pedestrian speed or walking times). Many of the reviewed microscopic simulators are able to give rise to these self organizing emergent phenomena and result suitable for testing the overall traffic efficiency of different pedestrian environment designs, in different density conditions.
In case of dense crowds and emergency situations, it has been demonstrated that communication between social group members do not take place but that other social and psychological factors significantly influence pedestrians' movements and, in case of crowd accidents, cooperative behaviors emerge. The dynamic of this temporal cooperation between pedestrians in crowds in emergent situations should be further studied and modeled:the reviewed models seem to not include it.
A robot that navigates in a pedestrian environment (as well as a video game player, or a person doing training, in a virtual environment) interacts with a population of pedestrians or avatars (in the second case).In these cases, heterogeneity in the behaviors of the pedestrians/avatars populationbecome crucial.Most current simulators animate homogeneous crowds. Some include underlying parameters that can be tuned to create variations within the crowd, others implement perception cognitive models and a few models use a personality model (Wiggins, 1996) as a basis for agent psychology. There is still considerable controversy in personality research over how many personality traits there are. Further research in agent psychology will increase the plausibility of virtual worlds and thus, improve robustness of robot navigation and of training activities.
The study of pedestrian social groups plays a very important role also in the case these groups include mobile robots as individuals and as a robot team. This may happen in next future in case of security problems or in case of natural risky events where robots and humans are required to efficiently cooperate.

ACKNOWLEDGMENTS
The research has been carried out thanks to a MIT-UNIPI seed fund and the project "Analisi e simulazione del comportamento pedonale per una progettazione di ambienti accessibili" funded by the University of Pisa, Italy.

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SIMULATING THE IMPACTS OF AIRPORT CLOSURES ON AIRLINE ROUTE NETWORKS

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ABSTRACT
Air transport represents the fastest way of moving people and goods. For this reason, it is critical to the global economy and the welfare of society. The resilience of air traffic networks is, therefore, of great importance. In the past two decades, various events have shown that air transport is vulnerable to disruptive events, such as extreme weather, terrorist attacks, volcanic eruptions, earthquakes, and pandemic influenza. The severity of the impacts on passengers and economic activities, and overall losses to stakeholders and for society in general, would highly depend on the vulnerability and resilience of these networks. The current research seeks to develop an agent-based model to simulate and analyze the vulnerability and resilience of airline routes to airport disruptions.

Keywords: Agent-based modeling; airport disruption; air transport vulnerability; resilience

1. INTRODUCTION

Transport networks represent core resources and critical infrastructure and facilities that enable social and economic development around the globe. The transportation sector is growing globally over the next decade (Transport Canada 2015). Air transport is among the fastest growing in the transportation sector. Nevertheless, they may be vulnerable to natural, technological, and human made hazards. In order to improve supply chain reliability, transportation systems must become more agile and resilient to such threats (Transport Canada 2015). Despite the fact that some of these networks have built-in redundancies (i.e., alternative infrastructures) more sustainable and viable strategies call for effective management of existing infrastructure that is based on thorough understanding, modeling and optimization of the underlying complexity of network systems when disruptions occur (Chow, Szeto, Wang, and Waller 2015).

For example, Barnhart and Smith (2012) reported that ice and snowstorms in recent winters left passengers stranded in airplanes for up to 11 hours and caused havoc in the affected airlines' systems for several days, besides resulting in direct costs to airlines. They noted that such disruptions have visible and harmful impacts on passenger goodwill.

The current research seeks to develop an agent-based model to capture and analyze the emergent dynamics generated in airline networks, in order to better assess the vulnerability and resilience of these systems. Risk and business continuity managers of both airlines and airports could utilize such a model to better understand the impacts of disruptions and to develop strategies and policies that could reduce vulnerability and enhance the resilience of airlines and airports.

The model has been developed using AnyLogic simulation software 7.3 (AnyLogic 2016). We used AnyLogic's GIS environment, which enables agents' interactions in space and time. As a case study, the authors report on simulated disruption impacts on the most important hub within the simulated system, the Toronto Pearson International Airport.

The rest of this paper is organized as follows: Section 2 provides a brief review of the current research. Section 3 describes the agent-based modeling (ABM) approach. Section 4 describes the case study. Section 5 provides details of the simulation. Section 6 presents the key results of the simulation followed by conclusions in section 7.

2. STATE OF THE ART

The network modeling approach enables an intuitive representation of several structural elements of air transportation systems. The major portion of previous work in this area has considered models of traffic, either in terms of aircraft or passengers (Wei, Chen, and Sun 2014; Lordan, Sallan, Simo, and Gonzalez-Prieto 2014; Bratu and Barnhart 2005; Nicolaides, Cueto-Felgueroso, Gonzalez, and Juanes 2012).

Several aspects of the air traffic network have been studied. Initial works (Barrat, Barthelemy, Pastor-Satorras, and Vespignani 2004; Guimerà, Mossa, Turtschi, and Amaral 2005), were focused on structural description of the air transport system (i.e., a topological description of the network structure). However, delay propagation dynamics can be also studied using this approach (Fleurquin, Ramasco, and Eguiluz 2013a; Fleurquin, Ramasco, and Eguiluz 2014; Fleurquin, Campanelli, Eguiluz, and Ramasco 2014).

Due to interconnectivity, the air transportation network is vulnerable to propagations (i.e., domino effects). Since the airlines operate on this network, their operations are also subject to propagation effects. A disruption in one flight or airport can quickly spread and have a cascading impact affecting other parts of the air transport network (Beatty, Hsu, Berry, and Rome 1999; AhmadBeygi, Cohn, Guan, and Belobaba 2008).
Several mechanisms allow the propagation of delays through the air transportation network, such as aircraft rotations, passengers and crew connections, or airport congestion. These factors considered in the models developed to reproduce delay propagation. Understanding how delays propagate in the airport network starting from primary events is thus of high economic relevance (Campanelli, Fleurquin, Eguíluz, Ramasco, Arranz, Etxebarria, and Ciruelos 2014).
Although airlines deal consistently with operational disturbances (e.g., deviations in departures and arrivals due to traffic congestion at the airports or in the airspace sectors), they also face disruptions (i.e., high impact disturbances) that impact their pre-planned operations. For example, severe weather conditions, such as icing on a runway, can close an airport for several hours (Rosenberger, Johnson, and Nemhauser 2003). The influence of schedule adherence of aircraft rotation becomes more significant when the consequences of flight delays are investigated on a network scale (Wu and Caves 2002). Vulnerability and resilience of transport networks have been typically addressed by means of graph theory, primarily through topological studies. Since these studies consider static information only, they cannot include the dynamic behaviour of the network (travel demand, aircraft rotation, passenger and crew connections, and others), so they miss the emergent effects (e.g., delay propagation) that appear due to the influence of a failure on the rest of the elements within the system. Airlines could improve their performance in operations by considering the possibility of disruptions during the planning phase (Rosenberger, Johnson, and Nemhauser 2004).
Various works concerning vulnerability of transport networks have been carried out. A very extensive survey of these publications is provided in (Mattsson and Jenelius 2015). However, very few of the reported studies are related to air transport. A recent study of resilience analysis for air traffic networks reported in (Dunn and Wilkinson 2016), reveals that only static analysis of the networks (topological approach) has been applied. In the present work, the aim is to apply a systemic approach to cover the gap in the current literature, developing a dynamic model through ABM.
In recent years, two agent-based models to study and forecast delay propagation in the USA and European networks were introduced (Fleurquin, Ramasco, and Eguiluz 2013a; Ciruelos, Arranz, Etxebarria, Peces Campanelli, Fleurquin, Eguiluz, and Ramasco 2015). However, both investigations focus only on operational delay effects (i.e. low impact disturbances).

3. AGENT-BASED MODELING APPROACH

ABM is chosen because the more widely used approaches (topological, based on graph networks) impose unrealistic restrictions and assumptions on the system being modeled under aggregate data considerations. In contrast, ABM can be used to conduct policy experiments to investigate the vulnerability and the resilience of airline routes, including the emergent effects due to dynamic behaviour on the system under analysis (Crooks and Wise 2013). In particular, ABM simulation allows:

- virtual simulation of the consequences of decisions,
- integration of multiple theories regarding the phenomenon under investigation,
- representation of agents with multiple decision strategies, and
- modeling of heterogeneous actors who can modify their behavior over time.

In the last decade, ABM has been successfully applied to a variety of domains. Several research projects have demonstrated the potential of this technique to advance science, engineering, and policy analysis (Anderson, Chartuvedi and Cibulskis 2007; Collier and North 2012; Asakaura, Aoyama, and Watanabe 2011), which expands its applicability with the integration of geographical information systems (GIS) (Crooks and Wise 2013).

4. CASE STUDY

This simulation was applied to a selection of Air Canada flights. Air Canada has major hubs in four Canadian cities (Toronto, Montreal, Vancouver and Calgary). Air Canada's network currently provides service directly to 63 Canadian destinations, 56 destinations in the United States, and 86 in Europe and other continents. Air Canada operates on average 1,500 scheduled flights each day (Figure 1) and, in 2015, carried more than 41 million passengers (AirCanada 2016). Air Canada is among the 20 largest airlines in the world. Air Canada's Airbus aircraft that were incorporated into the present model are:

- A320 family (37),
- A321 family (14),
- A319 family (12), and
- A319 Air Canada Rouge family (7).

Figure 1: Air Canada Routes Network (OpenFlights 2016)

5. SIMULATION MODEL

The simulation model is composed of four major components:

- Map and visual interface,
- Agents,
- Input interface, and
- Output interface.

The map and visual interface shows the evolution of the simulations considering different traffic introduced in the input interface and simulation set up. The map and visual interface dynamically visualizes the real routes (obtained from Flight Radar 24 website) that are used by the aircrafts. It also allows the users to see the variations of the routes, when there is one or more airports disrupted. Besides, the map and visual interface shows the location of different airports in the model, considering an accurate geo-positioning of the airports.
Figure 2 shows the map and visual interface that includes airports (for the route network under analysis) and aircrafts on their routes at a specific time.

Figure 2: Simulation Model Map and Visual Interface

In the present model, two different agents were implemented:

- Destination (airport), and
- Airplane.

Figure 3 shows the state chart for the airplanes. The agent "Destination" represents the airports that are included in the model. These airports correspond to the origins and destinations for the aircraft (scheduled flights). Each airport contains different features and information such as the airport name, latitude and longitude, the length of the main runway, and one variable that represents the availability of the airport (if it is open or close due to some disruption). The current model has 29 airports already implemented: 12 Canadian airports, 6 USA airports, one Mexican airport, and 11 Caribbean airports.
The agent "Airplane" represents the aircraft fleet included in the flight schedules under simulation. It needs to consider each aircraft and its rotation. The aircraft rotation is considered as a set of legs for this aircraft in a specified time period.

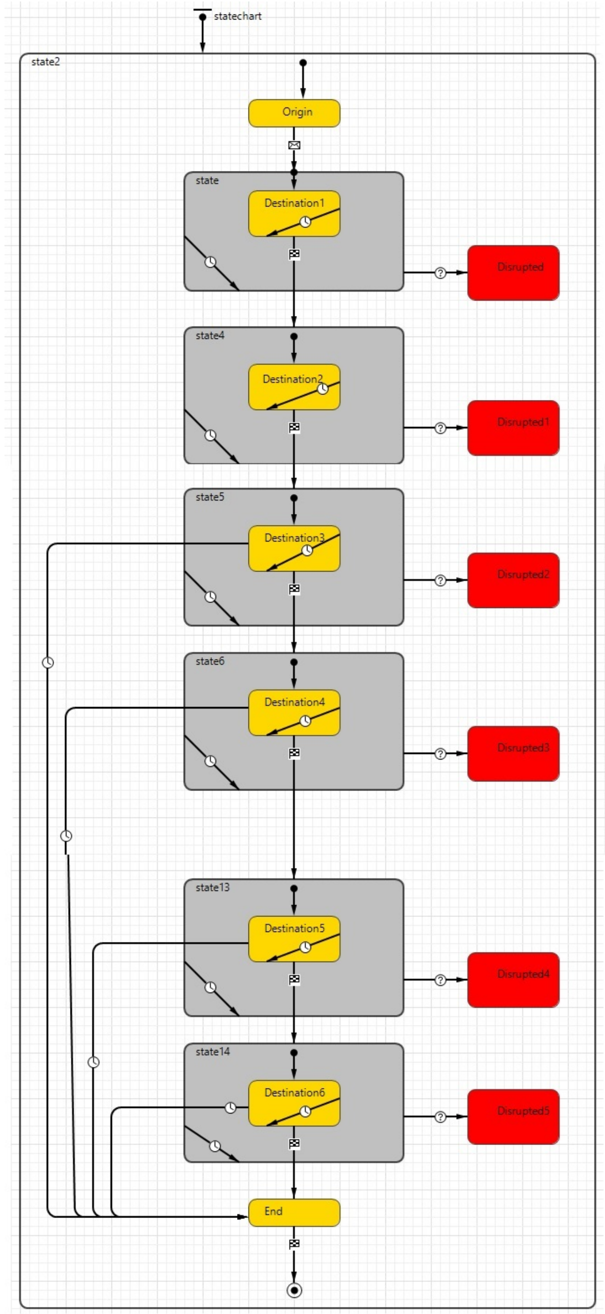

Figure 3: Airplane State Chart

Each aircraft has to respect certain conditions before taking off from an airport of origin to its destination. The first condition is the take-off time. An aircraft can take off only at a specific time and that aircraft has to stay at least for a specified time in an airport (in the current model this time is 45 minutes, which represents the time to complete the turnaround process in the airport before taking off again). The second condition is the availability of the destination airport. If this condition is not satisfied, the aircraft cannot take off. In the simulation, this state is highlighted in the map and visual interface, where this aircraft turns yellow. This color change means that either the origin or the destination airport is not available before taking off. On the other hand, if one aircraft is able to take off but during the flight the destination airport is not available (because of an internal or external disruption) the aircraft has to change its destination and the simulation shows the aircraft in red. This color signifies that the aircraft has been disrupted. In this case, the aircraft needs to go to another airport as follows:

- Aircraft tries to reach the nearest destination from the current position.
- Aircraft selects the nearest airport that has the minimum runway length needed for that aircraft.

In selecting each of the above options, the Extended Twin Operations (ETOPS) conditions should be met. ETOPS describes the operation of twin engined aircraft over a route that contains a point further than one hour's flying time from an adequate airport at the approved one-engine inoperative cruise speed (Martins, Nerosky, Fernandez, and Senna 2007; Ballal and Zelina 2004). The purpose of the ETOPS conditions is to provide very high levels of safety while facilitating the use of twinjets on routes which were previously restricted to three- and four-engined aircraft.
It is possible to set the ETOPS certification value as an additional parameter for each aircraft. In the current model, only three different ETOPS certifications are considered:

- ETOPS 90 (this means that an aircraft can follow one route that is not far from the nearest airport more than 90 minutes),
- ETOPS 120 (this means that an aircraft can follow one route that is not far from the nearest airport more than 120 minutes), and
- ETOPS 180 (this means that an aircraft can follow one route that is not far from the nearest airport more than 180 minutes).

Therefore, when an aircraft changes its destination because of an airport disruption, this aircraft has to check not only if the nearest airport has an adequate length of runway but also if the time to reach this new airport is compliant with the aircraft’s ETOPS certification.
There are different variables that represent the attributes of each aircraft. It is possible to check the *state* of each flight. The various states are:

- *departed* when the aircraft takes off,
- *arrived* when the aircraft lands,
- *diverted* if the aircrafts is diverted to a new destination because of airport disruption,
- *cancelled* if this flight is cancelled because the aircraft cannot take off from the originally scheduled airport because of airport disruption.

Other attributes of aircraft are the *origin* and *destination* for all the aircraft rotation, the *scheduled departure time* and the *scheduled arrival time* (taken from Flight Radar 24 website) for each flight, the *real arrival time* for each flight, the *delay* for each flight, the *total delay* for one aircraft (calculated as the sum of flight delays). There is also a *scheduled flight time* for each flight. In addition, there are specific information about each aircraft such as *aircraftID* (serial number), *FlightCode*, type of *Airbus* and number of *seats*.
The input interface allows the user to set up different parameters. For instance, the user can decide the closure of an airport by writing the name of the airport in the edit box. The user can also decide to change the time frame for the disruption through a slider created in this part of the model. Moreover, the user is able to set a disruption area by drawing a circle or polygon (this is more useful in case of certain hazards that impact large areas such as hurricanes, volcanic eruptions, etc.).
It is also possible to add different new aircraft in the model through an external database file. In this database, it is possible to add different schedules and aircraft attributes such as *departure time*, *arrival time*, *flight time*, *origin* and *destination names*, *aircraftID*, *flight code*, *number of seats*, type of *airbus*, minimum *length of runway for landing*, and *ETOPS certification*.
Figure 4 shows the interface for the Input Section where the users can set up different parameters.

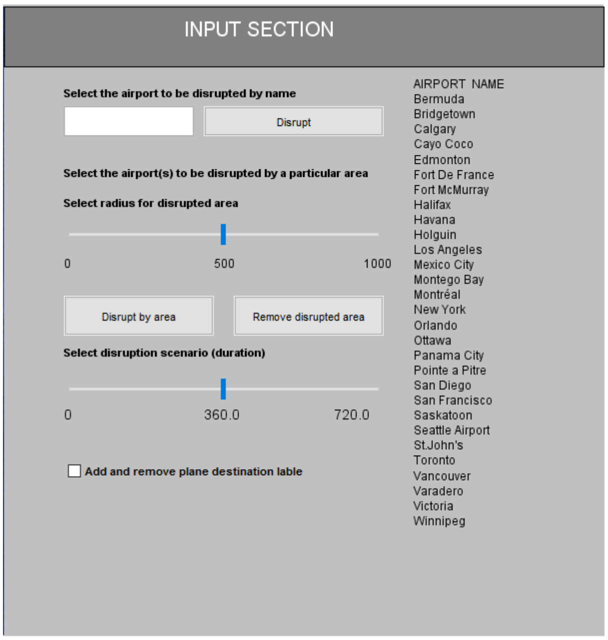

Figure 4: Interface for the Input Section

The interface for Output Section shows the results that can be obtained after running the simulation. As default, the model provides the following indicators:

- *Planes Chart* is a Time Plot with the number of airplanes in a network before completing their rotation.

- *Planes Disrupted* is an indicator showing the number of the aircraft disrupted at any given time; according to the current model, an aircraft is considered disrupted if it has at least one flight delay of more than 15 minutes.
- *Flights Disrupted* shows the number of flights disrupted based on the time; in particular a flight is considered disrupted if its delay is more than 15 minutes because of an airport's clouser.
- *Flights Diverted* shows the number of flights diverted at any given time; a flight is diverted if it cannot reach its scheduled destination but it's already on flight; for these reasons this aircraft has to change its destination.
- *Flights Cancelled* shows the number of flights cancelled at any given time; a flight is cancelled if a previews leg is diverted and it is impossible for this aircraft take off from the scheduled airport.
- *Passengers Disrupted* shows the number of passengers disrupted at any given time; a passenger is disrupted if his/her flight is disrupted or diverted. We consider an average of 80% occupancy for each flight.
- *Total Delay* shows the amount of delays resulting from an airport closure after one day of simulation.

Figure 5 shows the indicators of the model in terms of number of aircrafts in one specific time frame, Plane Disrupted, Passenger chart, number of flights disrupted, diverted and cancelled, and Total Delay.

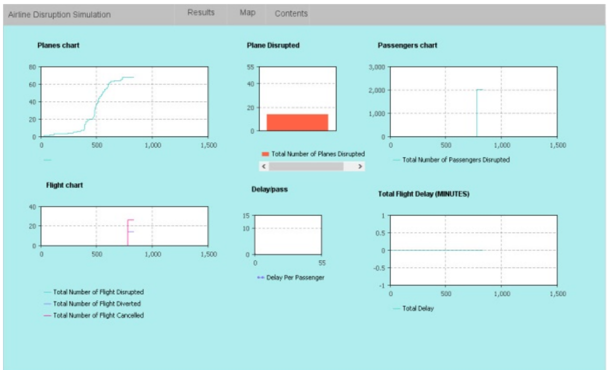

Figure 5: Interface for the Output Section

The presented model has been validated in two steps. First by means for an exhaustive *Structured walkthrough* and secondly by several *Data relationship correctness* revisions. Both techniques are commonly used in model verification and validation (Sargent 2013).

6. SIMULATION RESULTS

The capability of the model to simulate the impacts of a disruption on a predefined network allows one to compare Airline Disruption in different airports at the same time. It is useful to identify the most and the least vulnerable routes, aircrafts or even airports.
Table 1 reports the results of various disruption scenarios (based on the duration of disruptions) for the Toronto airport. It shows total number of aircrafts, flights, and passengers disrupted in each scenario, as well as the total amount of delay. Figure 6 and 7 show the number of aircrafts and the number of flights disrupted for each disruption scenario.

Table 1: Aircraft, Flights and Passengers Disrupted and Total Delay based on Different Simulation Experiments

Toronto (start at 00:00)				
Duration of closure (hours)	# of Aircraft Disrupted	# of Flights Disrupted	# of Passengers Disrupted	Total Delay [hours]
3 h	3	3	416	5.25
6 h	5	13	1808	27.80
9 h	31	92	12746	181.43
12 h	41	143	20004	550.38
15 h	48	164	23300	1030.50
18 h	51	172	24548	1541.80
21 h	55	179	25540	2074.80
24 h	56	181	25828	2613.30

Figures 6 and 7 exhibit behaviours of vulnerability indicators. In particular, it is possible to notice how the simulated network is time sensitive, due to workload variation among the flight schedules (Figures 8 and 9).

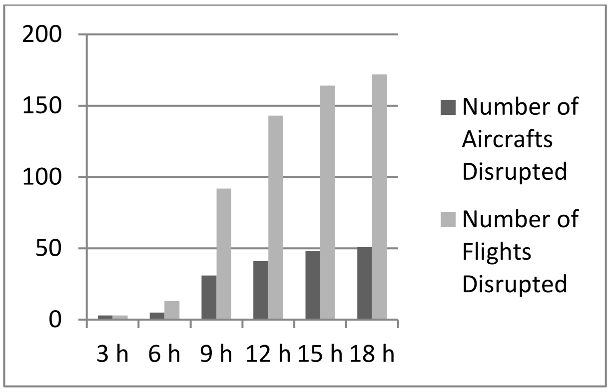

Figure 6: Numbers of Aircraft and Flights Disrupted under each Disruption Scenario

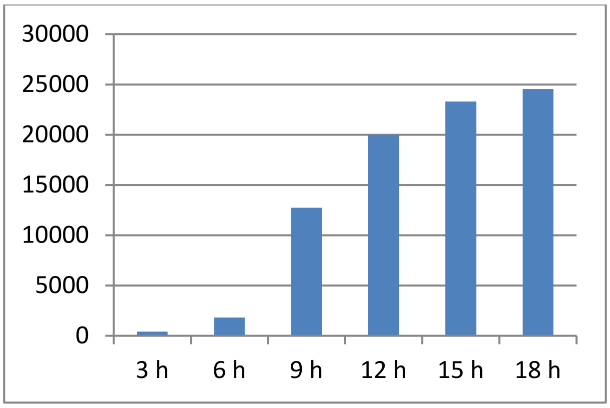

Figure 7: Number of Disrupted Passengers under each Disruption Scenario

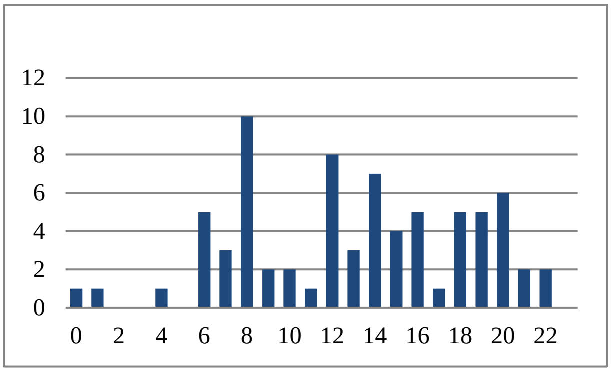

Figure 8: Number of Simulated Air Canada Scheduled Departures per Hour from Toronto Pearson Airport

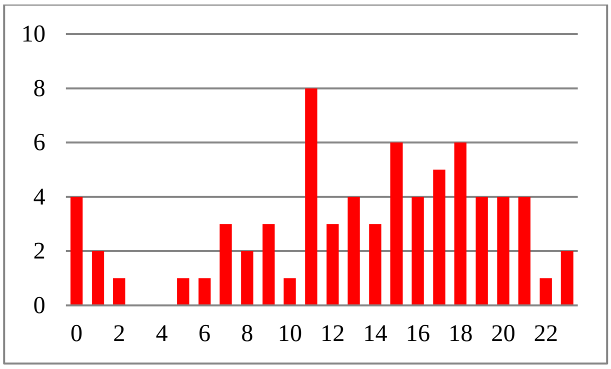

Figure 9: Number of Simulated Air Canada Scheduled Arrivals per Hour from Toronto Pearson Airport

7. CONCLUSIONS

The main goal of this study was to apply ABM to develop a support tool for the analysis of airport disruptions on airline route networks. In this paper, a specific airline network has been analyzed. The network includes 29 airports in Canada, USA, Mexico and the Caribbean and 70 aircraft which are categorized into four Air Canada Airbus families (A321, A320, A319, A319 Air Canada Rouge). Each aircraft has a specified number of legs and the current model includes 255 legs considering non-bidirectional routes. Based on these data and information, the authors have developed a simulation model that is able to generate relevant indicators about the impacts of an airport disruption on the network.

The simulation model allows a comprehensive and dynamic visualization of the main elements during the simulation (by means of the animation interface), with an easy to use input section (for parameters variation) and with an output section to show the simulation results. The model provides important information about Aircraft Disrupted, Flights Disrupted, Flights Diverted, Flights Cancelled, Passengers Disrupted, and Total Delay.

The present work provides a useful tool to assess the impacts of disruptive events on air traffic networks, providing insights about the most vulnerable areas and elements within the network under a systemic approach. Resilience measures could be estimated and verification of the possible improvements on the network's performance could be tested due to new configurations or new contingency strategies.

ACKNOWLEDGMENT

This research is undertaken through the Collaborative Research and Training Experience (CREATE) Program in Advanced Disaster, Emergency and Rapid-response Simulation (ADERSIM) at York University, which is funded by the Natural Science and Engineering Research Council of Canada (NSERC). The Modeling and Simulation Center–Laboratory of Enterprise Solutions (MSC-LES) of the University of Calabria, Italy, is an international collaborator in this program.

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TOWARDS AN INSTRUCTIONAL DESIGN METHOD TO DEVELOP M&S SUPPORTED PORT MANAGEMENT INSTRUCTIONS

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ABSTRACT

There are benefits to teaching complex systems using modeling and simulation (M&S) because learners can interact with system representation and conduct experiments that reveal system's behavior. Teachers can use M&S as a backbone of instructional activities, making them more interesting, motivating, and effective than traditional teaching strategies. Although many generic approaches to designing instructions are available they do not always provide the detailed guidelines for designing specific instructional activities supported by M&S. This paper reports on efforts to create an instructional design method (IDM) focused on the Scalable End-to-End Logistics Simulation (SEELS) M&S environment with port management as the subject of instruction. The concepts applied in the proposed IDM can be generalized for M&S-supported learning approaches. IDM will aid instructional designers define instructional content and determine their strategy for developing engaging and effective instructional material supported by constructive M&S.

Keywords: modeling and simulation, instructional design, port management

1. INTRODUCTION

Teachers, such as educators, instructors, lecturers, and faculty members can benefit from using modeling and simulation (M&S) because M&S-based lessons can be interesting, motivating, and effective (Balaban, Russell, Mastaglio, & Dykes, 2016). Using properly designed instructional approaches, students engaged with M&S can tap into the higher cognitive levels of Bloom's taxonomy i.e. analyzing, evaluating and creating. The use of simulation models can support new game-based (Epper, Derryberry, & Jackson, 2012) and collaborative project-based (Bell, 2010) instructional strategies. Students can conduct experiments relevant to real world problems and learn problem solving skills using M&S. Students generate results of experiments using simulation models, which provide them with direct feedback on their decisions and planning solutions. M&S can offer teachers a whole new set of instructional strategies and evaluation mechanisms. M&S should allow design of appropriate strategy for instructions targeting both analogical and adaptive transfer. The development of computer-generated models of seaports and their main components, like terminals, operational areas and resources – as the ones proposed in Longo (2012) and Bruzzone and Longo (2013) – ensures that students understand both structure and operations. Modeling and simulation (M&S) of proposed designs, concepts, or changes that could be made to a port enables proactive thinking (Balaban et al., 2016). This must be supported by a highly usable M&S tool that presents relevant information and hides unnecessary details. Moreover, teachers should be able to improve instruction based on their teaching experience and evaluation of student performance using M&S artifacts. Teachers may consider adding new activities, changing sequence of activities, and improve the content of activities by adding new concepts and new M&S scenarios. A flexible and reconfigurable M&S environment should support new exercises related to advancements within the area of study so teachers can easier improve their curricula.

Designing instruction for teaching complex concepts can be difficult and time consuming (Jonassen, 1997). Epper et al. (2012) pointed out that most games and simulations are too narrow to allow widespread adoption at multiple institutions. Moreover, general M&S software requires highly specialized knowledge, often beyond a teacher's expertise. If the learning curve is high this may inhibit the use of M&S as supporting materials. There would have to be a person involved who knows how to use specific M&S artifacts to implement supporting materials. On the other hand, if the learning curve is low teachers will be able to develop M&S materials themselves. Jonassen (1997) pointed out that although generic recommendations for simulation and other problem-solution types of instruction are available, no instructional design guidelines explain how to design specific components of instructions. This can significantly inhibit adoption of M&S in educational settings. Supporting M&S artifacts must be easy to implement and tailorable in the context of required instructions. Finding balance between functionality, usability, flexibility and effort when developing content using M&S environment is very important. Moreover, although a number of instructional design approaches are available they fall short in the context of providing guidelines to design instructions supported by M&S, especially within industry specific fields.

This paper looks into how to empower an instructional designer, who may be also a teacher, to facilitate development of port management lessons supported by the SEELS environment. Balaban et al. (2016) proposed technical approach to developing M&S based lessons, but more specific guidelines are needed. This initial effort to create IMD considers constructive M&S for designing and developing more engaging and effective instructional materials. The development of an M&S-based IDM is bottom-up, focusing on a particular M&S environment and knowledge domain, but its elements can be generalized to serve a broader M&S worldview. The words student and learner are considered synonymous in this paper.

2. INSTRUCTIONAL DESIGN: BACKGROUND

Instructional design can be defined as a systematic and reflective process of translating principles of learning and instruction into plans for instructional materials, activities, information resources, and evaluation (Smith & Ragan, 1999). This section briefly introduces selected instructional design models and their limitations in the context of developing M&S supported lessons. Although IDMs are commonly called models, this work labels them as methods. This is assumed by following M&S convention where a method is used to develop a model (Balaban, 2015). Using this parallel, IDM is used to develop units of instruction.

2.1. Generic instructional design methods

This subsection provides an overview of IDMs as an initial point of discussion. Molenda (2003) investigated the origins of Analysis, Design, Development, Implementation, and Evaluation (ADDIE) method and noted that this term is used as an umbrella of instructional design approaches with over 100 different variations. It originally consisted of four phases; objectives, pretest, instruction, and posttest, as well as a looping process for revision purposes. It was an adaptation of a system engineering process for problems associated with workplace training and instruction. Over the course of time, the method has been revised to include the current five ADDIE phases. Evaluation is a key provision that takes place in every phase. While the behavioral aspect handled procedural tasks, the addition of cognitive theoretical underpinnings addressed nonprocedural tasks (2006). Dick, Carey, and Carey (2001) proposed well-defined steps in an iterative cycle, providing more granular view of the steps as compared to ADDIE. They proposed separate steps for specifying learner entry behavior and instruction characteristics, both directing toward objectives. Similarly Kemp, Morrison, and Ross (2004) provided a more detailed view of iterative phases, but characterized by unspecified order of steps to facilitate more flexibility in developing instructions and emphasized the importance of management of instructional design. Others proposed simplifying the instructional design into just three phases emphasizing iterative characteristic, importance of understanding, agility, and collaboration (M. Allen & Sites, 2012; Piskurich, 2015; Wiggins & McTighe, 2005). A different focus for instructional design was offered by Pearson and Gallagher (1983) who proposed the level of student independence as a guiding principle. The approach originated with a focus on the reading skills but it could be used more broadly. It has four phases:

1. demonstration, where teacher delivers instructions,
2. guided instruction, where teacher leads students through instructions.
3. collaborative learning, based on group activities, and
4. independent student practice (Fisher, 2008; Fisher & Frey, 2013).

All presented IDMs have provided important guidelines, but they do not include elements critical to supporting M&S-based instructions. In order to facilitate delivering instruction using M&S environments, the instructional designer or teachers themselves must acquire sufficient M&S knowledge to develop the learning activities. A new perspective on what IDM is and how it should guide development is needed; one that incorporates translating instructional activities into M&S activities and that is in a form that can be applied by those not proficient in M&S.

2.2. Levels of IDM for M&S supported lessons

Honey and Hilton (2011) proposed a research agenda for simulations and games in learning science where they pointed at the need to research design features, methodologies, and their links to learning outcomes. Depending on their purposes IDMs for M&S could be specified at different levels as defined by their universality and precision (Popper, 2002). Figure 1 demonstrates this based on the example of four IDMs starting from a more universal and less precise approach at the top of the graph to more precise and less universal at the bottom.

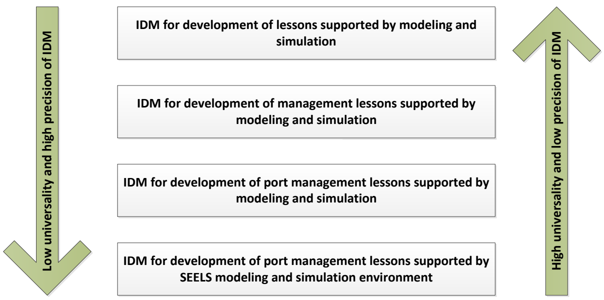

Figure 1. Concept of IMD levels based on universality and precision

The top type of IDM should be used when no low level IDMs exist and the instructor designer has M&S expertise. This level may also be sufficient when more precise guidelines do not benefit teachers because the subject area is well-established and general, and a set of existing simulation models with detailed instructions can be obtained to support lessons. On the other hand, more specific IDMs would be beneficial to instructional designers without M&S expertise and for those topics related to specific knowledge and skills that have not been widely explored using M&S and for which there is not easy access to supporting M&S materials.

The existence of IDMs for a specific knowledge domain and relevant M&S tools can aid development of more advanced and specific lessons. For instance, if the IDM provides guidelines specific to both port management and SEELS it could offer more specific mapping between learning objectives, business objectives, and M&S objectives. On the other hand, this view is a simplification relative to the current state of the art of IDMs. The benefits related to the specification of the knowledge area within IDM may be discounted in the future, making both universal and precise IDMs possible by providing sufficient guidelines across broader areas of knowledge and a more general M&S view. The second level from the top in Figure 1 shows generalization across for both management and M&S views, while the top level IDM shows implicit generalization of knowledge domains under the M&S umbrella. This paper can be placed at the bottom level of Figure 1. The specific goal is to propose IDM guidelines focused on port management instructions supported by SEELS environment. Based on this work a more general IDM for M&S could be also derived in the future.

3. IDM FOR PORT MANAGEMENT SUPPORTED BY SEELS

A developed model of an instructional unit is the main product of IDM. The instructional unit specifies types of activates, that including assessment activates, their sequence, and supporting materials. A traditional lesson as a unit of instruction would consist of both class and home activities. Depending on type of delivery, e.g. class, online or mixed, teachers may consider different activities and levels of control over instruction. Activities can also be characterized by the type of feedback from learners, level of learner's control, level of interaction between students, and Bloom's taxonomy level.

3.1. The purpose of M&S based IDM

Instructional design facilitates guidelines that help to develop effective and appealing instructions that require minimum time to learn concepts (Smith & Ragan, 1999) and minimize time to produce instructions. Instructional design may involve many collaborators, e.g., instructional designers, M&S developers, and teachers. It is possible for single faculty members to perform all three roles. If subject matter experts (SME) are tasked to develop an M&S-based port management curriculum, they need to learn IDM and M&S. If instructional designers are tasked to develop it, they need to learn the subject area, e.g., port management and M&S. It is common in a university setting that faculty members along with their graduate students develop or improve curricula. They may have some expertise in both instructional design and a subject. This helps because only additional M&S expertise is needed. IDM aims to be sufficiently generic, with the respect to the role of instructional designer and developer, so it only assumes that the person designing instructions and developing instructional materials follows the IDM, has access to domain knowledge, and has access to M&S resources. IDM guides selection of instructional and assessment activities, their scaffolding in sequence, and implementation of instructional material as necessary. The aim of M&S based IDM guidelines is to empower instructional designer to design M&S-based instructions and guide them in developing or reconfiguring M&S materials.

M&S is a broad discipline and knowing what type of M&S capability may be more applicable in the context of designing instructions for a particular domain can be challenging for faculties not experienced in M&S. Because of that M&-based IDM should facilitate guidelines sufficient for successful use of M&S capabilities. To design engaging and effective lessons, the use of capable M&S environment tailored to a particular field is important. The selection of instructional activities and their sequence should be supported by scaffolding principles. Engaging and effective instructions that gradually move control over learning process to students should facilitate the right amount of interaction between teacher and students, amongst students, and between the student and M&S artifacts. Moreover, teachers should specify appropriate communication channels for situations when students face challenges beyond their current capacity. This will ensure that students can keep up with the pace of instructions. The activities should consist of assessment mechanisms which inform teachers about their effectiveness, and help improve instructional activities.

3.2. Overview of the proposed IDM

Figure 2 shows main steps of the proposed M&S-based IDM. It consists of 7 main steps. Steps 4 and 5 contain iterative sub-steps.

3.2.1. Initial assumptions

In this step one should list initial assumptions about an instruction that will be developed including the unit of instruction, e.g. a weekly lesson, type of delivery, e.g. class, online or mixed, assumed students' weekly time-effort, and in-class time constraints, e.g., 90-minute class meeting. A set of instructional units can comprise higher order units such as course curricula.

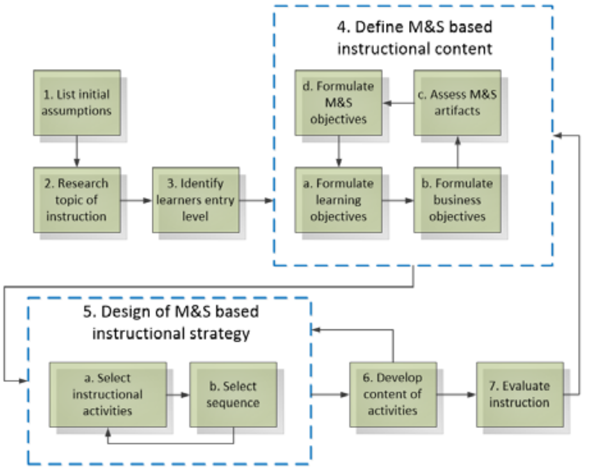

Figure 2. Proposed steps of M&S based IDM

3.2.2. Researching about a topic of instruction

In this step instructional designer identifies scope of the instruction by gathering and organizing resources other than M&S artifacts e.g. book chapters, papers, web articles, and videos. The port management area of expertise is large, but has defined disciplinary boundaries (Alderton, 2013; Bichou, 2014; Song & Panayides, 2012). Making an ordered list of main concepts within a unit of instruction, e.g., port structure, terminal configuration, container processing, and berth occupancy ratio will allow one to better conceptualize the structure of the content. The list should include all the knowledge and skills students should acquire in relation to the selected concepts by the end of a particular unit of instruction specified at the desired level of Bloom's taxonomy.

3.2.3. Identifying learners' entry level

Instruction of complex and advanced concepts related to port management often requires learning both general and specific prerequisite knowledge and skills. The learners' entry level to a course pertains to their educational background and their exposure to the industry. The learners' entry level for each unit of instruction is related to the progression through the curriculum, where the instructional designer should be able to estimate already acquired knowledge and M&S skills from completion of previously introduced units.

If students are or were employed in the relevant maritime industry, they may pursue advanced degrees to advance their careers. They may already be SMEs in many of the concepts and skills covered within a course. These students will differ from entry-level students, which can pose challenges to properly pace instructions in order to keep all students engaged but not overloaded. Properly designed instruction should be able to take advantage of the SMEs and increase amount of time spent on collaborative activities, making sure to divide SME students into separate groups. Before the beginning a semester, faculty should assess learners' entry level to identify and properly 'allocate' SME students.

Identifying each learners' entry level at the beginning of a unit of instruction, e.g. a lesson, allows the instructor to select the applicable activities which support learning at the desired Bloom's level. The difference between desirable level and entry level identifies the gap that should be closed, provides an input to the content definition and strategy design, and establishes a baseline for evaluation.

3.2.4. Defining M&S based instructional content

In this iterative step the proposed content is systematically analyzed. In order to define instructions that include M&S requires identifying three types of objectives: learning objectives, business objectives, and M&S objectives. Figure 3 displays the relationship between learning objectives, business objectives and M&S objectives. Based on the desired Bloom's level specified in step 2 concepts will be used to specify knowledge and skills and write learning objectives. Learning objectives will be examined from the business perspectives. Both, learning and business objectives will in turn provide input for writing M&S objectives, which are used in the next step: designing of M&S-based instructional strategy.

Figure 3. Relations between learning, business and M&S objectives

Formulating learning objectives

Learning objectives are the main components of a unit of instruction, e.g., a lesson. It is defined here as a statement describing intent of instruction in terms of learners' Bloom's level that will be achieved by the end of the instruction. Next one must identify the main components of learning objectives include the learner, the concept to be learnt, the time required (or available) for the instruction, and a verb indicating which Bloom's level will be achieved. Figure 4 provides an example of learning objectives with main components color-coded.

Formulating business objectives

The business objectives link instructions and the real world. One learning objective may consist of zero or more business objectives. Business perspectives can be particularly useful in the context of teaching port management.

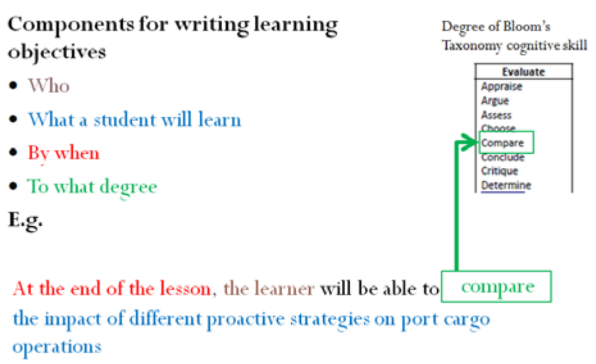

Figure 4. Writing learning objectives

If possible, the educational goal should include concurrent and emergent problems in the industry understanding of which will better prepare students for the job. In general, business problems are mapped to produce evidence supporting a decision. For instance, in the port management business objectives are perspectives that port managers experience. This provides for teaching students relevant problem-solving and decision-making skills. Lagoudis (2012) identified research gaps in the container terminal industry and specified a set of problem categories. Based on an extensive literature review he identified methods used within each category, e.g., mathematics and operations research, management and economics, simulation, and stochastic. Balaban et al. (2016) used a general *problem – decision* concept approach where M&S is used as a problem remediation method. Figure 5 represents the relationship between business objectives and M&S objectives using transition points.

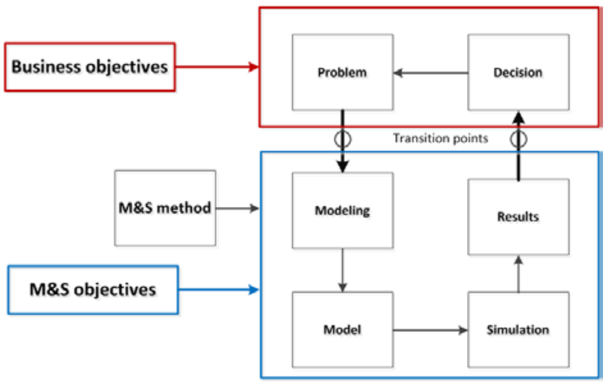

Figure 5. Division of business and M&S objectives within problem – decision space

Business objectives include a problem space and a decision space. Problem space is translated using M&S method into M&S components, which are applied to produce results translated back into decision-making within the business objectives area. Although an M&S method was used, other methods can be also used either in place of M&S or in combination with M&S. Figure 6 provides an example of business objectives with main components color-coded.

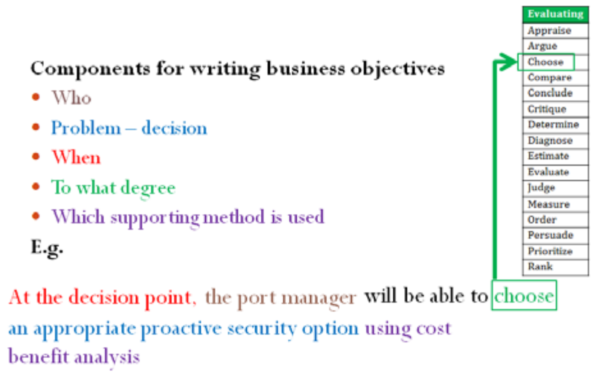

Figure 6. Writing business objectives

Assessing M&S artifacts

In order to determine the appropriateness of M&S to support specific learning and business objectives the supporting M&S environment should be analyzed to assess its capability to cover the targeted concepts. Usually, M&S environments have specific M&S artifacts. Although more generic M&S tools often provide a common set of artifacts, SEELS in its current state is focused on analysis of logistical networks of cargo ports. The following subsection introduces main SEELS artifacts, which will be used during the development of M&S objectives.

SEELS enables representation of a logistical network that can be composed of multiple cargo ports. A network of seaports can be represented with their hierarchal structure that consists of multiple terminal areas, which in turn consist of operational areas. The following are the main M&S artifacts of SEELS environment:

Actor is an M&S artifact with specific characteristics and functions:

- Cargo are goods, e.g., containers, vehicles, people, and bulk. Cargo are carried by the transports or resources.
- Transports move cargo, e.g., container ships, trains, and tucks.
- Port resource is equipment or personnel used to process cargo and transports within a port or terminal, e.g., container cranes, straddle carriers, pumps, and line handlers.

Area is an M&S artifact that serves as a structural building block for a model, e.g., port, terminal, berth, staging area, gate, and inspection station. Changes made to one area affect output factors for that area, other connected areas, and not directly connected areas because of cascading effects. The greater the number of areas involved, the higher the level of cognitive burden imposed on the learner due to increasing numbers of connections and related dependencies. On the other hand, more areas can provide more realistic scenarios, and more challenging problems can be designed.

Profile is an M&S artifact that defines a complete set of transports and cargo loads for a logistical network consisting of a single or many ports and terminals. Profiles describe a schedule of transports, transport quantity, destination of each cargo load associated with each individual transport, among other characteristics. Transports can arrive empty or loaded with a mix of cargo headed for different destinations (Mathew, Mastaglio, & Lewis, 2012). We recommend logically dividing transports and cargo loads into multiple profiles.

Process is an M&S artifact that defines handling of transport and cargo within an area. They are used to capture business rules of ports, terminals, and operational areas. SEELS processes are handled as input data allowing for ease of modification during experimentation.

Input factor is an M&S artifact used to specify characteristics of other M&S artifacts, e.g., process times within an area, route time between areas, quantity of resources, physical attributes such as length, weight, and area, and arrival times.

Programmatic event is an M&S artifact which impacts *input factors* at simulation run-time.

Output factor is an M&S artifact that represents a particular business concern often closely related to business objectives, e.g., throughput, turnaround, utilization, footprint, and cost.

A simulation scenario can consist of multiple profiles, which can be mixed and configured to work with one of multiple network configurations in order to experiment with different structures and varying resources providing end users experimental flexibility. See (Mathew, Leathrum, Mazumdar, Frith, & Joines, 2005; Mathew et al., 2012) for more information about SEELS environment.

Formulating M&S objectives

M&S objectives are the base with which problems can be represented and the decision-making within business objectives can be supported and explained. The M&S environment can be also used to explain concepts within learning objectives, but which do not have relevant business objectives.

Based on the coverage of learning and business objectives by M&S artifacts, an instructional designer can analyze when and how to use M&S to formulate M&S objectives. M&S objectives within the scope of constructive M&S can be characterized by various components of M&S methodology, e.g. conceptual modeling, design of experiment, and simulation output analysis. These components in turn use M&S artifacts, which are more or less specific to an M&S environment. Based on the list of SEELS artifacts, the instructional designer can assess their coverage related to learning, business, and M&S objectives based on the following ordinal scale: full coverage, significant coverage, medium coverage, low coverage, and no coverage. The end result can be displayed in a table or as a graph. For instance, a radar chart shown in Figure 7 displays an example coverage of learning objectives, business objectives, and M&S objectives using SEELS artifacts. It informs the instructional designer about possible partial M&S coverage, and the necessity to complement M&S activities with other activities to ensure full coverage of concepts not already covered.

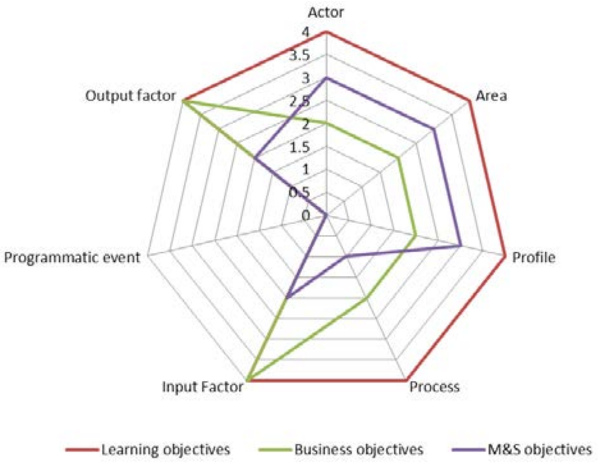

Figure 7. Coverage by M&S artifacts

Figure 8 provides an example of M&S objectives with main components color-coded.

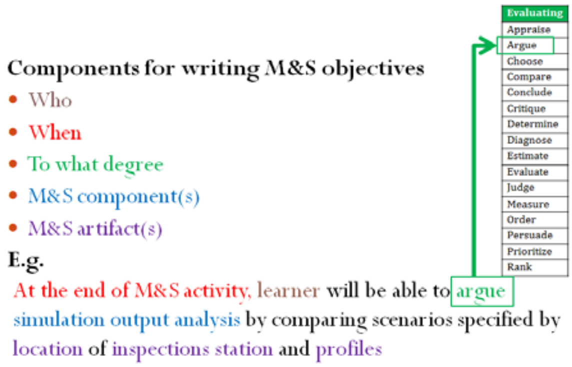

Figure 8. Writing M&S objectives

3.2.5. Design of M&S based instructional strategy

In order to design M&S-based instructional strategy M&S components and M&S artifacts must be allocated to activities as instructional media ensuring learning tasks and assessment are congruent with one another. This section introduces M&S instructional activities. They are briefly discussed with the intention of providing a future research agenda. After introducing M&S-based instructional activities we discuss the initial guidelines on selecting and sequencing them.

M&S based instructional activities

M&S activities are created by adding an M&S component to traditional instructional activities. They are the building blocks of instructional units. Constructive M&S activates require M&S software. For those activities that require sharing the screen of a computer with the rest of the class, a projector or other form of broadcast media is required. In addition to M&S materials, M&S activities can be supported by most traditional teaching materials, such as articles, textbooks, video tutorials, and web content.

M&S lecture involves using M&S artifacts in a one-way transmission of information from a teacher to students. The teacher explains a topic to students switching between M&S artifacts and presentation slides. *M&S lecture* requires minimal student knowledge and skills: it aligns well with lower Bloom's levels facilitating learners' recall and understanding of the topic.

M&S individual laboratory is an activity that involves using M&S artifacts with the teacher gradually moving control of the instruction to students. The instruction is presented in steps supported by working with a number of M&S artifacts. Each students works separately. First, students learn how to complete simple M&S objectives by following a teacher's demonstration and/or tutorials. Then, a teacher leads students through a combination of M&S objectives to achieve a level of student ability to aggregate M&S objectives and to accomplish the business and learning objectives. *M&S individual laboratory* is more appropriate at higher Bloom levels, such as understanding and beyond.

M&S group laboratory is a collaborative activity where students work in groups, using shared knowledge and M&S artifacts to accomplish business objectives. This activity can be extended using a game mode, e.g., groups compete or collaborate, students within group compete or collaborate, or a mixed mode of both competition and collaboration at various levels of group/student. *M&S group laboratory* is more appropriate at Bloom's levels such as apply and beyond.

M&S discussion session is an activity that uses M&S artifacts to transmit information bi-directionally, between students. The teacher defines the scope, facilitates discussion, and monitors the direction of the session. During discussions students can propose alternative ideas and critique potential solutions, which then can be implemented, analyzed and evaluated using M&S thus providing immediate feedback of the proposed ideas and decisions. Students use M&S artifacts to implement their ideas. *M&S discussion session* can be used at many Bloom's levels, which depends on the desired scope defined by the instruction. It provides formative evaluation insight about students' Bloom's level related to the concepts being taught.

M&S student presentation is an activity where an individual student presents to their class using M&S artifacts. Student assume a teacher's role, with a limited control over the instruction. *M&S student presentation* supports different Bloom levels, depending on a student's expertise about the topic. This activity supports formative evaluation.

M&S individual question session is an activity that employs M&S artifacts in the formative assessment of each student. Teachers asks questions of individual student about knowledge that was covered and skills that were practiced. This activity is more appropriate near the end of a unit of instruction. A student can answer questions and demonstrate knowledge and skills using M&S. *M&S individual question session* can be used to achieve many Bloom's levels, depending upon the teacher's questions and the student's knowledge and skills.

M&S group question session is an activity that uses M&S artifacts as a formative evaluation of the collaborative efforts of a group of students. The teacher asks questions to groups of students about knowledge that was explained and practiced. Students within the group communicate to generate a consensus response. Students answer questions to demonstrate their knowledge and collaborative skills using M&S artifacts. *M&S question session* supports many Bloom levels. Place this activity near the end of a lesson.

M&S home activity involves using M&S artifacts for teacher-assigned tasks completed by students at home. It can often serve as an assessment. Tasks focused on previous lessons help reinforce concepts using M&S artifacts and deepen knowledge. *M&S home activity* can also be used in a flip class format as a mechanism for preparing students for an upcoming lesson by covering prerequisite knowledge and skills, or by providing a refresher based on the previous instruction.

M&S performance assessment is an activity that uses M&S artifacts to assess learners' achievements of learning objectives, business objectives, and M&S objectives. This is a summative assessment, usually covering multiple units of instructions.

M&S *individual project* is an activity in which student must propose solutions to real world problems and conducts necessary analysis and evaluation to support them using M&S. To complete the project, student will be required to demonstrate knowledge of port management using M&S skills across multiple levels of Bloom's taxonomy. Problems may be proposed by a teacher or by a student. The time to complete the project will be determined by teacher and will likely span multiple units of instruction. This activity differs from *M&S home activity* because it has a larger scope, encompassing multiple lessons and serves as a summative evaluation.

M&S group project is a version of *M&S individual project* in which a group of students work together on a project. We recommend using *M&S group projects* before *M&S individual project* to enable students to collaboratively learn the tools, concepts, and the process of developing M&S-based solutions.

Selection and sequencing of instructional activities

Selection and sequencing of instructional activities aims to ensure a proper coverage of skills and knowledge at the desirable Bloom levels. It should also promote both durable and efficient learning by considering both short-term and long-term goals (Rawson & Dunlosky, 2011). While future research is necessary to increase our understanding of how the brain and cognition changes as a function of learning (Ansari, De Smedt, & Grabner, 2012), e.g., in problem solving (Stevens, Galloway, & Berka, 2006) during M&S activities, the example guidelines are specified based on information gathered in the previous steps of IDM, principles of effective instruction (Munro & Clark, 2013), and cognitive load theory framework (Wong, Leahy, Marcus, & Sweller, 2012). These guidelines can serve as an initial idea demanding an empirical research necessary to establish base line dependencies between factors. They should be used to develop more precise method for selecting and sequencing instructional M&S activities. Because at this point of research we do not have data supporting selection and sequencing, the guidelines have qualitative, informative character.

In order to select M&S activities, one should establish a time budget of all activities, including total assumed time of weekly student effort. This time includes the total time for in-class activates. It is assumed that in-class M&S activates range between 10 and 30 minutes to keep learners engaged and motivated. The goal is to sustain the cognitive activity at a sufficiently high level to enable effective learning, but not too high to avoid cognitive overload. Assuming traditional weekly format found at universities, the process of selecting M&S activities should consider several factors affecting cognitive load:

- Total assumed time of weekly student effort (step 1)
- Total time weekly in class meetings (step 1)
- Initial Bloom's level (step 3)
- Desirable final Boom's level (steps 2 and 4)
- M&S coverage (step 4)
- Assumed time required for each single activity (step 5)

If the M&S environment limits a particular knowledge or skill, then other activities must be incorporated to complement M&S activities. While traditional lecture-oriented instructions are not well equipped to stimulate higher Bloom's levels, M&S activities arguably can improve learning at higher Bloom's level. With better representation of the domain knowledge and skills using M&S artifacts, we can expect the cognitive load during learning to be higher because more dependencies can be learned and practiced at ever higher Bloom's levels.

Instructional designers should estimate how many M&S artifacts, and how many dependencies between them can be effectively learnt within a given time. For long activities with a large number of M&S artifacts, the information may exceed working memory limitations and make learning ineffective. If more time is required to achieve a higher Bloom level it is better to break a single lesson into two weeks and use M&S activities that enable transitions between levels. This is where new research is needed to facilitate quantitative estimations. Taking into consideration these limitations, in Figure 9 we show an example of using generically sequenced M&S activities to assemble a unit of instructions.

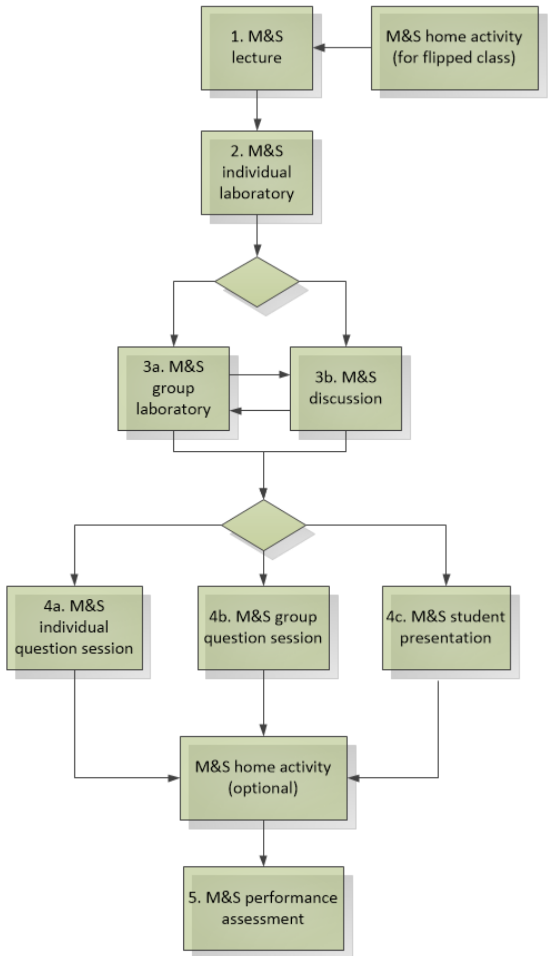

Figure 9. Generically sequenced M&S activities to assemble a unit of instructions

When introducing new knowledge within a unit of instruction, we recommend starting with *M&S lecture* as the initial activity. *M&S lecture* aligns well with low Bloom's level to facilitate learners' remembering and understanding of the topic, facilitating student learning of vocabulary, definitions, visual representation, and a basic understanding of system behavior. Next, it is important to practice the knowledge by applying it to move the knowledge from working memory to long-term memory. *M&S individual laboratory* can serve this purpose. Based on schema theory (Wong et al., 2012) we recommend next the use of the *M&S group laboratory* or *M&S discussion* where students can 'borrow knowledge' from other's long-term memory through discussion, collaboration, and competition. These activities when properly moderated by a teacher should facilitate situations where problem-solving skills are acquired. If highly collaborative problem-solving skills are desirable, we recommend stacking these activities one after another. The next activity is selected from a set of three M&S activities: *M&S individual question session*, *M&S group question session*, or *M&S presentation.* They provide opportunities to generate more feedback from students about their progress through instructions, providing formative assessments.

Teachers may prescribe *M&S home activity,* to allow practice at home using M&S as directed in their assignments. Optional *M&S home activity* can be also used when prerequisite material must be acquired by students before class. This is commonly called a flip class format. In this format teacher can provide simulation models and video tutorials to the class, so students become familiar with a subject. This way time of *M&S lecture* and *M&S individual laboratory* can be minimized, leaving more time for collaborative activities. After all the learning activities are completed *M&S performance assessment* is conducted to evaluate results of the students completing multiple units of instruction. One can combine traditional assessment methods with the use of M&S artifacts.

3.2.6. Developing content of activities

Based on the selected M&S activities and their sequence, instructional designers should be able to develop all instructional M&S artifacts and prepare formats and mechanism for reporting results of for those M&S artifacts developed by students. For instance, emails or cloud storage for managing M&S artifacts within learning management system can be used. The SEELS interface allows for very fast and intuitive development of highly configurable models. No programming is required to develop instructional material in SEELS. Models are defined using GIS maps and semi-transparent polygons representing infrastructure. SEELS allows the saving of both the simulation model and output data within a single file; this makes it easy to communicate most of the M&S artifacts except for processes which are external to the main graphical user interface.

3.2.7. Evaluation of instructions

Evaluation is used to continuously improve instructions. Many methods can be used to conduct evaluation of instructions (Cohen, Manion, & Morrison, 2013). Evaluation of instructions may, for instance, include objective evaluation of the students' learning outcomes, subjective evaluation based on learners' feedback, and subjective feedback from instructional designers who applied IDM.

Moreover, evaluation of factors related to the instructions themselves should be considered. The length of M&S activity is an important factor that should be evaluated. The evaluation should also assess feasibility of advancing to the desired Bloom level based on M&S coverage within the M&S activity and the total weekly class time. Automatic recording of total usage time of SEELS by students, and more detailed information about student interaction with the M&S environment could offer valuable insights for improving the curriculum and specific learning activities. For instance, it could provide insight about how much practice is enough to reach a particular Bloom level, about including a single learning activity versus relearning activities, and about common learning strategies used by students (Rawson & Dunlosky, 2011). This brief discussion covering evaluation of M&S based instructions is not limited deserving of a separate paper.

4. FUTURE WORK

This paper described initial efforts to create M&S based IDM. A case study demonstrating the use of proposed IDM to design and develop a sample lesson, including M&S artifacts, is planned as an extension of this work in the near future.

The future work should include continuous improvements related to selection and sequencing based on evaluation of instructions. Refinements can initially be made by adopting the "learning by doing" approach, i.e., using IDM to develop more instructions for port management and then evaluating them. Our insights could be considered for applicability across different domains and different M&S environments as a basis to improve and generalize IDM. Guidelines for selecting appropriate M&S environments based on more tangible criteria in the context of educational purposes is yet another topic that needs more research.

The cognitive load during knowledge and skills acquisition based on using M&S activities is difficult to measure using available methodologies thus limiting the use of objective criteria for selecting instructional activities. More research is needed in estimating cognitive load during M&S activities. Evaluation methods for M&S-based instructions are still in their infancy. Future work should find a way to devise more precise research methods at the intersection of neuro-education (Ansari et al., 2012) and M&S. The improvement of IDMs would be facilitated through more synergy between academic programs specific to a domain, academic programs that educate future developers of M&S environments, and industry partners that commercialize them.

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MODEL OF AN ADVANCED PLANNER FOR INTEROPERABLE COMPUTER INTERACTIVE SIMULATION

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ABSTRACT
This work proposes the use of stochastic discrete event simulation as a strategic tool for supporting decision-making process in Maritime Interdiction operations. The case study is set within the framework of anti-piracy operations and can be easily converted to the illegal immigration context. The simulation involves different kind of assets such as surface vessels, underwater vehicles, MPA, UAVs, helicopters etc.

Keywords: *Modelling and Simulation, Joint Naval Training, Decision Support System*

INTRODUCTION
Nowadays, Naval Maritime Interdiction framework includes missions of complex, specific and articulated nature. Bright cases are migrants flows, especially when accessing south Europe through sea routes and piracy.
Performing these activities, the Navies involved need to operate effectively and efficiently through sustainable actions to reach durable results while facing limited resources. Furthermore, the available assets are designed for different purposes: deployment of such units imply a significant effort in term of cost and adaptability.
Another crucial element is the strong dynamism of the phenomena under analysis. In fact, the players tend to respond quickly to countermeasures while dynamically adapting their strategies, forcing the Navies to revise planning and procedures continuously.
Indeed, the actors are often aggregated in different structures, working both as a single National Navy and as part of different coalitions (e.g., EU, NATO) in presence of other entities (e.g., NGOs, other Navies). In addition to all these elements, cooperative operations are often very intense, widely distributed over a geographical area and strongly stochastic, which makes planning more difficult. Indeed modern Navies need to integrate Maritime Interdiction operations (among others) with innovative technological solutions, such as use of autonomous systems and advanced data fusion techniques combining different sources (e.g. public information and military coverage); the configuration and calibration of these innovative systems and their integration with traditional assets for the intended use require often support by Modeling & Simulation (M&S). In facts by this approach it becomes possible it to evaluate the overall performance in order to understand the specific procedures to be adopted for using them in the most effective and efficient way and to avoid/anticipate potential problems (Massei et al. 2011). All these issues are subjected to stochastic factors such as failures, false alarms, times, costs, etc.; so it is evident that the simulation is the cornerstone to support this context. In fact, the systematic use of the M&S (Modeling and Simulation) provides strategic support in decision-making process improving both the effectiveness, that the flexibility and robustness of the planning (Bruzzone et al. 2014b; Bruzzone et al. 2013e).

1. CURRENT SITUATION AND RESEACHES
The advent of technological innovative solutions such as autonomous systems increased the flexibility of modern Navies during recent years, and while in other sectors they are already very integrated, in this context they are often a not a complete operative part of the missions. In facts the capability of autonomous assets could enhance mission success; therefore it is necessary to analyze how such innovative assets should be used so to finalize their selection or parameters design as well as to define operational procedures and policies (Bruzzone et al. 2014a, Kaymal 2016).
In the Naval sector, both civilian and military, numerous studies have been conducted in the field of Modeling and Simulation to evaluate the benefits of innovative solutions (Bruzzone et al. 2013d); indeed the marine environment is often very conservative due to the challenges provided by the sea that requires very high reliability in an hostile framework all around the clock and in all weather conditions; for these reasons the use of simulation to address a priori potential problems is very useful and provides very useful insight in advance (Longo et al., 2013, Longo et al. 2015) even when dealing with emerging behaviors and situations (Oren and Longo, 2008).

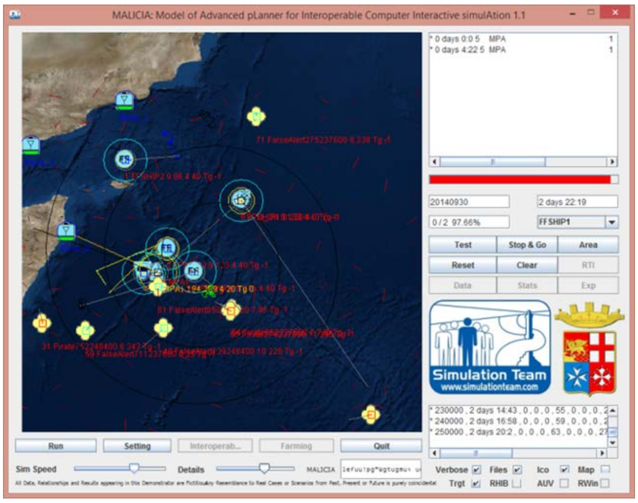

Figure 1 – MALICIA GUI

Simulation of maritime operations is thus an advanced and consolidated tool, using sophisticated models to reproduce the actual behavior of different types of vehicle involved in these scenarios. Among others, there have been developed specific models of MPA (Maritime Patrolling Aircraft) and UAVs to study the advantages and possible applications (Brennan & Denton, 2004, Pereira et al. 2009). Indeed, the scenario under analysis is very complex characterized by total heterogeneity of vehicles and strongly the environmental conditions have a very significant influence; due to these reasons the simulation is used for planning operations and as support in the decision-making process (Bruzzone et al. 2011b). Indeed, it is fundamental to integrate in the simulation the available models able to reproduce the weather and oceanographic conditions and their impact on the assets and vehicles (Pautet et al. 2005; Delbalzo & Leclerc, 2011; Lundquist 2013). The inclusion of environmental condition effects is beneficial as the scenario analyzed consists even of small-medium size boats (e.g. pirates, fisherman) and assets (e.g. UAV, AUV, USV) greatly influenced by weather conditions (Bruzzone et al. 2011c, Slootmaker et al. 2013); indeed in specific weather conditions even sophisticated sensors have reduced capability to detect specific kind small medium boats (e.g. RHIB) so it is evident the importance to model these aspects.

In Maritime Interdiction applications, stochastic dynamic simulation offers many advantages compared to conventional studies, which would require to simplify the problem with limited generalization capabilities. These kind of models were developed originally due to the increase on piracy that had a great on commercial maritime traffic, estimated between 1 and 16 billion US$ by UNCTAD (United Nations Conference on Trade And Development); this leads commanders and policymakers to task scientists to develop decision support tools generating patterns and behavior of maritime piracy actor (Varol & Gunal 2015). Planning effective activities is even a matter of considering the trade-off between operations costs and security; such tools are based even on agent-based models and game theory (Bruzzone et al. 2009, Jakob et al 2012, Jeong & Khouja 2013, Marchione et al. 2014). In fact, such a scenario is very complex: in it there are different types of vehicles as surface vessels, underwater vessels, MPA, UAVs, helicopters etc. with different technical characteristics, rules of engagement and differently influenced by boundary and environmental conditions. Simulation re-creates all of these different models interacting with each other by means of IA-CGF (Intelligence Agent Computer Generated Force) (An et al. 2012, Bruzzone 2012, 2013b, 2015a). Intelligent agents are able to recreate the behavior of pirates present in the simulation reproducing rational and emotional reactions to patrolling assets (Bruzzone et al. 2015b). The autonomous assets follow an action/reaction logic that allow them to interact with each other, thus creating a dynamic simulation (Bruzzone 2015c).

Considering the huge amount of data, interactions and information to be processed in naval operations to evaluate the effectiveness of a certain planning or strategy the simulation is a very useful tool (Bruzzone et al. 2011a, Cavallaro et al. 2007). By this approach the simulator could result able to manage and use effectively unmatched input parameters and to address the uncertainty of the scenario. In addition, the simulation is rapid, within minutes it is possible simulate days, weeks or even months of activity, allowing making multiple replications of the same scene by varying the boundary conditions to understand their influence.

Currently these models, originally developed for piracy, are under adaptation to be used in sea border protection and anti immigration operations.

2. CONCEPTUAL MODEL

The simulator proposed in this paper is called MALICIA (Model of Advanced pLanner for Interoperable Computer Interactive simulAtion). MALICIA model derived from a previous project called PANOPEA (Piracy Asymmetric Naval Operation Patterns modeling for Education & Analysis) and represent a stochastic discrete event simulator for maritime interdiction (Bruzzone et al. 2011d). In facts MALICIA is focusing on Maritime Interdiction Scenarios and could be applied to different cases from piracy to illegal immigration or anti-smuggling missions; The simulator simulates the maritime interdiction by modeling the general framework, platforms, C2 and even the specific anti-piracy operations or illegal immigration interdiction procedures. MALICIA reproduces weather conditions over wide area considering influence on sensor and platforms; the model cover fog, rain, wind, current, waves. In addition the simulator includes models of multiple assets such as MPA, Vessel, AUV, Helicopters, Submarines, Cargo, Yachts, Fishermen Boat, etc.; these entities are driven and operated by IA-CGF (Intelligent Agent Computer Generated Force) that reproduce their behavior and their interaction dynamics (Bruzzone et al. 2013c). In facts the assets simulated by intelligent agents interact dynamically each other in to recreate the dynamic simulation needed to those kind of scenarios (Bruzzone 2013a).

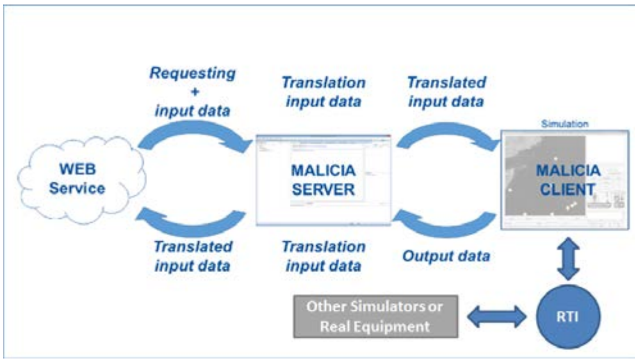

Figure 2 – MALICIA Architecture

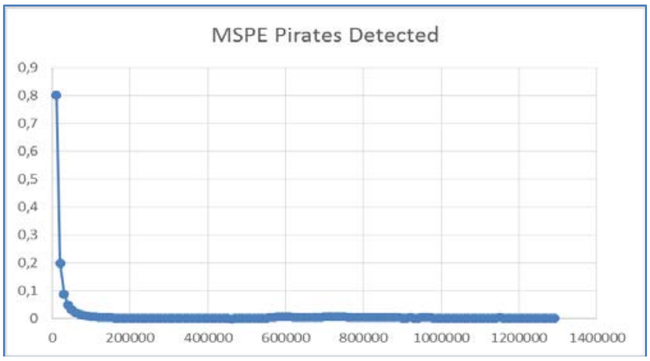

Figure 3 MSPE of Prates Detected Target Function

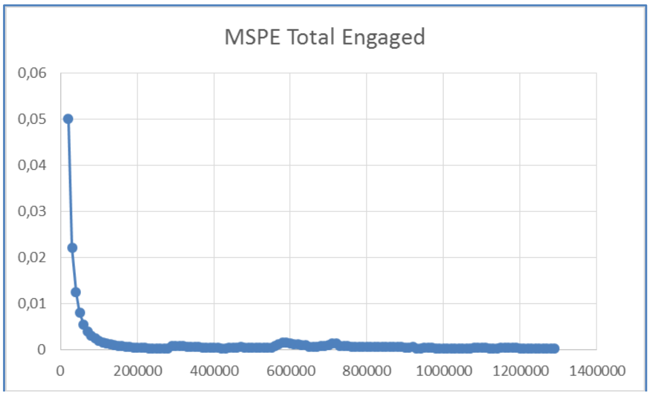

Figure 4 MSPE of Total Small Boat Engaged Target Function

The model receives the data input from web services and interacts with Tactical Naval Situation; the model includes commercial traffic, threats and false alarms. MALICIA evaluates the measures of merit as individual factors as well as overall performance covering Efficiency, Risk and Costs of the whole planning proposed by the user or generated by an intelligent decision support system (Bruzzone et al. 2006). For these reasons, MALICIA represents a useful instrument for supporting dynamic Operation Planning and Optimization. In facts the proposed approach support both the automated used in connection with optimizers as well as interactive use with decision makers refining interactively the planning based on the result of the simulator.

3. IMPLEMENTATION

MALICIA GUI (Graphic user interface) is proposed in figure 1, while the overall structure is presented in figure 2 and described in the following. The simulator is divided into two components: MALICIA Server and Client.

The Server is the component developed to establish the communications with the web services and MALICIA Client and it operates as Dbase server. The Server main tasks are receiving requests and data input from web applications especially related to the up-to-date situation of the vessels and the weather conditions; the server takes care of acquiring the input data in the correct way and to propose them to MALICIA Client and send back the results of the simulation to web services connecting MALICIA with the planning framework that uses touch screen technologies over wide board for supporting decision makers in their planning..

The Client is the real simulator elaborating input data simulating the scenario and providing the output to the Server; MALICIA is designed to be federated within an High Level Architecture interoperable federation with other models in case it should be used as part of a distributed simulation.

Indeed MALICIA is ready to be used both stand-alone and federated, as well as connected with Dbase by web services or operating on local data sets. In stand-alone mode the input data should be pre-compiled, instead when is connecting with web services the Requesting application should send the data input continuously to keep the simulator on-line with the real situation (Bruzzone et al. 2002a, 2002b).

Due to the quantity and the complex nature of input data it proposed a specific set of variables that could be also partially incomplete.

This particular solution has been adopted in order to run the simulation even in case of missing data. In this case users feeds the simulation with his available data and for the missing ones it is assume to use the standard value from a reference dbase developed and implemented by the authors based on historical data.

MALICIA Client receives as input from Dbase manager:

- Weather Conditions: actual and provided during the period of the simulation (given by a web services when is possible)
- The assets used in the simulation with a defined set of technical characteristics (e.g. name, speed, autonomy) and rules of engagement.
- Patrolling routes associated to the assets.
- A probability map of possible presence of pirate threats or illegal immigrants.
- General data about number of interactions, duration of the simulation, resolution of output data, the scenario size.

The model reproduces assets behavior during the period of simulation, taking into account their interactions and the influence of the boundary conditions. Simulation is able to run real time or fast time based on user preferences; in a complex scenario involved a dozen of assets with their resources (i.e. on board helicopters, UAV, RHIB) the simulator at fastest speed is able to cover 3 days of activity in few minutes.

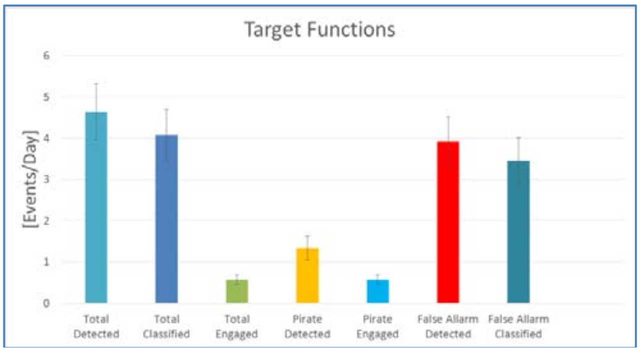

Figure 5 Events per Day for each Target Function

The simulator reproduces small-medium size boat representing commercial traffic and pirates. The assets employed in patrolling and block operations are capable to Detect (boat enters asset sensor range), Classify (distinguishes pirates from false alarms) and Engage (performs actions to intercept or neutralize menaces). Succeeding in the actions depends on onboard systems availability and reliability, influenced by the stochastic evolution of the simulation (e.g. drones not available because in maintenance, sensor failure) and by weather condition. The simulator provides detailed log about the operations such as:

- Patrolled area by the assets employed
- The tracking and operations of all the different assets and their technical-operational conditions
- A scenario general overview including the cumulative temporal distribution of the following target functions: number of false alarms, number of piracy threats, number of detections, classifications and engagements performed for each category (False Allarms, Pirates, Overall) during the time period simulated and differentiated for the different types (i.e. successfully classified, unsuccessfully classified)

4. EXPERIMENTATION

The experimental campaign is focusing on a specific set of the target functions covered by the simulator and specifically on the following ones:

- Total Small Boat Detected by the assets
- Total Small Boat Classified by the assets
- Total Small Boat Engaged by the assets
- Pirates Detected by the assets
- Pirates Boat Classified by the assets
- Pirates Engaged by the assets
- False Alarms Detected by the assets
- False Alarms Boat Classified by the assets
- False Alarms Engaged by the assets

Replicated simulations with the same initial boundary conditions, but different random seeds for the statistical distributions of the simulator have been performed. The Data have been collected every 10’000 simulated seconds for a total simulated time of 15 days (1’296’000 seconds).

In figure 3 and 4 it is proposed the analysis of the experimental error due to the pure influence of stochastic component for Pirates Detected and Total Small Boat Engaged Target Function (Balci 1998, Montgomery 2000, Kleijnen 2007, Telford 2012).

ANOVA technique have been applied and it was possible to verify and validate the target functions stabilization based on Mean Square pure Error Temporal Evolution analysis. So, Figure 5 shows the average number of events per day for each target function and the amplitude of the confidence band due to the stochastic nature of the simulation. Obviously the variance is pretty large, therefore the values and results result consistent with the fidelity requirements for being applied to maritime interdiction planning.

CONCLUSIONS

Maritime interdiction has evolved along last years and the recent immigration issues are emphasizing the importance to improve efficiency and effectiveness of these operations. MALICIA simulator, described in the paper, represents a good example of interoperable, strongly reliable Modelling and Simulation approach to support planning. The simulator has been validated through the experimental campaign and the results proposed demonstrate its potential.

The analysis are conducted on simulations confidence band, the results validate the simulator, showing a good convergence of the MSPE after the second simulated day. The positive results show the potential of these types of simulations applied to maritime interdiction and the possibility to integrate it with intelligent planning optimization tools. The simulator in this case would be elaborating and testing the proposed planning to support decision making process. Currently the authors are developing a tailored configuration to address sea border protection.

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Author's index