THE 21TH INTERNATIONAL CONFERENCE ON HARBOR, MARITIME & MULTIMODAL LOGISTICS MODELLING AND SIMULATION

SEPTEMBER 18 – 20, 2019
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We are honored and pleased to welcome you to The 21st International Conference on Harbour, Maritime & Multimodal Logistics Modelling and Simulation taking place in Lisbon, Portugal.

Although its long tradition, still today this conference is particularly timely in view of the tremendous importance of industrial logistics, multimodal transportation, supply chain management and Logistics within the current economical and scientific framework. This is even truer considering that improvements in the aforementioned sectors are essential in many economic activities and therefore with high application potentials.

With this in mind, we believe that the scientific program provides a special opportunity for academic scientists, researches, industry representatives, engineers and other representatives to exchange experience, gain new knowledge and establish contacts.

This year, we are particularly proud of the quality of the works that have been selected for publication encompassing high impact research achievements. Promising approaches based on optimization algorithms, simulation, heuristics, agent-based modeling, extended reality, conceptual modeling and many others are accurately presented guaranteeing that taking part in the forthcoming conference provides excellent opportunities for all stakeholders to learn from each other's practice and to shape future research directions.

At this point in time we ought to express our gratitude on all the people that have so hardly worked on putting the conference together. Thank you to all the people who have worked to plan and organize both the technical program and the social arrangements. Most of all, thank you to the authors for their outstanding contributions.

We wish all a fruitful and memorable time in the breathtaking city of Lisbon.

Agostino Bruzzone,
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EXAMINATION OF LOGISTICS SYSTEMS OF CONCENTRATED SETS OF URBAN DELIVERY POINTS BY SIMULATION

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ABSTRACT

In the field of logistics, the examination of urban concentrated sets of delivery points (e.g. shopping malls or markets) is an important, new area. In these sets, there is a relatively large number of stores with significant goods traffic, which generate significant customer traffic, air and noise pollution, while their logistics systems are not properly designed. Despite all this, city logistics research does not specifically target this field, there are no models that can be used to examine any kind of urban concentrated sets of delivery points. Earlier, only few subsystems have been examined, so we started to study and model the concentrated sets of delivery points generally. As a first step in our research project, we collected data about concentrated sets of delivery points, and this data made it possible to start the simulation modelling and to develop new solutions.

Keywords: logistics, city logistics, modelling, simulation

1. INTRODUCTION

Earlier, several researchers worked in the field of simulation modelling of urban logistics systems. In a paper from 2015, 31 city logistics models were examined and evaluated (Anand, Van Duin, Quak and Tavasszy, 2015). The results of this study gave us a useful input for modelling. In the review, the selected models were evaluated based on four factors of the review framework: stakeholders, descriptors, objectives, and solution approach. Based on the conclusions of this paper, there are several possibilities to develop the examined city logistics models. They note that the dynamic nature of urban freight systems and the variation of the presented problems make it difficult to create a standard framework for urban freight transportation modelling, so we need to develop a new model for the actual problems.

Since the area under study is complex, its different subsystems should be examined by simulation modelling separately. For example, we can examine only the restaurants, whose goods should be handled in a separated logistics system, like in the case of a research project from Vienna, Austria (Fikar and Gronalt, 2018). Another possible research field is the urban supply system of fruits and vegetables. In the case of Teheran, Iran, this system was examined and redesigned by use of modelling methods (Saeedi, Teimoury and Makui, 2018). We have chosen a bigger urban logistics subsystem for our research topic: we examine the current and possible future city logistics system of concentrated sets of urban delivery points with use of mathematical and simulation models. *This research field is very important because of the possible significant savings and due to the lack of the general mathematical and simulation models which could be used generally for examination of these sets.* We started this research projects in 2015.

1.1. Urban concentrated sets of delivery points

The urban delivery points can be divided into two main groups for our research (see on Figure 1). There are single delivery points and concentrated sets of delivery points (referring to CSDP). *The concentrated sets of delivery points are sets including multiple single delivery points grouped together according to some given aspect.* In the case of them the density of the delivery points is very high in a relatively small area.

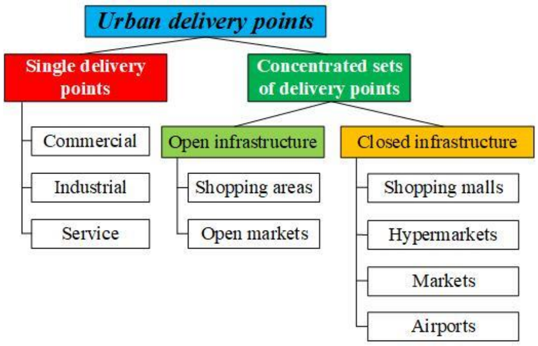

Figure 1: Groups of urban delivery points

The examined sets can be characterized by two main types of concentrations.There are concentrated sets of delivery points with open and closed infrastructure. *In case of open infrastructure, the road transportation infrastructure (roads, squares) provides the borders of the examined concentrated set of delivery points.* This can be noticed in case of a shopping area bordered by roads or a market bordered by a square. *In case of closed infrastructure a given building provides clearly defined boundaries of the examined concentrated set of delivery points.* This can be noticed in case of shopping malls or in case of the duty free area of airports.

As it can be seen on Figure 1, there are several subgroups in the two main group of CSDPs. The shopping areas have the most opened infrastructure, in their case, there are densely located single delivery points in an open urban area, and we can assign them to a CSDP based on their proximity. In a similar, but more compact way can we assign delivery points to a set in case of open markets. The stores of shopping malls, markets in buildings, hypermarkets and airports can be assigned to a set based on their connection to a given building and to its owner.
In our research project, we primarily examined Budapest, where we can notice all the subgroups. There are several shopping malls (see on Figure 2, with borders of the city and the main roadsó), hypermarkets, markets (both with open and closed infrastructure), a significant shopping area and an international airport.

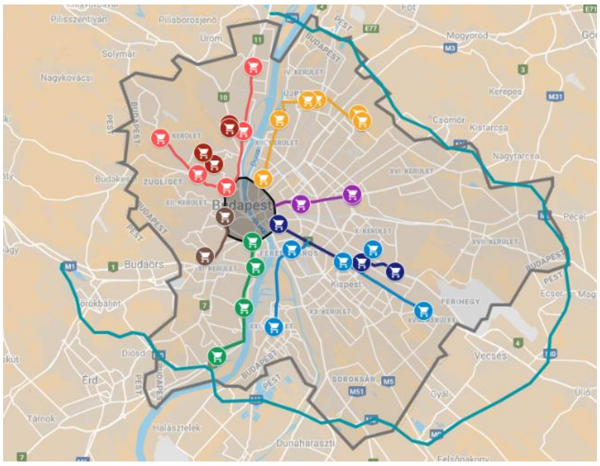

Figure 2: Shopping malls in Budapest on Google Maps

Despite the significant goods traffic of these concentrated sets of delivery points, few research projects have examined their complex city logistics systems directly. Indeed, in their design phase the sizing, optimization and simulation of their logistics systems are neglected, they deal primarily with the aspects of shopping flow, so to develop models for the sizing and simulation is going to be a very important task. Research in this field mostly deals with some given elements of these logistics systems, and not with whole complex system. One of these studies examines the common optimization of the location of shopping malls and logistics centres (Yang and Moodie, 2011), omitting the shopping areas or markets from the model. Another known study also deals only with the shopping malls, highlighting the use of their loading bays and evaluating the impacts of new solutions (Chiara and Cheah, 2017). City logistics issues related to airports were also specifically examined in a research project (Boloukian and Siegmann, 2015), and several studies analysed consolidation centres or cross docks alone.
In some European cities, there are urban logistics systems that serve given CSDPs, mostly shopping areas. For example, in Bristol, Great Britain, the Broadmead Freight Consolidation Scheme system serves 63 stores of the shopping area in the city center. By implementing this new system, the number of delivery transactions was reduced by 75% and in the examiend period the CO_2 emission was reduced by 22.5 tons (Hapgood, 2009). Similar systems are operating in Padova and Lucca in Italy, and in Nijmegen and Utrecht in the Netherlands.
In the case of CSDPs with closed infrastructure, we can only examine some existing and documented systems. A city logistics project serves the processes of Heathrow Airport in London, Great Britain, where this gateway-concept based city logistics system is a significant element of their sustainable transportation plan (Matthews, 2014). We would like to highligt the Franprix system from Paris, France, where the shops of a supermarket chain are served by cargo ships. In this system, the cargo ships deliver the goods in containers from a consolidation center to the supermarkets in the city center (Janjevic and Ndiaye, 2014). The delivery points in this system are not CSDPs (according to our definition), but it is possible to implement this solution for CSDPs as well.
Since only a few subsystems of this complex logistics system have been studied in the past, we chose to study the concentrated sets of delivery points generally. This is a very important task to make the examination and the simulation of the city logistics systems of CSDPs possible for future projects. Our main purpose was to develop general mathematical and simulation models, which can help us to examine any type of CSDPs, and to show the possible savings and emission reductions in multi-stage logistics systems.

1.2. Characteristics of the examined CSDPs

In the first phase of our research project, we needed to collect data about the logistics characteristics of the examined CSDPs to provide input data for the simulation. Previously, we assumed that the examined stores handle relatively large amounts of goods arriving in mostly smaller quantities and vehicles. Between 2015 and 2018, we collected data about 490 stores from four CSDPs (3 shopping malls and 1 shopping area). For the data collection, we used our own research methodology with an exploratory and a descriptive research part. In the exploratory part, we performed a field study, an expert interview and the examination of the bylaws. In the descriptive part, there was a complex questionnaire with 31 questions about the general properties of the stores, the delivery parameters, storage parameters, properties of inverse logistics and home deliveries, IT system and their main aspects for joining to a new, gateway-concept based city logistics system (Mészáros, Sárdi and Bóna, 2017).
Based on our results, in the current logistics system the delivery transactions are not synchronized (except in case when multiple stores use the same logistics provider), and this results that the sizable amount of goods is delivered in small parts and the utilization of the vehicles (which are mostly passenger cars and lorries) is low, so our earlier assumptions were proven right. For 420 stores of 4 CSDPs, this means 0.67 daily delivery transactions (244 yearly delivery/store and 119,568

delivery/420 store). In these deliveries, the stores handle nearly 3,000 boxes daily, approximately 200 pallet unit loads, 2,700 clothes hanger units and 1,000 other units (N=330). This means 60 t of goods per day (24,000 t per year) for them, and now we examined only responder stores from 4 CSDPs. Based on these results, the amount of goods is significant, but we assume that t the logistics processes could be more effective with new organizational solutions.
It was also important to collect information about the main aspects of the storeowners for joining to a new system and these results of the questionnaire showed us a direction for the next steps of the research. It can be seen on Figure 3 that stores who would like to join to a new system considered the emission reduction to be of higher importance than the financial and reliability aspects. In a five-point rating scale this means a willingness of 3.15, which is nearly equal to the medium value of 3. In case of urban transport this value is 3.04 and all the other aspects are under 3, reliability is the less important aspect for the responding storeowners (average value 2.51). On the figure dark green means that the given store definitely would like to join, in case of yellow the given aspect is neutral for the responding storeowner and red means that the completion of the given aspect absolutely won't make them to join to a new system.

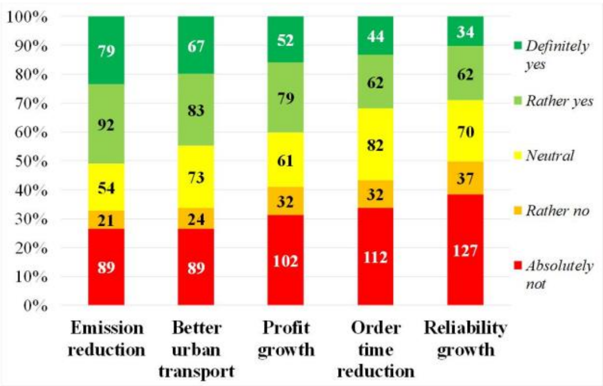

Figure 3: The importance of different aspects of examined stores (N=336)

The described results of the data collection showed us that the suspected problems in the examined city logistics system are real, but green logistics aspects are important for a significant share of the stakeholders. In case of new systems, it is going to be significant to reduce the emissions and make the city logistics processes more sustainable, because it seems to be also important for the storeowners.
In the next steps of our research, we needed to fix the structure of the current system based on the collected data and to develop new system concepts too.

2. THE EXAMINED LOGISTICS SYSTEMS

For the modelling, we had to specify the structure of the current logistics system, and to develop the structure of the possible future system concepts, to be the basis of developing the mathematical and the simulation model. We developed two main, gateway-concept based new concepts to model and simulate, and some other concepts as well.

2.1. Current city logistics system

We created the structure of the current city logistics system of the concentrated sets of delivery points based on the processes of the earlier examined 4 CSDPs (3 shopping malls and 1 shopping area in Budapest). The current structure can be seen on Figure 4 (this structure was desribed in our simulation model). To desricbe, model and simulate the current logistics system was an important task in our project, because of the validation of the models of the new concepts and in the evaluation phase it is generally a better solution to compare models with models.

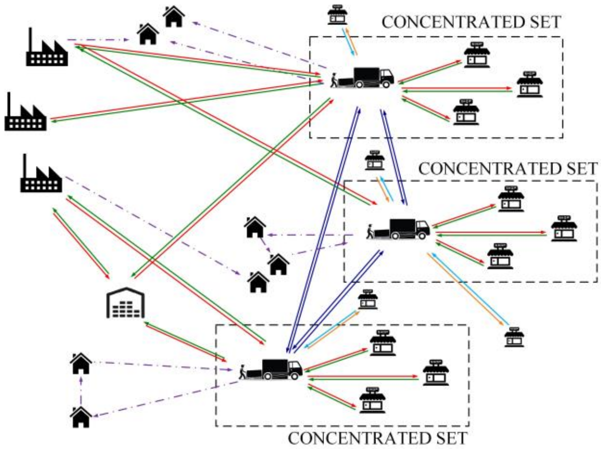

Figure 4: Current city logistics system of CSDPs

As we can see, in case of CSDPs, we have several stakeholders. The goods are delivered from the suppliers to the logistics area (or common loading area in case of open infrastructure) of the CSDP directly or via a logistics centre. The deliveries are mostly FTL organized because of the bigger amounts, but in some cases (e.g. in case of logistics providers) there are LTL organized transactions too. From the loading area, the employees of the suppliers or the stores move the goods to the store or to its storage. On the inverse way, they handle the empties (e.g. empty pallets), the return goods, and the goods, which must be delivered to service. We have in this system home deliveries from the suppliers and from the stores of the CSDPs too, and we have deliveries between stores of different CSDPs or between single delivery points and stores of CSDPs too (Sárdi and Bóna, 2017).

2.2. New city logistics system concepts

In our research project, we developed gateway-concept based, multistage city logistics systems. In the basic concept, we place a consolidation centre (referring to CC) between the suppliers and the CSDPs (this is the first gateway), where we can consolidate the delivery transactions. Suppliers can deliver directly to the CC, and it can have also an inventory handling role, which makes it possible for the suppliers to have less delivery transactions with bigger amounts. At the CSDPs, we replace the logistics and loading areas with cross-docks (these are the second gateways, referring to CD). We can organize this system even in more stages with having second and third gateways too, e.g. in the case of shopping areas with use of CDs and common loading bays. In this concept, we deliver from the CC bigger amounts in bigger vehicles to the CDs, where we have cross docking (short term storage, e.g. to make night deliveries easier). For these consolidated deliveries, green lorries or cargo trams could be used in the same structure (see on Figure 5). In the second case, naturally we need side-tracks to the CSDPs (Sárdi and Bóna, 2017). In this new structure, we can organize home deliveries from the CDs in round trips. In this case, the goods to be delivered are prepared in the CC to special units; they can be directly delivered to the customers from the CDs after transshipment, so the number of tasks of store workers will be also reduced.

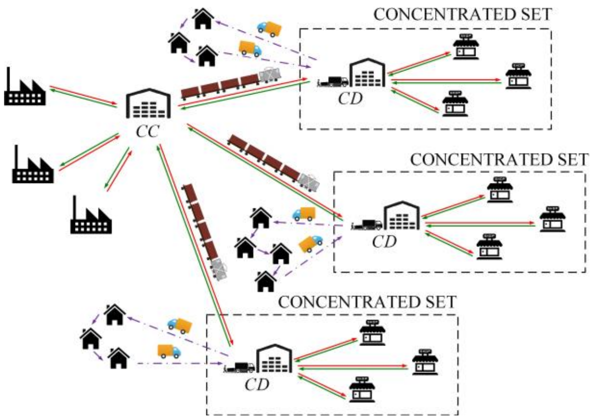

Figure 5: New city logistics system concept by use of cargo trams for CSDPs

We developed some other system concepts in our research, which are not modelled yet, but it is an important future challenge to examine them by simulation as well. For example, we can use cargo ships in a similar structure, where we deliver from the CC to transshipment points at the river, and from them we deliver by road vehicles (cargo bikes, lorries) to the CDs of the CSDPs, as it can be seen on Figure 6. In this system, we can load the road vehicles of the last mile deliveries in the CC and deliver them by ship to the transhipment points. In these gateway-concept based solutions we can combine the use of cargo bikes even with lorries, cargo trams or cargo ships too, e.g. for the deliveries between stores of CSDPs or for home deliveries. It is also possible to use them for delivery transactions with smaller amounts (for example if they get the goods from lorries at a transshipment point). In this solution, the transshipment point could be on an inner ring of the city in a radial city structure, and the cargo bikes could serve the CSDPs via the "rays" of the city (Sárdi and Bóna, 2018). It is also imaginable to use the metro lines or drones in similar city logistics concepts.

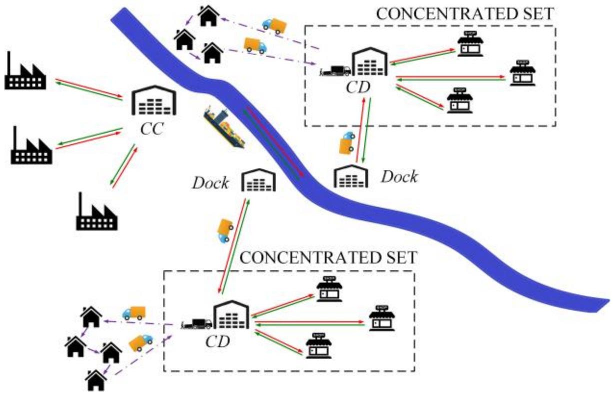

Figure 6: New city logistics system concept by use of cargo ships for CSDPs

3. MATHEMATICAL AND SIMULATION MODELLING

After describing the examined system structures, we modelled the current system and the two basic future concepts (the concepts where we deliver from the CC to the CDs in lorries or in cargo trams). The first step of the modelling was to develop the mathematical model of the logistics processes and the cost structure, both for the current system and the two new concepts. This was followed by developing a mesoscopic level simulation model in MS Excel for all examined solutions, based on the mathematical models. After all this, we developed the topological model of the shopping areas because of their specialties, to make it possible to examine the open infrastructure CSDPs. In our models, 30-day long periods are handled.

3.1. Mathematical modelling

The mathematical model was developed based on the presented results of the data collection phase and the described system structures (Sárdi and Bóna, 2019). The resulting mathematical model describes all main properties of the examined city logistics processes for a one-month period and describes exactly the operation of the simulation model. In this section, we are presenting the main components of the mathematical model both for the model of the current and the new system. In the mathematical formulas, "i" means the examined delivery transaction, "j" is the given day, and "l" is the given hour of the given day.

The basis of the model (both in the model of the current system and in the model of the new concepts) is the delivery generator, which specifies the actual delivery time on the actual day, if the given delivery transaction is realized. In the current system, we have one generator at the suppliers and for the new concept, in addition to this, there is another generator at the consolidation centre, which generates the deliveries to the CDs (according to the demands of the stores). The first component of the generator in the current system can be seen in Equation (1). Here, $x_{i,j}$ is the variable, which shows us whether the given transaction is realized on day no. „j" or not (this belongs to a given store, but to one store more transactions and variables can belong).

$N_i^{sup\_day}$ gives us in this formula the maximum number of monthly delivery days, $r_{i,j}$ is a random number between 0 and 1 with uniform distribution, and q_i is the probability parameter of the examined transaction.

$$x_{i,j} = \begin{cases} 0, \text{if } \sum_{k=1}^{j-1} x_{i,k} = N_i^{sup\_day} \\ 0, \text{if } x_{i,j} - 1 = 1 \text{ and } N_i^{sup\_day} < 7 \\ 0, \text{if } \sum_{k=1}^{j-1} x_{i,k} < N_i^{sup\_day} \text{ and } r_{i,j} \geq q_i \\ 1, \text{if } \sum_{k=1}^{j-1} x_{i,k} < N_i^{sup\_day} \text{ and } r_{i,j} < q_i \end{cases} \quad (1)$$

The second component of the delivery generator gives us the specific times of the transactions (more than one transaction per day is possible in the model) in the given day, if $x_{i,j}$ has the correct value, as it can be seen in Equation (2). Here, $R_{i,j}^l$ is a random number between 0 and 1 with uniform distribution, Q_i is another probability parameter of the examined transaction, $N_i^{max(day)}$ and $N_i^{max(month)}$ are the daily and monthly maximum number of transactions, $TW_i^{SH(LL)}$ and $TW_i^{SH(UL)}$ are the lower and upper limit of the time window of the examined store.

$$x_{i,j}^l = \begin{cases} 1, \text{if} \begin{cases} x_{i,j} = 1 \\ TW_i^{SM(UL)} \leq k \\ TW_i^{SM(LL)} \geq k \\ \sum_{k=1}^{l-1} x_{i,j}^k < N_i^{max(day)} \\ \left[\begin{array}{c} \sum_{h=1}^{j-1} \sum_{g=1}^{24} x_{i,h}^g + \\ + \sum_{k=1}^{l-1} x_{i,j}^k < N_i^{max(month)} \end{array} \right] \\ R_{i,j}^l < Q_i \end{cases} \\ 0, \text{otherwise} \end{cases} \quad (2)$$

After generating the variables of the delivery transactions, the model generates the goods amount (weight and volume), calculates the sum delivery distance, the delivery performance, the fuel consumption (and electric energy consumption in case of cargo trams), and the emission (for five examined pollutants: CO, CO_2, NO_X, PM, HC). We calculate the performances and the emissions linearly from the distance. In Equation (3), the distance between the suppliers and the CC can be seen, where we handle so called "merged transactions", because of the inventory-handling role of the centre. As it can be seen in Equation (3) adjacent, the distance between the two examined points is given as input data. From this calculated distance, we can linearly calculate the delivery performance based on the goods weights. This indicator can be seen in Equation (4). The consumptions and emissions can be calculated from the distance in a similar way, from given specific parameters.

$$S_{i,j}^{land,CC} = \begin{cases} s_i^{land(l)}, \text{if } x_{i,j}^{CC} = 1 \\ 0, \text{otherwise} \end{cases} \quad (3)$$

$$Q_{i,j}^{land,CC} = S_{i,j}^{land,CC} \cdot M_{i,j}^{CC} \quad (4)$$

In our research, we modelled the empties handling as the inverse of the deliveries. In these processes, the vehicle, which performs the delivery transaction, delivers the empties (e.g. empty pallets, empty compartments) back to the supplier. After analysing the data we collected earlier, we concluded that the return goods deliveries and the service deliveries are rather sporadic processes with small amounts. Therefore, in a mesoscopic level for a one-month long period we don't need to integrate them to our model, and we can assume there is capacity for handling them in the empties handling process because of the small amounts.

At modelling the home delivery transactions, we use VRP (Vehicle Routing Problem) estimation formulas for calculating the number of round trips and the sum distance. We chose the Clarke&Wright formulas for a circle area, because of the approximately round shape of the primarily examined Budapest and other big cities. We modelled the home deliveries both in the current and in the new system with lorries, assuming an LTL organized system. Then (in the new system, for one given CSDP), the sum estimated distance of the home deliveries in one day can be seen in Equation (5). Here, $J_j^{hd\_CSDP}$ is the minimum number of home delivery round trips from a CSDP, $L_j^{in\_out}$ is the distance from the CD to the served area and back, and L_j^{area} is the sum distance inside the served area, between the home delivery points.

$$S_j^{hd\_CSDP} = J_j^{hd\_CSDP} \cdot \left(L_j^{in\_out} + L_j^{area}\right) \quad (5)$$

These two distance parameters are given by the Clarke&Wright VRP estimation formulas, based on different conditions about the maximum number of home delivery points per trip. For example, if the empirical condition is met (in case of a circle area), Equation (6) gives us the sum distance inside the examined territory. Here, $A_j^{hd\_CSDP}$ is the surface of the served area (in km^2), , $N_j^{hd\_CSDP}$ is the sum number of requested home delivery transactions of the CSDP, and $C_j^{hd\_CSDP}$ is the average number of home delivery points to be served in one round trip.

$$L_j^{area} = 0{,}680 \cdot \sqrt{A_j^{hd\_CSDP} \cdot N_j^{hd\_CSDP}} \cdot \frac{C_j^{hd\_CSDP}}{N_j^{hd\_CSDP}} \quad (6)$$

At the home delivery processes, the mathematical model also describes the fuel consumption and the emissions, and with this all, we realized the mathematical model for all delivery processes.

In the new system, for the model of the consolidated deliveries, we needed to define the necessary number of consolidated deliveries per CSDP in the examined day. This is given by Equation (7) for road vehicles, and it is similar for cargo trams. Here, $C^{sup\_CC\_road(m)}$ and $C^{sup\_CC\_road(m)}$ are the capacity parameters of the delivery vehicle in weight and volume, M_j^{CSDP}, and V_j^{CSDP} are the sum demand of the examined set for examined day in weight and volume, and r^{road} is an average utilization factor for the vehicle.

$$N_j^{CSDP} = \left\lceil \max\left\{ \frac{C^{sup\_CC\_road(m)} \cdot r^{road}}{M_j^{CSDP}}; \frac{C^{sup\_CC\_road(V)} \cdot r^{road}}{V_j^{CSDP}} \right\} \right\rceil \tag{7}$$

The mathematical model also describes the main inventory points of the system; these are the supplier sites, the consolidation centre and the stores (and their storages). We modelled backlog handling only in case of the CC, while in all other cases the unsatisfied demands were lost. In all inventory points, the model generates for every delivery transaction an opening stock and a safety stock. As an example, Equation (8) gives us the stock at the supplier site, for delivery transaction no. "i" on day "j". In this model, the stored goods amount is added to the closing stock of the last day, and the amount of delivered goods in the given day is subtracted. The stock amount is not allowed to be less than zero in the model.

$$K_{i,j}^{SUP} = \max\{K_{i,j-1}^{SUP} + M_{i,j+1} - M_{i,j}; 0\} \tag{8}$$

The opening stock for the supplier sites is given by Equation (9), based on the basic safety stock-model, where U_i^{SUP} is the safety factor of the given supplier (calculated based on the distribution and generally with 95% reliability), and $D(M_{i,j})$ is the standard deviation of the goods to be delivered. Over the safety stock, the opening stock covers the demands of the first three days (this is an experimentally set parameter) and the lead times (delivery times) are constant 1 days with 0 standard deviation.

$$K_{i,0}^{SUP} = U_i^{SUP} \cdot \sqrt{D(M_{i,j})} + \sum_{k=1}^{3} M_{i,k} \tag{9}$$

In addition to all of these, the mathematical model describes the necessary loading time at the suppliers, in the CC, in the CDs (logistics areas) and in the stores. It also generates the customer demands and the home delivery share (in percentage of the customer demands), based on the expected demands and the expected share. With this all, we developed the full mathematical model of the current and the new city logistics system of the CSDPs of delivery points (Sárdi and Bóna, 2019).
For the examination of all significant parameters, the mathematical model of the cost structure of the examined systems was needed to be developed. This cost model was prepared in a former phase of our research project, where we described the costs in linear structure, grouped by cost centres and process types (Bóna, Róka and Sárdi, 2018). In the examined logistics system, the cost centres are the supplier sites, the delivery routes, the cross docks (logistics and loading areas in the current system), the internal material handling routes and the stores (with their storages). In the current system there are delivery routes between the suppliers and the CSDPs, while in the new system separately between the suppliers and CC and between the CC and the CDs of the CSDPs.
In the examined cost centres, there are five main process types: loading, storage, delivery, intralogistics operation and administration processes. Based on this structure, the cost parameters can be represented and simulated in a three-dimensional structure. As an example, on Figure 7 the simulated monthly logistics costs of five companies from three CSDPs can be seen. On the figure, dark green means the lowest and red means the highest cost values, and we can see the costs of given companies, in given processes and in given cost centres.

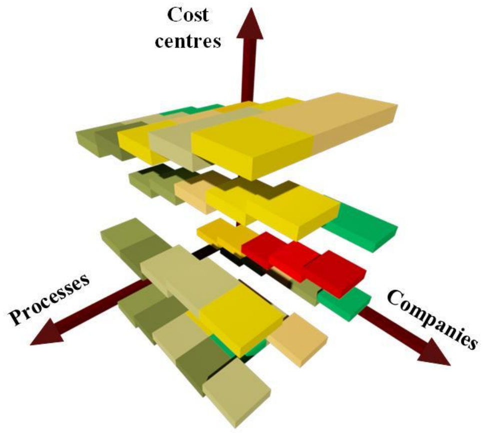

Figure 7: Representing logistics costs of the stores of a CSDP in a 3D structure

After developing the mathematical model of the processes and the cost structure, we developed the simulation model.

3.2. Simulation modelling

The mesoscopic simulation model of the examined city logistics systems was developed based on the presented mathematical model, in MS Excel (Sárdi and Bóna, 2017). We have chosen Excel for the modelling, because as a first step we could build the current and the new systems relatively simply, by use of functions (mainly random generators) and visual basic-based macros. This MS Excel-based simulation model is a discrete event simulator, where the departure and arrival of the delivery transactions and the appearance of demand give us the discrete events to be handled.
The simulation model maps the entire mathematical model for the current system and for the new system concepts. Its basics are random number generators, which are generating the parameters of the transactions (customer demands, deliveries, empty handling, home deliveries) based on the statistical properties of the distributions.

3.2.1. Simulation model of the current system

The simulation model has two main components. The first component (an Excel-workbook) describes the current logistics system and it generates the different parameters on different worksheets, the second (another

Excel-workbook) examines the processes of the new system concepts.
In the tables of the given worksheets one transaction belongs to one row, which is defined by a CSDP ID (on Figure 8 it is a shopping mall ID), a supplier ID, a store ID and an SKU ID. The columns are given by properties of the transactions and the days of the examined month, as you can see it on Figure 8.

	A	B	C	E	F	G	H
1	Transport informations						
2	Mall ID	Supplier ID	Shop ID	Opening stock	1	2	3
3	SM001	SUP0001	SH0001	4,8	4,8	4,8	4,8
4	SM001	SUP0002	SH0002	43,1	17,1	17,1	33,1
5	SM001	SUP0003	SH0003	47,1	47,1	47,1	44,1
6	SM001	SUP0004	SH0004	264,1	298,1	308,1	275,1
7	SM001	SUP0005	SH0005	69,4	69,4	21,4	71,4
8	SM001	SUP0006	SH0006	849,6	849,6	72,6	72,6
9	SM001	SUP0007	SH0007	374,4	60,4	=MAX(0;I	60,4
10	SM001	SUP0008	SH0008	361,7	366,7	391,7	388,7
11	SM001	SUP0009	SH0009	23,4	20,4	20,4	10,4
12	SM001	SUP0010	SH0010	140,9	43,9	43,9	43,9
13	SM001	SUP0011	SH0011	2542,1	2778,1	2869,1	2203,1
14	SM001	SUP0012	SH0012	663,6	844,6	1075,6	992,6
15	SM001	SUP0013	SH0013	44,1	193,1	416,1	416,1

DAILY WEIGHT | DAILY VOLUME | SUP MAT HAND (T) | SUP STOCK (W) | STARTING POINT | DISTANCE (C) | DISTANCE (L) | PERFORMANCE (C)

Figure 8: Calculation of the suppliers' stock parameters in the simulation model of the current system

In the case of some parameters (delivery transactions, goods amount, performances) in the current system, the processes needed to be handled per hour, as it was possible to have the same delivery transaction more than once in a day, with different parameters.

3.2.2. Simulation model of the new system concepts

The second component of the simulation model (its other workbook) describes the processes of the new system concepts. Between the suppliers and the CC, it handles the processes similarly to the current system, the different transactions can be found in different rows. It generates all parameters by stores, suppliers and days on different worksheets, and it generates the actual demands of the stores and the amount to be delivered in the same way.
In the case of the consolidated deliveries from the consolidation centre, the simulation model handles all processes consolidated by CSDP and SKU ID, so we can see the processes by the examined CSDPs and days, still on different worksheets, as it can be seen on Figure 9.

	A	B	N	O	P	Q	R	S	T	U
1			Daily deliveries/shopping mall [kg]							
2			12	13	14	15	16	17	18	
3	SM001	SKU001	28485,3	28102,3	27232,9	28942,5	20341,3	26250,0	31589,1	25404
4	SM006	SKU001	11520,3	21571,4	8108,9	21077,4	8060,7	23252,3	5494,2	5457
5	SM018	SKU001	6836,2	10018,4	13606,2	12309,7	13004,7	14163,4	12472,7	11071
6										
7			Daily deliveries/shopping mall [m³]							
8			12	13	14	15	16	17	18	
9	SM001	SKU001	112,7	135,7	102,1	115,5	79,7	112,3	142,2	121
10	SM006	SKU001	72,6	95,4	76,4	88,2	56,5	79,7	39,9	48
11	SM018	SKU001	57,9	83,2	99,5	80,0	113,8	121,2	110,1	100
12										
13			Count of deliveries/shopping mall/day (road vehicle)							
14			12	13	14	15	16	17	18	
15	SM001	SKU001	4	4	4	=KEREK	3	4	5	
16	SM006	SKU001	3	3	3	3	2	3	2	

HOME DEL DEM (W) | HOME DEL CC-SM (W) | CC-SM DELIVERIES | DISTANCE (C) | PERFORMANCE (C) | CONSUMPTION (C) | EMISSION (C)

Figure 9: Calculation of the number of consolidated deliveries in the simulation model of the new system

To calculate the number of deliveries for each CSDP is one of the most important components of the simulation model of the new system concepts. The simulation model handles the same time (on the same worksheets) the deliveries by lorries and by trams and generates the parameters for each of them.

3.2.3. The simulation process

After developing the simulation model in MS Excel both for the current system and for the new concepts, it was validated and verified based on the goods amounts in the delivery, empty handling, and home delivery processes, and the experiment design and simulation runs were automated. The simplified process of the simulation runs can be seen on Figure 10.

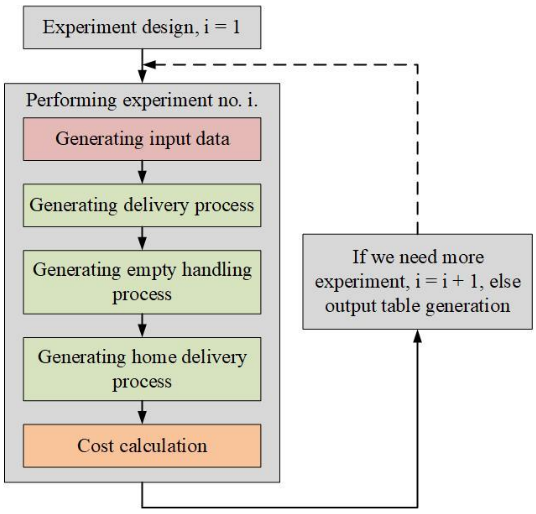

Figure 10: The simplified simulation process

We can declare that the developed mathematical model and the simulation model structure are general, we can examine all types of the CSDPs by use of them. In former city logistics projects, this kind of general device was gravely missing.

3.3. Modelling specialties of shopping areas

In case of the CSDPs with closed infrastructure, the floor map of the given building gives us the area where the processes can be examined; the internal routes can provide the material handling distances, the time values etc. In the case of open infrastructure, primarily at shopping areas, a more extensive area must be examined, where there are lots of stores, loading areas, cross docks, there are several special road traffic regulations and more external connections with the transportation infrastructure. Because of these, we need a different approach to the modelling, and the topological model of the examined area is needed to be developed, in addition to the existing mathematical and simulation model. This can make it possible to examine the routes, distances and time values, and in the future, it is going to help to integrate e.g. location search algorithms into our simulation model.
The first step of the topological modelling was to develop the data structure, which can provide the city logistical

topological model of shopping area after appropriate data collection. The frame of this data structure is defined by the graph of streets and nodes in the area. The edges of the graphs are the urban roads (so the road infrastructure) and the nodes are the contact points or breakpoints of the roads. In this model, several objects and their attributes had to be defined with considering both the current and possible future logistics solutions. In the topological model of a shopping area, the following objects are handled: roads, nodes, urban railways, railway nodes, bus stops, waterway docking points, commercial and service stores, accommodations, store-groups, brownfield lands, parking areas, connecting points of the transportation subsectors and barriers. They have several properties, e.g. size, capacity and coordinates. In this data structure, the roads are in the centre of the model and the other objects are assigned to them.
After developing the topological model, we performed data collection for a shopping area in Budapest. For this, several public online databases were used, and on-site data collection was performed too. The results of the data collection can be seen on Figure 11. This topological model makes it possible to implement the models for shopping areas, therefore this is a critical element for our future research.

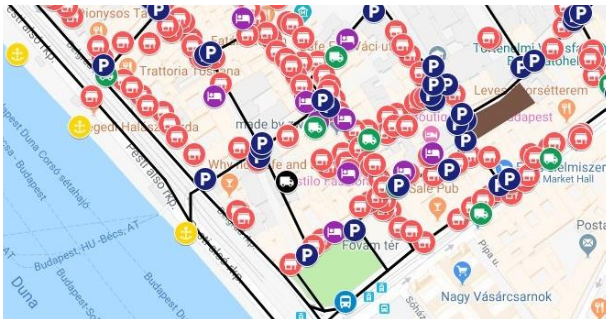

Figure 11: Topological model of a shopping area in Budapest, on Google Maps

In the next section, we are going to present the results of the simulation runs for three shopping malls, but we started to examine with this model shopping areas too.

4. RESULTS OF THE SIMULATION

In the simulation, the processes of 178 stores from three shopping malls were examined; their data (from the data collection phase of the project) was the most detailed and most exact (Sárdi and Bóna, 2017). After experiment design, we performed 100 experiments for all system concepts. This number of experiments proved to be sufficient to make conclusions about the examined parameters with 95% reliability.

4.1. Performance and emission in the current system

Based on the results of the simulation, in the current system in one month (for 178 stores of three malls in Budapest), the sum amount of goods is 1,346.1 t (st. dev. 31.8 t, min. 1,275.7 t, max. 1,427.1 t). This generates 44.8 t of empties to be handled (st. dev. 0.4 t), and 54.1 t of all the good must be delivered to homes (st. dev. 2.3 t) from the shopping malls. So, in the current system there are monthly 3,396.7 delivery transactions to the malls (st. dev 16.5, min. 3,360, max. 3,451) and all of them have an inverse version (with or without empties to be handled). In addition, there are monthly 4,097 home delivery transactions in the examined system (st. dev. 72.8, min. 3,952, max. 4,250).
During these transactions, the vehicles need to go 635,385 km, which generates monthly 3,132.2 l petrol, and 37,253.1 l fuel oil consumption. This consumption generates high emissions. As an example, the CO_2-emission is 7.11 t monthly and the NO_x-consumption over a month 14.3 kg for 178 stores. During the delivery and empties handling tasks, the sum delivery performance is 152,851.7 tkm in the current logistics system.

4.2. Performance and emission in the new system

The current system can be compared with the two examined, gateway-concept based solutions based on the results of the simulation runs.
In the new concepts (based on the experiments), the modelled goods amount is 1,356.2 t between the suppliers and the consolidation centre (st. dev. 77 t, min. 1,173.4 t, max. 1,611.0 t). Between the CC and the stores, 1,338.1 t goods are delivered (st. dev. 41.5 t, min. 1,241.2 t, max. 1,435.2 t), based on the experiments. The difference between the expected values comes from the independent experiments and from the independent random number generation. In case of empties, we deliver 43.9 t (st. dev. 2.7 t) and 47.4 t (st. dev. 1.6 t) on the two main section of the delivery routes, and there is monthly 49.8 t (st. dev. 3.7 t) of home delivery goods in the modelled new system.
These amounts are generating 1,338.9 delivery transactions per month between the suppliers and the CC (st. dev. 16.7, min. 1,305, max. 1,380). Between the CC and the CSDPs, there are monthly 268.7 consolidated transactions by lorries (st. dev. 6, min. 255, max. 283) or monthly 123.1 transactions by trams (st. dev. 3, min. 115, max. 130), if 90% average utilization rate is expected. The comparison of the number of transactions can be seen on Figure 12.

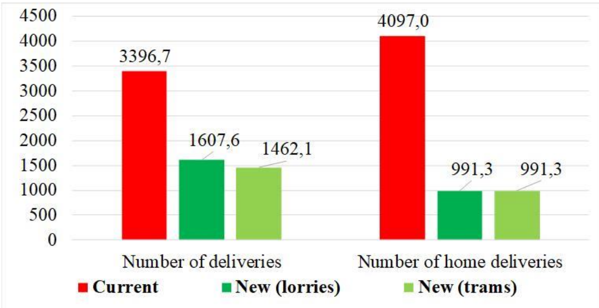

Figure 12: The number of delivery transactions

To perform these transactions in the new system, the vehicles need to travel 316,109 km, if we use lorries (so the sum distance is reduced by 50.2%), which generates 1,729.2 l petrol consumption (reduced by 44.8%) and

17,473.8 l fuel oil consumption (reduced by 53.1%). This pulls the reduction of emission, for example CO_2-emission is reduced to 3.5 t (by 51.5%). If trams are used in the new system, the sum distance is reduced to 312,890.1 km based on the simulation results (by 50.8%), and these transactions by trams give us 17,169.2 kWh electricity consumption, and it reduces a little bit more the sum emission in the new system. In case of lorries, the sum delivery performance is 174,983.4 tkm (14.5% growth), in case of trams it is 181,136.9 tkm (18.5% growth). In case of the delivery performance, there is growth because of the new node in the system (the consolidation centre). Therefore, all the goods need to travel more, but because of the reduction of the number of transactions, all the other parameters are reduced in the new system. The change of some important parameters (in percentage, where the current system is 100%) can be seen on Figure 13.

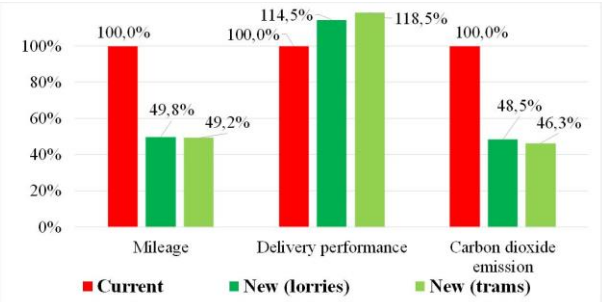

Figure 13: Comparison of the current and new systems

4.3. Cost parameters

After analysing the performance parameters, the costs had to be examined too, based on the simulation. Earlier, we assumed that the operation of the new system is going to be more expensive because of the new node (CC). Based on the simulation runs, the sum logistics operation cost (for 178 stores; these costs must be payed by the storeowners) in the current system is 287,993 EUR/month (st. dev. 6,859 EUR, min. 273,489 EUR, max. 311,067 EUR). Most of it comes from the delivery cost, which is 229,411 EUR/month.

Contrary to our assumptions, based on the experiments we can reduce the sum logistics costs in the new system. By use of lorries, it is 216,153 EUR/month (st. dev. 4,654 EUR, min. 206,579 EUR, max. 227,125 EUR, 24.9% reduction), and by use of trams, it is 195,599 EUR/month (st. dev. 4,815 EUR, min. 183,423 EUR, max. 206,836 EUR, 32.1% reduction). This is a significant reduction, mostly due to the reduction of the delivery cost (by lorries 43.8% and by trams 53.9% reduction). This means that in the new system, not only the performances and emissions, but the operation costs could be reduced as well, this is one of the most important results of the simulation runs. In the future, the analysis of the investment costs and the sizing of the nodes of the new concepts are going to be very important tasks.

By use of the simulation model, we performed sensitivity analysis too, looking for the correlation between the sum savings and change of some parameters. Based on the results of the simulation, the growth of the number of deliveries (and with them the growth of the goods amount) has the most significant effect, because of the high impact of the delivery costs. By use of the real (current) input data, the saving is 71,840 EUR/month, which is going to be 211,216 EUR/month with the number of deliveries doubled. The change of specific delivery costs has also a significant effect (this scenario can be significant e.g. in case fuel prices growth), but the growth of the home delivery share does not change the savings significantly, as it can be seen on Figure 14.

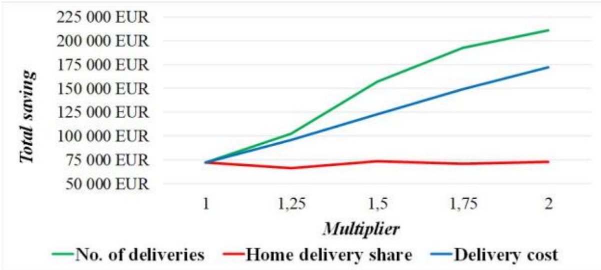

Figure 14: Change of the total savings

5. NEXT STEPS OF THE RESEARCH PROJECT

Naturally, there are several additional tasks in our research project, especially with improving the simulation model of the logistics systems of CSDP. The MS Excel based discrete event simulator became slow because of the big amount of data to be handled, so we started to develop the simulation model in an agent-based simulation software, which also has a supply chain simulator module. The pilot simulation model in this software gave us similar results for the new system with lorries for one shopping mall. In addition, we reckon that it is still a possible direction to examine discrete event simulator, but instead of MS Excel we would like to test a specific simulator built for this system. It is going to be significant to develop the simulation model in one of the above modes, and we would like to examine the shopping areas by use of our simulation models as well. We created a pilot model for them and the results were similar to the earlier presented ones.

Sizing of the system is going to be also very important. We started this phase of our research with sizing cross docks for open and closed infrastructure CSDPs, and we are going to continue this phase with examination of consolidation centres and loading areas. In their cases, not only the sizing going to be significant, the calculation of their number and optimal location by use of the simulation model can be also a vital task of our research.

6. SUMMARY

We started our research without any real data about the logistics systems of concentrated sets of urban delivery points, so earlier the effects of new logistics solutions could be only estimated without specific, general models. In the first phase of our project, we collected data of 490 stores of four CSDPs, to construct the current structure and provide input for the models. In the next steps, we developed some new city logistics solutions, the

mathematical model and the mesoscopic simulation model of the current and new city logistics systems of CSDPs, and the topological model of shopping areas. *These models can make it possible in the future to examine the given concentrated sets by simulation*, if the input data is available. The provided simulation results are going to help us to compare the current system with new system concepts in terms of performances and costs. Earlier, without a general simulation model this was not possible, and in former city logistics projects only some subsystems (e.g. only shopping malls or only shopping areas) were examined.
Based on the results of some former European projects and our simulation results, we can conclude that there is a significant saving potential in the operation of new, gateway-concept based systems compared to the current one, in case of the concentrated sets of urban delivery points. Performance and emission parameters could be reduced by up to half, with 25-30% reduction of the logistics operation costs. The investment costs of new systems can't be neglected but based on the results it is clear that the presented models can provide us the necessary information in the design phase of new city logistics systems for CSDPs. These models are going to make it possible to develop the optimal system architecture, to choose the best city logistics solutions, so they are going to help green logistics efforts, make cities more liveable, and to help future city logistics projects.

ACKNOWLEDGMENTS
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TOWARDS A SIMULATION-BASED DECISION SUPPORT TOOL FOR CONTAINER TERMINAL LAYOUT DESIGN

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ABSTRACT
Recently, seaports have paid much attention to container transportation by rail to evacuate huge container flow received by sea. In this line, Le Havre seaport, as the first French port in terms of containers' traffic, plans to put into service a rail-road terminal near the Paris region. The main purpose of this new inland terminal is to restrict the intensive use of roads on the Le Havre-Paris corridor and achieve a better massification share of hinterland transportation. Containers are routed by train between Le Havre and this terminal and the last/first mile remains done by trucks. This paper aims to propose a decision support tool based on simulation for the layout design problem of this new terminal. This tool is tested using a set of scenarios and the obtained results are then discussed.

Keywords: Modelling, Discrete event simulation, Decision support tool, Rail-road terminal, Layout design problem

1. INTRODUCTION AND LITERATURE REVIEW

Nowadays, some ports seek to achieve a better massification share of hinterland transport by promoting rail and river connections, because containers are moved massively to and from ports at economic costs and in more environmentally friendly manner than road mode. However, they are only profitable over long-haul destinations (Boysen et al. 2010). Besides, geographical constraints heavily penalize rail and river modes, since pre- and end-haulage of containers by road is needed to reach the final destination. In Europe, and particularly in France, the predominance of road-only culture is obvious for door-to-door transport (see Figure 1). In order to restrict this intensive use of roads, the European Union, since recent times, encourages environmentally friendly transport mode as part of a long-term strategy that aims to reduce greenhouse gas emissions (Woodburn 2013), thus executing container transportation in an ecologically efficient way.
Following this strategic vision of green transport, the massification of door-to-door transport has become a core concern for Le Havre seaport authority. The aim is to achieve a better massification share of hinterland transport, which is currently quite weak compared to that of its major competitors in the northern European range, such as Hamburg, Rotterdam, Bremen, etc. To this end, recently the GPMH (Grand Port Maritime of Le Havre) put into service a multimodal terminal that acts as a link between the port and its hinterland. In addition, to provide a more cost-attractive transportation service by rail between the multimodal terminal and Paris, the GPMH plans to build a new rail/road terminal near the Paris region (Figure 2). The main objective is supplying containers as close as possible to their final destinations by rail in order to reduce the part of road mode.

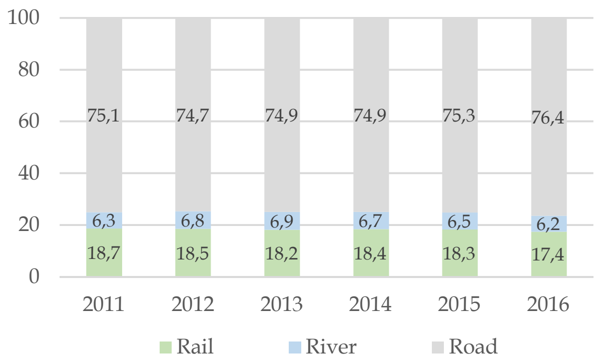


Figure 1. Modal split of inland freight transport in 2011-2016. Source: (Eurostat, freight transport statistics 2019)

This new rail/road terminal is a logistic platform with two interfaces (railside and roadside) and an operating yard. Import containers (inbound flow) arrive at the terminal by railside on mainline trains and leave terminal by trucks for the last-mile distribution to customers. Conversely, export containers (outbound flow) are delivered to the terminal by trucks and moved to Le Havre seaport by mainline trains. In the operating yard, containers move from trucks to trains and vice-versa, and some of them might be stacked temporarily in storage spaces, called buffers, waiting for further transportation. This yard includes transshipment tracks for trains, driving lanes for truck traffic and transfer points for handling operations on trucks. The railside is equipped with holding tracks for receiving, disassembling and reassembling of mainline trains, and the roadside

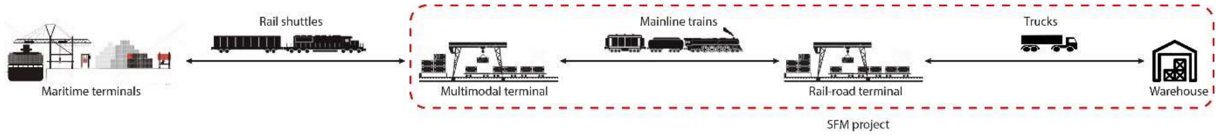


Figure 2. The proposed door-to-door container-transportation service between Le Havre and Paris.
*SFM: Service Ferroviaire Modulaire Project

contains entry and exit gates, a gauge control gate where the physical control of the container takes place, parking lots for waiting trucks and traffic lanes.
The literature is full of studies addressing container terminal problems (Stahlbock and Voß 2008), however, the majority of research focused on maritime terminals because seaside operations are the most complex ones, besides specific papers on rail/road terminals are scarce. Container terminal' layout design problem has been widely addressed particularly using simulation-based decision support tool. However, most papers have focused only on strategic and tactical decisions, (Ballis et Golias 2002), (Lee et al. 2006), (Lee et al. 2008), (Benna et Gronalt 2008), (Caballini et al. 2009),(García et García 2012), (Cartenì et de Luca 2012), (Leriche et al. 2015) et Chen et al. 2018), a few ones have included operational decisions in their models (Liu et al. 2002) and (Sun et al. 2013). Indeed, it is important to take into consideration all decision levels because they influence each other, i.e., decisions made at a higher-level influence those at lower-levels and vice versa. In addition, most reviewed papers used only one types of handling equipment (for example, gantry crane, reach stacker, etc.), although it would be interesting to evaluate container terminal layout with different types of equipment to figure out which one fits with the designed layout.
The objective of this study is to develop a simulation-based decision support tool that allows wide flexibility in terms of equipment and resource choices. Moreover, this tool evaluates the designed layout according to the incoming container flow as well as the handling rules and management policies to be used in the terminal. As perspective, we plan to integrate into our simulation model, a heuristic based approach for container processing problems (unloading-loading and storage-retrieval of containers), internal equipment scheduling and resource allocation.
This article is a part of work done under the project SFM (''Service Ferroviaire Modulaire'': modular rail service). In this project, we also focused on the optimization of container drayage by trucks. Here, we introduce only the connection with the optimization model, more details will be given in (Benantar et al. 2019).

2. SIMULATION-BASED DECISION SUPPORT TOOL

2.1. Discrete event simulation model

Container terminals are dynamic and distributed platforms where containers are received from multiple modes of transportation and are then subjected to diverse operations that are linked to each other. Simulation is a suitable approach to study this kind of complex system. It offers the possibility of analyzing system behavior to a given action over time, also simulation makes it possible to check what is theoretically valid is actually applicable and priori will have the expected effects. Designing a simulation model for a complex system requires a modeling approach, i.e., a roadmap to build the model. In this way, the conception of our model was guided by an iterative approach with a set of steps: analyze, design, implementation, and verification. This process is iterative because, for example, in the implementation step one can notice that certain insights or assumptions included in the first step are incomplete or erroneous. More details are given in (Abourraja et al. 2018a).
The proposed simulation model for the studied rail/road yard is illustrated in Figure 3. This model is made up of three main processes, namely, train transportation process, terminal management process, and truck transportation process. These processes include all activities related to receipt and departure operations of transportation mode, resource allocation, internal equipment scheduling and deployment, handling tasks assignment, storage space management, handling operations and container flow generation.
Train transportation process concerns the generation of day-to-day incoming trains and import containers flow. Trains are injected into the simulation model at each arrival moment. Containers are loaded on trains according to the following parameters: container arrival date and size, maximal filling rate and length of trains, and the number of trains per day.
Each incoming train is broken up in smaller fragments called "coupons" (i.e., a set of railcars) at the Railside (Figure 4). A handling schedule of all coupons is established to decide on which coupon is to be moved first and so on, and then one by one, coupons are pushed over a link track to the operating yard. Afterward, handled coupons, called full coupons, return back to their respective holding track where they are assembled with the existing full coupons to make an outgoing train to Le Havre seaport. When the departure time is reached, mainline trains leave the terminal.
As regards trucks, they arrive at the terminal through entries gates, then those with containers (full trucks) move first towards the check gate while the unladen ones (without containers) go directly to their position within the terminal. For loading or unloading operations of a truck, a vacant transfer point in the operating yard is assigned, otherwise, all transfer points are busy, the truck is forwarded to the parking area and once one becomes available again, it is assigned to the truck. Besides, if the container to be loaded on a truck is not yet arrived at the operating yard, the truck must wait for it in the parking

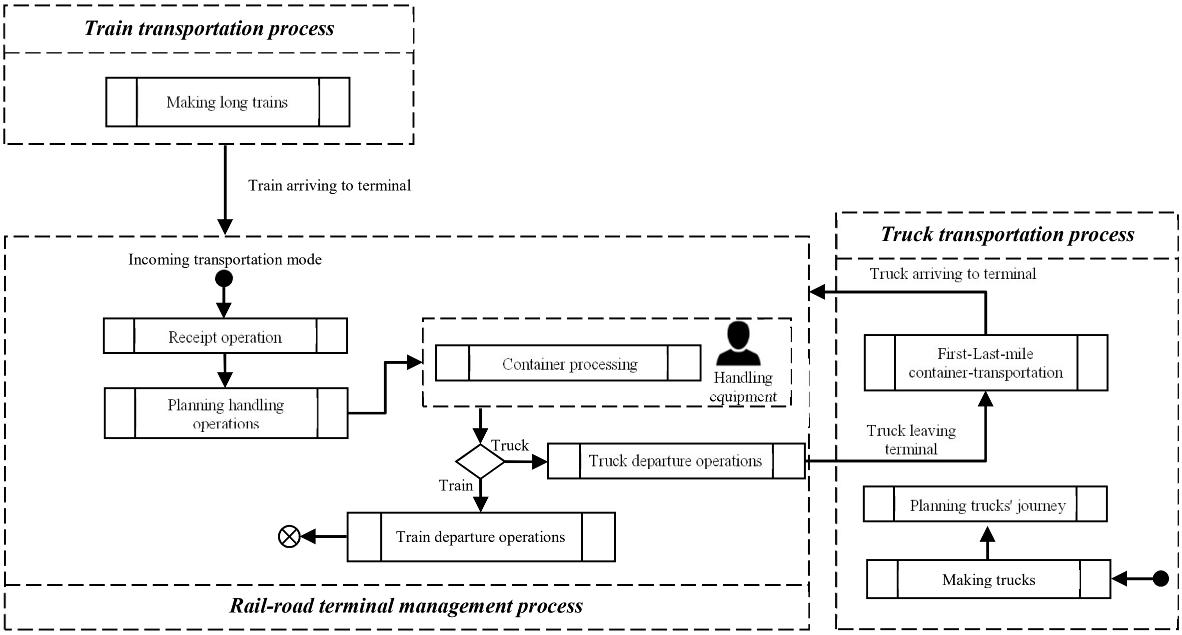


Figure 3. Simulation model

area. When the handling operations are performed, the truck moves to the exit gate of the terminal.

Container moves between trains and trucks are processed in the operating yard by handling equipment. Handling equipment carries out loading and unloading tasks according to the chosen handling rule. A container is picked up from a transportation mode or a buffer and then dropped off either on another transportation mode or on a buffer. In the buffer, the containers are conventionally grouped by departure date, size, flow type, outgoing transportation mode, or a mix of criteria, etc., see (Abourraja et al. 2017) and (Abourraja et al. 2018b).

The last process concerns export containers flow and deals with trucks routing problem, it plans a journey route each day. This decision depends on the daily container flow to be delivered and/or collected to/from customers in addition to the availability date of each container. More details about this process will be given in (Benantar et al. 2019). Resources allocation to transportation mode is ruled by FIFO policy, and trucks have priority during handling operations, so they can leave the terminal as quickly as possible.

2.2. Decision support tool design

The decision support tool is designed based on the simulation model and it is implemented on Anylogic simulation software. The tool contains three modules, namely, layout settings, simulation settings and dashboard.

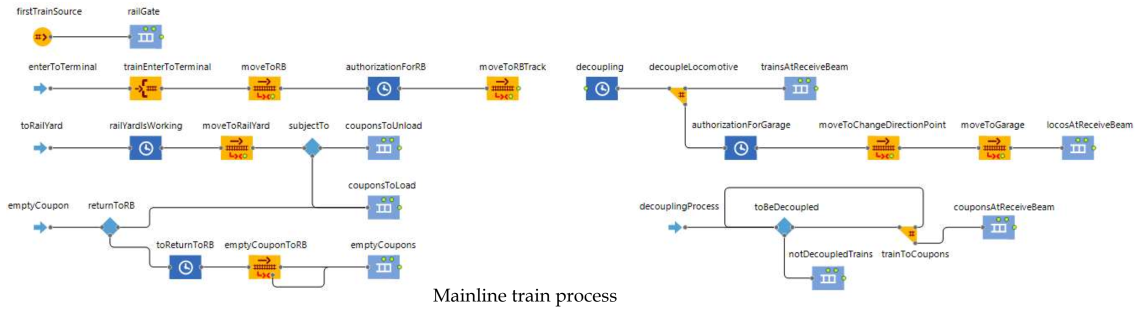
The first module is to set parameters for all facilities needed to build the layout. As described above, the terminal includes three areas: railside, operating yard and roadside, each of them consists of a set of elements. These elements are defined by the following parameters: dimensions (length, width), number, stack height, and equipment type. The first parameter concerns rail tracks, container slots, buffers, parking lots and driving lanes. Number is a common parameter, and the last parameters are for buffers and handling equipment, respectively.

The second module adjusts simulation parameters, such as arrival rate of transportation modes (timetables), motion speed, handling times for loading and unloading operation, service time at the terminal gate, inspection time at gate control, and handling and management rules. These parameters have a significant impact on how operations are progressing into simulation runs. In reality, the values of these parameters are not known with certainty because they are related to humans and system behavior; there are only estimated values (Cartenì and de Luca 2012). Thus, the randomness is introduced in the simulation model to evaluate terminal designed layouts under different scenarios.

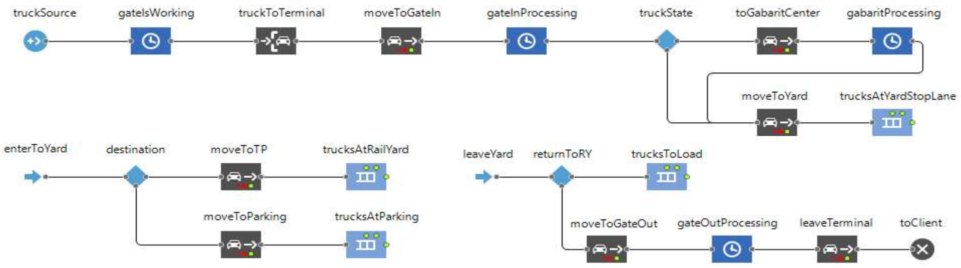
The dashboard module is used to report simulation outcomes. The obtained results help users to make reasonable decisions about terminal facilities (equipment and infrastructure) that might be used to serve on time the incoming transportation mode and container flow. The results concern equipment' activity and utilization, trains and trucks turnaround times inside the terminal, and the used capacity of the sized resource. A design is accepted if all mainline trains and trucks are served during the working day and container delivery delays are avoided. In addition, from the used capacity metric, the designed tool determine the needed entrance/exit gate, transfer points, buffers, handling equipment, parking lots and containers slots. For example, if the used capacity of parking is 50 %, we deduce that only the half of the parking positions is sufficient to receive the incoming truck fleet.

3. EXPERIMENTS AND RESULTS

Different scenarios are tested (Table 1). The estimated container flow per day is between 78 and 98 FEU (only forty-foot equivalent unit containers are considered in the model) on import and export. Each day one train arrives at the terminal at midnight and leave soon the next day. A train can be composed of six or seven coupons of seven



Mainline train process



Truck process

Figure 4. Trains and trucks activities diagram

wagons. Whereas the number of trucks varies from day to day according to import and export container flow, and they start arriving at the terminal after 6h am. The terminal will operate using one of the following working shifts: (1) [00:00 - 05:00] - [06:00 - 20:00] named separate shifts; (2) [06:00 - 13:00] - [13:00 - 20:00] named joined shifts. In the first working shift, trains are served between midnight and 5 am, and trucks are unloaded and loaded within the second part. While, in the other working shift, both of them are handled simultaneously. This data was collected from documents provided by Le Havre Port Authority. Table 2 exposes input values for design parameters, the designed tool run on these values to determine the needed resource for each scenario. All the experiments were carried out by using simulation' parameters reported in Table 3, more details are given in (Cartenì and de Luca 2012). The used handling rules in this paper are explained in (Leriche et al. 2015).

Figure 5 plots the obtained results for each scenario and Figure 6 gives a simulation screenshot. In the real-world yard, import and export containers are stacked in separate buffers, however, although some terminals use mixed storage mode, import and export containers are not put on top of each other. In this study, separate storage mode

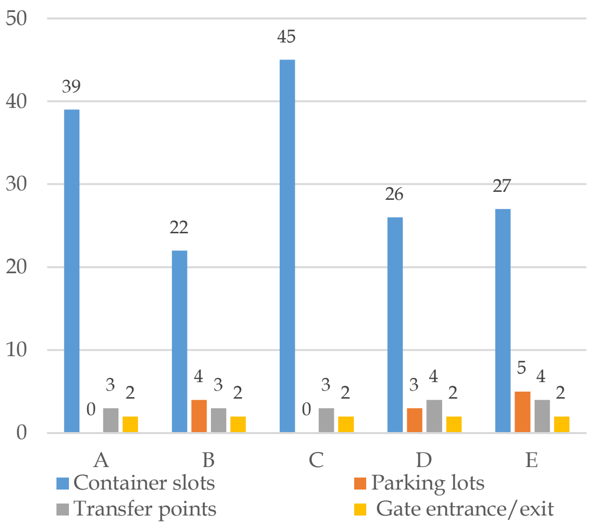


Figure 5. Scenarios results

is used. As can be seen from Figure 5, scenarios A and C need more container slots than other ones. The reason behind this is the usage of the separate working shifts. Indeed, with these working shifts, all containers are first moved to buffers before later being loaded on their respective transportation mode, that is, only double handling moves are performed. Whereas, in the other

Table 1. Simulation scenarios

Scenarios	Container flow (TEU)	Trains per day	Train start arrival	Train dimension (coupon x wagons)	Trucks per day	Trucks start arrival	Work shifts
A	78	1	00:00 h	6 x 7	45	06:00 h	[00:00 - 05:00] - [06:00 - 20:00]
B	84	1	00:00 h	6 x 7	45	06:00 h	[06:00 - 13:00] - [13:00 - 20:00]
C	90	1	00:00 h	7 x 7	48	06:00 h	[00:00 - 05:00] - [06:00 - 20:00]
D	95	1	00:00 h	7 x 7	54	06:00 h	[06:00 - 13:00] - [13:00 - 20:00]
E	98	1	00:00 h	7 x 7	54	06:00 h	[06:00 - 13:00] - [13:00 - 20:00]

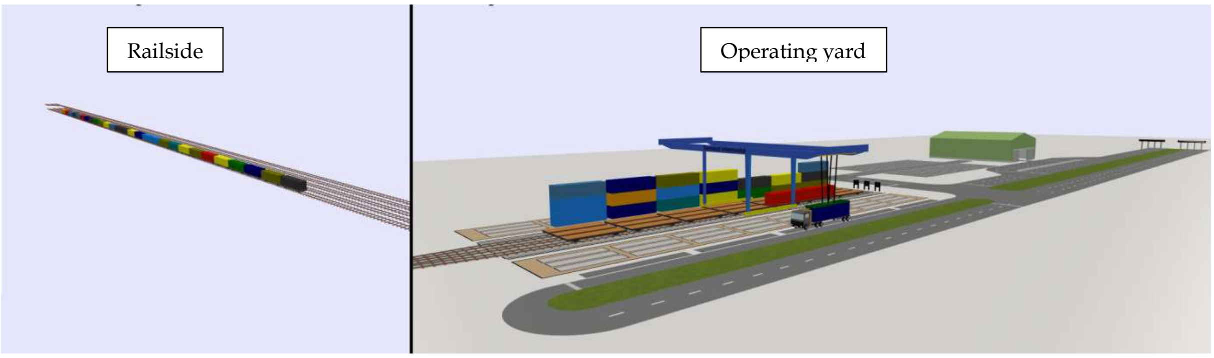


Figure 6. Simulation screenshot

scenarios (B, D and E), direct container moves from train to truck or vice-versa are also carried out by handling equipment. It is also obvious that in scenarios A and C there is no need for parking positions since all import containers are already waiting for trucks at buffers, thus trucks move directly to the operating area to be unloaded and loaded. As regard transfer points and gate entrance/exit, they are fairly similar for all scenarios. We can also notice that the required transfer points increase with an incoming truck fleet and container flow growth. As regard handling equipment, the workload and the distance traveled are more important in the case of separate shifts, because equipment has to move twice per each container. In spite of that, these shifts minimize the turnaround time of transportation mode and allow rapid evacuation of containers to their destination.

4. FUTURE AND CURRET WORKS

4.1. Connection to the model of container drayage by trucks

The optimization model (see (Benantar et al. 2019)) plans the working journey for each truck. This decision depends on the daily container flow to be delivered and/or collected to/from customers in addition to the availability date of each container. This planning is introduced into simulation via "Truck transportation process". The simulation in turn recalculate the availability date for each import container and provides these dates as input data for the optimization model to produce a new trucks planning in the next iteration. The availability date is specified when an import container arrive to the operating yard, that is, the container is ready to be loaded on its respective truck.

Table 2. Input data

Container slots per buffer	Parking lots	Transfer points	Gate entrance/ exit
96	15	5	3

4.2. Further improvements to the simulation model

To improve our simulation model, we are developing an optimization approach for container processing in the operating yard. This section describes briefly this approach. In this yard, handling equipment moves containers across the yard from their pick-up position to their drop-off position. A position might be a railcar position, a container slot in a stack or a transfer point. In addition, a container has one origin position, one or more intermediate positions, and one target position. The origin and target positions of an import container are a railcar position and a transfer point, respectively, whereas it is the opposite for export containers, i.e., they are transferred from a transfer point (origin) to a railcar position (target). The intermediate position can be only a container slot and in the case of reshuffling, containers move from one to another. Therefore, to decide on the containers' position in the operating yard over the working days, the following problems must be resolved:

- Container storage problem: assign containers to blocks, i.e., container-to-block allocation, and assign containers to specific locations within the selected block, i.e., container-to-slot allocation (Carlo et al. 2014).
- Train un/loading problem: consists in determining the best assignment of export containers to railcar positions.

Table 3. Simulation settings

Motion speed	Crane speed	$\bar{x}$=11.498 and s=4.586 km/h
	Train speed	6 km/h
	Truck speed	12 km/h
Handling time	Crane time to get a container from a shuttle	$\bar{x}$=0,888 and s=0,352 min
	Crane time to get container from stack	$\bar{x}$=0,769 and s=0,380 min
	Crane time to get a container from a truck	$\bar{x}$=0,888 and s=0,352 min
	Crane time to put container in shuttle	$\bar{x}$=1,331 and s=0,434 min
	Crane time to put container in stack	$\bar{x}$=0,760 and s=0,309 min
	Crane time to put container in truck	$\bar{x}$=0,888 and s=0,352 min
Service time	At gate entrance	$\bar{x}$=2 and s=1 min
	At gate control	$\bar{x}$=10 and s=4 min

- Transfer-point-to-truck assignment: consists of assigning export and import containers to transfer points where they will be pick-up from and collected by trucks, respectively.

To provide solutions solving whole problems together, we are developing a genetic algorithm. Because, the three described problems are fairly similar. Genetic algorithm (GA) is chosen because it is suitable for these kinds of problems. The proposed algorithm is based on rolling horizon approach, that is, at each planning epoch, the algorithm draws a 3D matrix that indicates the position (or positions) of each incoming or existing container in the operating yard.

5. CONCLUSION

This paper has focused on layout design for a new rail-road terminal. To this end, first, a simulation model is designed, second, upon this model, a decision support tool is built to size terminal layout under different scenarios. Then, the obtained results are reported and discussed. As can be seen, the designed tool needs improvements, so as perspective we plan to integrate in our simulation model, an optimization approach for container processing (unloading-loading and storage-retrieval of containers), internal equipment scheduling and resource allocation. Moreover, an optimization model for container delivery and pickup by trucks is developed and it will be coupled to our simulation model.

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REALIZATION OF FOOD DEFENSE AND FOOD SECURITY STANDARDS IN POLISH MARITIME TRANSPORT

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ABSTRACT

This article touches on the issue of Food Defense and Food Security in Polish maritime transport. It seems indispensable to refer to the food defense as any action that the company must take to prevent the intentional contamination of food products by biological, chemical, physical or radiological factors which cannot be expected based on hazard analysis and which may arise in connection with human activities as a source of contamination (FDA). Temperature-controlled food transport is one of the most critical elements in today's supply chain, which is reflected in an increase in the demand for fresh and frozen products. In the case of sea transport, this will require temperature control in refrigerated containers. The effect of research on the impact of the stream of descending air and its free passage on the duration of storage of natural food products, which are presented in the article, are guidelines contained in military procedures.

Keywords: sea transport, logistics, food safety.

1. INTRODUCTION

The subject matter of the article made the authors choose specific information content. Therefore, the problems of transport safety in the food sector are presented in the effect of the analysis of Polish and foreign literature. Theoretical context of the discussed issue of the phenomenon of food defense, food safety, food transport in controlled temperature and humidity HEADING, Polish and international legal regulations is to show the practical application of the conducted research on the influence of the stream of descending air and its free flow on the period of storage of natural food products. The question was: Are the standards of food protection and food safety, as defined by the law, maintained in Polish maritime transport? The answer to this question also included naval transport carried out by the Polish Armed Forces. It is an undoubted added value in the discussion on food protection and food safety since there are no references to this form of sea transport in the subject literature. The statement to be verified through the analysis of documents, literature, legal acts, and research reports was that the standards of food defense and food safety in the Polish maritime transport are maintained.

The changes taking place in the modern world allow us to observe economic phenomena permeating across national borders, which means international integration of commodity, capital, and labor markets, and thus determines the economic dimension of globalization. Transport is a factor of great importance in this respect. There is no doubt that the development of transport technologies influences the reduction of transport costs, which therefore favors the expansion of geographical borders of markets, including the regional (semi-global) and global level.

Transport is a sector of the economy that contributes to competitiveness, social development and world integration. It is also an essential component of civilian and military logistics systems. Transport conditions space-time to be overcome by carrying out tasks related to the movement of parts, materials and finished products in supply, production, and distribution subsystems. The world population has doubled over the last 50 years. That increased the demand for all kinds of goods, which means an almost seven-time rise in the value of goods produced in the world. Some of them are intangible services transmitted using communication, while the others are goods sold at the place of production. The remaining ones are vast quantities of products that need to be transported to a recipient.

International maritime transport that serves most of the world trade in goods, both in terms of quantity and value, plays a crucial role in this process. It determines the effectiveness of global trade, ensuring the efficacy of liberalized commodity markets as well as the efficiency and flexibility of global supply chains and networks. It is, therefore, becoming one of the main pillars supporting and consolidating the processes of globalization and development of the global economy. The analyses conducted indicate that since 1970 maritime trade has been growing on average by 3.2%, and the pace of growth was ahead of the dynamics of global GDP growth and industrial production of OECD countries, but it was lower than the dynamics of global trade growth - in the years 2000-2011 it amounted to 8.9% on average annually. If the current high growth rate of maritime trade on a worldwide scale is maintained, it means that in 2020 the volume of goods transported by sea will increase by 36-40%, reaching 12.0-12.5 billion tons, and in 2031 it will be doubled in relation to its 2010 level. As a result, the share of maritime transport in total world trade in tons may increase in 2020 to as much as 85% (in 2006 it was 75%), at the expense of reducing the share of land transport (rail, road, and pipeline) from the current 24% to 14.6%, while the share of air transport in world trade services increased from the current 0.3% to 0.4%. Grzelakowski (2012)

Poland is also one of the elements of the world's maritime transport. The conducted research on processes taking place in the period 2000-2010 indicates that it is not possible to accelerate the economic growth and development of foreign trade without effective and efficient transport. Therefore, Poland needs to create a coherent and efficient transport system, integrated with the European and global networks. The prepared Transport Development Strategy until 2020 (with perspective until 2030) sets out the most important directions of activities and their coordination to achieve the strategic objective. It should be stated that on the territory of Poland there are four sea ports of fundamental importance for the national economy, which at the same time are international sea ports belonging to the trans-European transport network - i.e. Gdańsk, Gdynia, Szczecin and Świnoujście - and 57 smaller ports and harbors, 18 of which are sea border crossings). Among the most important regional ones, the ports of Gdynia, Szczecin, and Świnoujście should be mentioned: Police, Kołobrzeg, Darłowo, and Elbląg. The Polish fleet of seagoing merchant vessels increased in the years 2003-2010: by 4.3% in terms of the number of ships and by 24.6% in terms of carrying capacity. In the whole period, most of those ships (83%-90%) were operated under foreign flags. The average age for seagoing vessels in 2010 was 16.8 years, while under 10-year-old ships accounted for 34.4%, aged 11-20 years - 37.8%, and aged over 20 years - 27.8% of tonnage). Foreign trade is progressively based on containerized transportation of goods. In 2010, the Polish maritime fleet lacked in suitable ships for their transport (traditional bulk carriers dominated 83% of them). Maritime transport was not a key area of interest of the Armed Forces of the Republic of Poland since they were focused on the implementation of activities related to the defense of the territory of the state. The international community, including key allies, expected Poland to take an active part in foreign missions. The creation of Polish Military Contingents was connected to the necessity of supplying troops abroad, thereby generating an urgent need to have the required technical capabilities in the form of refrigerated containers and access to sea transport.

2. FOOD DEFENSE VS. FOOD SAFETY

When addressing the issues of food defense and food safety in maritime transport, it is necessary to point out that defending food is not the same as food safety. The term 'food defense' appeared in the United States of America after the attack on the World Trade Center and concerned the protection of food against terrorist exposure, i.e., deliberate pollution. Food defense focuses on the protection of food resources from deliberate contamination by various chemical, biological or other harmful substances by people who want to harm a facility or population. Product contaminants may contain compounds that are not naturally present in food or are not tested for use in contact with food. The aim of an attacker may be to harm a food producer, destroy a country's economy or kill people - so in the US, those who are proven to have deliberately contaminated food are charged with terrorism and tried like terrorists. Intentional actions are not usually rational and are non-foreseeable.Food safety refers to the accidental contamination of food products during their storage or processing with biological, chemical and physical agents. Those unintentional contaminants are possible to foresee. They are typical of raw materials, types of technological processes, and kinds of packaging used. Anusz and Didkowska and Blanka Orłowska (2017). Regardless of the definition categories, both deliberate and inadvertent contamination of food is of vital importance for the development of a system that is preventive, i.e. that contamination can be predicted and action can be taken to minimize or limit the occurrence.

One of the systems of fundamental importance is the Hazard Analysis and Critical Control Point (HACCP) system. It was established in the 1960s as the result of NASA's cooperation with Pillsbury and US Army laboratories. It was developed to ensure food safety for the upcoming space expeditions and was subsequently used as a standard in the food industry. HACCP became the most revolutionary innovation in food safety in the 20th century. Nowadays, the obligatory HACCP system is a fundamental element of protection of human health against threats that may occur in food. This system considers all foreseeable hazards (microbiological, physical or chemical) that appear under the production conditions or in the food itself and that may occur inadvertently in the final product. However, HACCP hazard analysis does not include the intentional introduction of an agent that may be harmful to health or life into food. It is therefore also necessary to analyze the risks in the context of food defense.

IFS is a specific standard recognized and developed for all food manufacturers, mainly for retail chains and their brands. The main objective of this system is to verify the safety and quality of the product and its compliance with applicable laws and standards. IFS unifies requirements and introduces transparency in the supply chain, from raw material to final product. BRC is a Global Standard for Storage and Distribution. The standard has been developed to ensure the highest quality of delivered products internationally. The main bene-

fits of introducing BRC include reduction of the number of improper quality products, control of both the supplier and the customer, reduction of the number of audits conducted by customers, and unification of food safety requirements: documentation confirming the durability of the expected quality product.
Food Safety and Food Defense programs are independent of each other, but may have some common procedures, e.g., SOP (Standard Operating Procedure), a HACCP plan, or other ones for crisis response.

In Poland, several years ago, companies selling their products in the United States had to take certain actions in this area. The turning point was the publication of the sixth edition of the IFS Food Standard at the beginning of 2012.

3. POLAND IN THE FOOD DEFENSE AND FOOD SAFETY SYSTEM

Food and packaging, like any other product, should meet the needs of producers, logisticians and consumers by fulfilling certain characteristics: physical (e.g. dimensions, weight facilitating transport and storage), chemical (e.g. the composition of raw materials and their impact on the body, environment), technological (e.g. ease of manufacture and storage), organoleptic (e.g. pleasant to touch, taste, and smell), functional (e.g. easy to open, prepare for consumption, utilization, and convenient to track), economical (price, cost of preparation, utilization, transport), aesthetic (e.g. color, shapes), safe (e.g. harmfulness, healthiness, ease of monitoring the product quality, protection against thieves or destruction). Despite the awareness that all entities involved in the supply chain should have in this respect. The above is not always the case. Unfortunately, Poland is an example of that:

1. It was near Kalisz (Poland) that irregularities and negligence in the production of dried eggs were detected in two companies there. For many years, the produced powdered eggs were questionable in terms of their quality and impurities they contained (among others, heavy metals and bacteria from the Coli group). Irregularities were found only in 2012, while the dried eggs had been produced since 2008. About 26 tons of egg powder intended for sale to over 100 producers of pâtés, sweets, and pasta in Poland was secured. There was also an international issue concerning the powdered eggs. The trope leads to the Czech Republic and the Netherlands. It turns out that one of the entrepreneurs suspected in this case bought goods from a resident of the Łódzkie Voivodeship, who in turn imported dried egg mixtures from abroad.
2. In 2012, illicit trade in food grade salt was detected in Poland. The so-called ‘road salt’, which in its appearance resembles edible salt, was introduced on the food market instead of the latter. The chemical composition of the salt can be hazardous for human health since it can contain potassium or potassium nitrate, which can affect the heart rate and even lead to cardiac arrest. It is a technological waste in the manufacture of calcium chloride, which is suitable for road maintenance. The road salt was used instead of food grade salt in 646 confectioneries, restaurants, bakeries, including bakeries in Tesco and Auchan hypermarkets Szymonik (2017).
3. In 2011, 20 tons of chicken breast packaging imported from Poland by Slovakia turned out to be contaminated with salmonella. As the then Minister of Agriculture stated, ‘Poultry meat with a taste of salmonella’ went to several hundred supermarkets in the country. A few years earlier, a dispute arose over Polish vegetables and potatoes, which, according to Slovaks, did not meet the quality standards. On 23 January 2013, the Slovak Ministry of Agriculture applied to the European Commission for an analysis of the mechanisms of control of Polish agricultural and food products supplied to the EU market. The direct cause of the European Commission’s intervention was the case of contaminated milk powder from the regional dairy cooperative ‘Rokitnianka’ in Szczekociny used to produce sweets in the company ‘Magnolia’.

Poland takes active part in shaping the system of both food defense and food safety. That is reflected in the provisions of one of the most important documents, i.e., the National Security Strategy of the Republic of Poland. In the individual chapters we read:

- *Chapter I ‘Poland as a subject of security*’ – ‘... the above arrangement of interests gives rise to corresponding strategic objectives in the field of security: ensuring food safety’
- *Chapter III,* ‘*Concept of strategic actions. Operational strategy’*, point 104 *Strengthening food safety*: ‘It is necessary to implement the agricultural policy which will increase the resistance of agricultural production to unfavorable phenomena and maintain control over food economy divisions important for the state security and guarantee an appropriate level of food self-sufficiency’
- *Chapter IV ‘Concept of strategic preparations. Preparation strategy’*, point 4.5 *Economic subsystems* and further in point 149 *Food safety*: ‘In order to properly protect the health and interests of consumers of agri-food products, it is vital to strengthen food control so that state actions ensure uniform and efficient supervision of its production and distribution’.

Ensuring food safety is related to the implementation of food safety management systems such as the Good Hygiene Practice (GHP), Good Manufacturing Practice (GMP) and the HACCP system. It is a requirement of the law specified, among others, in the Act on Health and Safety at Work:

- Act of 25 August 2006 on Food and Nutrition Safety;
- Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures regarding that issue;
- Regulation (EC) No 852/2004 of the European Parliament and of the Council of 29 April 2004 on the hygiene of foodstuffs

In the light of the latter regulation, all food operators, regardless of the size and profile of their activity, are obliged to have the HACCP system implemented and functioning as of 1 January 2006:

- IFS (International Food Standard) - an international food safety standard developed in 2002 by the German retail trade. In 2012, an updated version of 'IFS Food Version 6' was published and came into force on 1 July 2012;
- BRC is an international standard (Global Standard) developed by the British Retail Consortium and required by a growing group of hyper- and supermarkets across Europe.

In January 2015, Version 7 of the Standard was published and it has been effective from 1 July 2015. The implementation of provisions contained in normative and legal acts and other standards and norms would not be possible without:

- a warning system for notifying of any direct or indirect threat to human health deriving from food or feed;
- risk assessment (means a scientifically supported process consisting of four stages: hazard identification and characterization, risk assessment and characterization) and their management;
- management of a crisis caused by hazards, which is defined as a biological, chemical or physical agent in or on food or feed, or a condition of food or feed likely to cause adverse health effects. Szymonik (2017).

The first Polish Food Act was issued on 22 March 1928. It was a Presidential Decree with the force of law (Journal of Laws No. 36, item 343), regulating the provisions governing: 'the manufacture, sale and other introduction into circulation of food products, their raw materials and those everyday items whose use, in accordance with their intended purpose, may prove harmful to human health'. This Regulation, as amended later, was in force until 1971. On 2 November 1970, the Act on Health Conditions of Food and Nutrition (Journal of Laws No. 29, item 245) was passed and amended on 6 November 1992 (Journal of Laws No. 91, item 456 of 1992). The act governed 'the production conditions of foodstuffs and tobacco products and the marketing of those products to the extent necessary to protect the health of the population...'. It also regulated, to the extent necessary for the protection of the health of the population, the requirements concerning devices, apparatus, equipment, tools, packaging, and other materials which are brought into contact with foodstuffs and substances in production or trade. The Polish legal act obligating enterprises to implement the HACCP system is currently the Act of 11 May 2001 'on health conditions of food and nutrition'. Under the current law, large and medium-sized companies involved in the production and marketing of food, that is, not only production plants but also wholesalers, shops and restaurants, shall implement the HACCP system.

One should not lose sight of the importance of the international standards in the field of food safety and food defense adopted by Poland for the national law. The Directive 89/397/EEC of 14 June 1989 on the official control of foodstuffs is one of the significant horizontal directives concerning the supervision of food health quality. The document recommends the protection of citizens' health in all EU member states and introduces official control over food additives, vitamins, minerals, trace elements, and food contact materials. It was repealed by Regulation (EC) No 882/2004 of the European Parliament and of the Council of 29 April 2004 on official controls performed to ensure the verification of compliance with feed and food law as well as animal health and animal welfare rules.

Subsequent acts include Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official acts performed to ensure the application of feed and food law, rules governing animal health and welfare as well as plant health and plant protection products, amending existing regulations on official controls and amending Regulations (EC) No 999/2001, (EC) No 396/2005, (EC) No 1069/2009, (EC) No 1107/2009, (EU) No 1151/2012, (EU) No 652/2014, (EU) 2016/429 and (EU) 2016/2031 of the European Parliament and of the Council, Council Regulations (EC) No 1/2005 and (EC) No 1099/2009 and Council Directives 98/58/EC, 1999/74/EC, 2007/43/EC, 2008/119/EC and 2008/120/EC, and repealing Regulations (EC) No 854/2004 and (EC) No 882/2004 of the European Parliament and of the Council, Council Directives 89/608/EEC, 89/662/EEC, 90/425/EEC, 91/496/EEC, 96/23/EC, 96/93/EC and 97/78/EC and Council Decision 92/438/EEC (Official Control Regulation).

In Poland, as part of the adaptation to the requirements of the European Union, Directive 93/43/EEC has been transposed into Polish law. The afore-mentioned Act of 11 May 2001 on Health Conditions of Food and Nutrition [Journal of Laws of 2001, No. 63, item 634, as amended], the wording of reference No. 1 entered into force on 17 October 2005 (Journal of Laws of 2005, No. 178, item 1480)] defines the concepts of Good Hygiene Practice and Good Manufacturing Practice (Article 3, points 33 and 34). The Act on Health Conditions of Food and Nutrition stipulated the obligation to implement the HACCP system in establishments conducting business activity within the scope of food production and trade. Article 3(1) (12) of the Act defines the HACCP system itself, whereas Articles 28 – 32 specify the obligation to apply it and the principles of the system.

The Act provided for the issuance of an executive regulation defining detailed hygienic requirements for the production and distribution of food. The version of the Regulation of the Minister of Health of 26 April 2004 on hygiene and sanitary requirements in establishments manufacturing or marketing food (Journal of Laws of 2004 No. 104, item 1096) replaced the Regulation of 19 December 2002 (Journal of Laws of 2002, No. 234, item 1979). It was repealed by the Act of 25 August 2006 on Food and Nutrition Safety [Journal of Laws of 2006 No. 171, item 1225 (i.e. Journal of Laws of 2018, item 1541, 1669, 2136, 2227, 2242, 2244, 2 245)]

Article 1.1. The Act specifies the requirements and procedures necessary to ensure food safety in accordance with the provisions of Regulation 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (OJ L 31 of 01 February 2002, p. 1; OJ EU Official Journal Polish Special Edition, Chapter 15, Volume 6, p. 463), hereinafter referred to as 'Regulation No 1788/2000'.

The adopted legal regulations mentioned above apply to maritime transport. Regardless of them, the provisions specific to this form of transportation shall apply. These include but are not limited to:

- Commission Regulation (EU) No 579/2014 of 28 May 2014 granting a derogation from certain provisions of Annex II to Regulation (EC) No 852/2004 of the European Parliament and of the Council regarding the transport of liquid oils and fats by sea;
- Commission Regulation (EU) 2016/238 of 19 February 2016 amending the Annex to Commission Regulation (EU) No 579/2014 granting a derogation from certain provisions of Annex II to Regulation (EC) No 852/2004 of the European Parliament and of the Council regarding the maritime transport of liquid oils and fats;
- Regulation of the Minister of Health of 23 February 2017 on specific hygienic requirements for the transport of bulk raw sugar by sea (Journal of Laws, item 451);
- Commission Regulation (EU) No 16/2011 of 10 January 2011 laying down implementing measures for the Rapid alert system for food and feed.

4. SELECTED FOOD SAFETY STANDARDS IN MARITIME TRANSPORT

A well-functioning food chain offers, among other things, high-quality foodstuffs at affordable prices while ensuring safety as well as traceability of food products to consumers Fajczak-Kowalska.and Motowidlam (2010) In line with the ISO 28000 standard, which is believed to be widely applicable to food products, the security of the supply chain in maritime transport will be seen from the perspective of its resistance to intentional and unauthorized action aimed at causing damage or destruction. The specific nature of competition in the market for maritime transport services makes it particularly notable for its participants to gain a competitive advantage over their rivals. Therefore, competitiveness in free market conditions is a central issue, and appropriate formulation of a competitive strategy becomes essential for the survival and development of an organization. Kisiel (2005). The main consequence of such a character is the necessity of observing the activity of competitors and predicting their reaction to individual actions. Forlicz (1996).

Due to the number of such negative phenomena connected with cases of security threats concerning food products, various examples of such practices can be found in the field of maritime transport or customs procedures. The programs implemented in the United States deserve special attention from in the light of the experience acquired in international trade.

The Customs - Trade Partnership Against Terrorism (C–TPAT) is a voluntary program that developed procedures for importers, maritime carriers, maritime transport intermediaries, multimodal transport operators without their own vessels, American ports and sea terminals, as well as requirements for seals and sealing.

Another program is the Container Security Initiative (CSI) aimed at pre-shipment security checks of containers so that the US border is the last and not the first line of defense. The program has implemented cooperation with various ports where containers with a US port of destination are loaded.

This initiative includes the Szczecin port as the only one in Poland. The implementation of the CSI scheme for maritime transport, while not specifically aimed at benefiting operators, has had plenty of unintended positive effects on international trade, notably the development of operational systems, improved control over transport and other processes, as well as reduced losses due to theft.

When recognizing the importance of risk in logistic processes, which result from internal conditions and above all from external dependence on business partners or random events, organizations are beginning to look for a methodology that would enable them to limit its level. Żabiński (2000).

All over the world, as regards the broadly understood defense of organizations against threats of intent leading to destabilization of the position of organizations in maritime transport, it can be concluded that programs and proposals in the area of food defense developed by organizations and government agencies in the United States are particularly valuable. It stems from the fact the country is extremely experienced in this respect due to terrorist attacks, as well as the number of programs aimed at counteracting threats in the field of food hazards.

To sum up, it is noticeable that various food safety and security agendas in the United States and the European Union are doing a great deal to prepare producers, processors and transport links of food chains to defend food.

Threats related to the above should be sought in terrorist activity and in a wide area of gaining competitive advantage. From the point of view of an organization, a competitive advantage is its unique position in the sector in relation to its competitors, enabling it to achieve above-average profits and get ahead of the competition. Żabiński (2000).

The modern concept of creating a competitive advantage places particular emphasis on the need to use the acquired knowledge and resources skillfully. Competitiveness does not arise spontaneously and automatically in the effect of changes in the macro and microenvironment, nor is it the sole result of entrepreneurship, but is the result of the actions of many actors of social and economic development. Staszewska (2007).

Furthermore, profit in the form of financial resources or the ability to handle as many personnel losses as possible is the overriding factor here. Is increasing income the primary goal of an enterprise? Is the aim of our work to earn money? The answer ‘yes’ to these questions is often described as evident. In 2012, alcohols from the Czech Republic were secured and then withdrawn from the market in the whole of Europe because they contained methanol, which is dangerous for human health and life. It is evident that the reasons for food contamination can be purely material and profit-driven. The activities undertaken as part of the Food Defense Program are intended primarily to reduce the likelihood of a malicious attack and to assure the public that the organization is taking adequate action as regards food defense. When analyzing the security mentioned above programs, it can be seen that it leaves a lot of freedom for organizations to create appropriate conditions for them in favor of food security. Such a situation has both positive and negative aspects. It is good to see that no unilateral, ready-made solutions are imposed due to the diversity of processes taking place in maritime transport. Besides, the general approach prevents a too single-sided view of the problem, in the context of existing risks, which in turn may limit the creativity of workers in proposing remedies appropriate to a given shipowner. The generality of the formulations contained in these programs, the requirements of the market, the rush to implement food defense systems and plans, and short deadlines imposed may lead to a situation in which certain essential aspects are overlooked and may contribute to mistakes being made, the occurrence of which is undoubtedly prevented by requirements or guidelines.

5. FOOD TRANSPORTATION AT MONITORED TEMPERATURE AND HUMIDITY

Progressive globalization and internationalization of food trade and the multiple relationships and interdependencies between actors in the maritime transport chain make defending a food product in the food supply chain an extremely complex process. An example of this type of chain in a simplified form was presented by E.R. Choffnes, D.A. Relman, L.A. Olsen, R. Hutton and concerned the USA. The time-consuming transport of foodstuffs (fresh products such as fruit, vegetables, meat, fish, dairy products, juices, and crustaceans) by sea requires extensive and specialized knowledge due to the sensitivity of food to transport conditions. When exposed to too high or too low temperature, too high or too low humidity, they wilt, die or rot, thereby losing their quality conditions, making them unfit for consumption. It is therefore imperative that those responsible for this process can adjust the temperature, humidity, and transport time to the requirements of the individual foodstuffs. Bieńczak and Starkowski and Zwierzycki (2012).

At this point, special attention should be paid to the flow of information, which is essential and accompanies a transport process from the very beginning of the product to its destination. Szymański (2018).

According to the authors, not only is today's food chain increasingly complex but it is also becoming anonymous.

When referring to the concepts of food protection and safety in this area, attention should be paid to the relationship between the actors and their interest groups. That makes the risks associated with the transport of food products by sea more complex and unpredictable. The threats related to maritime transport are, on the one hand, very diverse, but, above all, the implications of their possible existence and impact could be severe. In terms of economic theory, the consequences that arise from the effects of threats accompanying and generated by transport (including maritime transport) can be divided into those whose effects influence the entity that caused them and those that affect other objects (the victims). If negative consequences occur and affect the aggrieved bodies, and at the same time are not compensated by the entity or entities generating (causing) them, they should be understood as classic negative externalities. Droździecki (2014).

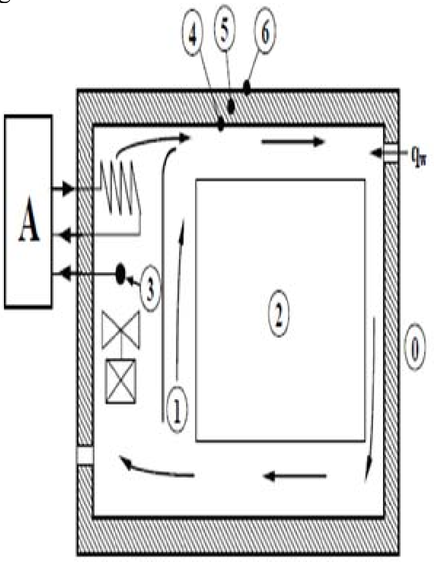
Temperature-controlled food transport is one of the crucial elements in today's supply chain, which is reflected in an increase in the demand for fresh and frozen products. In the case of sea transport, this will require temperature control in refrigerated containers.

It is during the transport service that food is exposed to damage resulting from the movement of goods - i.e., trans-shipment work, the transport itself, as well as climatic conditions. According to M. Jazdżewska - Gutta, international supply chains and maritime trans port are connected by many cooperation, production and transport links. For this reason, the consequences of unforeseen events in one place have adverse effects on other links. Jażdżewska–Gutta (2011).

Therefore, it is vital to carry out numerous activities carefully, starting from the principles of hygiene, through the selection of a proper container, adequate safeguards, uninterrupted operation of the unit in the appropriate temperature range, ending with the proper location of the container on the container vessel. That is why because it will affect the image of the manufacturer and supplier, as well as consumer confidence.

The range of own transport possibilities in the food sector was enriched when the decision was made to introduce a refrigerated container into the equipment of the Polish Armed Forces under the order No. 47 of the Head of the Inspectorate of Armed Forces Support. The tank underwent tests in the military center where the influence of the stream of descending air and its free flow on the period of storage of natural food products was investigated.

During refrigerated storage, considerable amounts of carbon dioxide are accumulated in the refrigeration chamber in the result of breathing food. The accumulation of carbon dioxide in the air, up to a content exceeding the oxygen content, causes enzymatic changes. Changing the direction of the breathing reaction causes the so-called intermolecular breathing, which is characterized by the release of carbon dioxide without absorbing oxygen from the air. Accumulating products of anaerobic respiration in the form of an acetaldehyde or ethyl alcohol leads to irreversible changes in taste and smell and loss of resistance of food products through its spoilage. That was the reason for the loss of foodstuffs



0 - external weather conditions
1 - internal air
2 - load
3 - temperature sensor inside the container
4 - internal container sheathing
5 - thermal insulation
6 - external container sheathing
A - cooling unit
q_w - heat flow exchanged due to ventilation.

Figure 1 Refrigerated container model

sent to soldiers stationed in Iraq, Bosnia, and Afghanistan on the occasion of the Polish Army Day. The model described in the paper "Refrigeration and Air Conditioning" was used in the research, and the container was divided into the following components – Figure 1 (Grajnert and Kwaśniewski 1998).

The tested 20-foot container with its power generator.

Figure 2: Refrigerated container with integrated refrigeration and power supply generator 2

The research shows that the proper capacity of a refrigerating unit is only possible if the cold air stream can move freely around the stored foodstuffs.

The arrangement of the load conditions the above. The smaller the ducts or the too narrow arrangement of the pallet units between the adjacent rows and walls of the container, the more air flow is reduced, which translates into an increase in temperature, by reducing the heat transfer intensity in the entire refrigeration space. The result of the investigations are guidelines contained in military procedures related to the distribution of food products in the refrigeration chamber and the proper selection of refrigerant recommended by the equipment providers in the form of, for example, R 134A. It is one of the varieties of purified freon with a purity level of 99.97%. As a cooling medium, it is characterized by better heat transferability than liquid nitrogen. In its gaseous state, it is heavier than air, non-flammable and non-explosive. What is more, it is economical in use as its vapors can be largely recovered and replenished. Concerning food products, proper selection of a refrigerant determines its chemical indifference to stored food products since it does not dissolve edible fats and has no influence on the change of taste and aroma of food products.

The conditions discussed above are confirmed by tests during the transport process and are subject to exceptional protection. Food is an extraordinary commodity because of its fundamental role as a source of energy and nutrients, having a direct impact on human health. A soldier is not only the final recipient of food, which he chooses and pays for but also the one who bears all the risk of health consequences associated with its consumption.

Intentional interference in this process will have an impact on the broadly understood safety and reliability of the logistics operator since it has been assumed that the cargo entrusted to it will arrive intact at their destination while preserving the highest safety standards. The safety of food products in the transport process with the controlled temperature kept and humidity is based on maintaining the suitability of food products for consumption. Most importantly, their use must not endanger human health and life.

Such assumptions initiated numerous legal regulations concerning the selection of the means of transportation, the most suitable mode of transport, the temperature of transport, loading, and unloading of food products requiring controlled temperature and humidity.

The main reasons for the organization's interest in increasing the safety of its food flow process include the necessity of strengthening the entrepreneur's position on the market and, most importantly, the need to protect the brand. It seems that the statement by T.T. Kaczmarek and G. Ćwiek is justified. They are convinced that apart from easy to measure direct financial losses resulting from a decrease in turnover, the necessity of incurring additional expenses related to restoration of technical equipment, or the payment of monetary penalties imposed on the company or logistics operator, there can be more challenging to measure losses related to the reputational risk of the organization. Ćwiek and Kaczmarek (2009).

Safety in the food supply chain with controlled temperature and humidity can be understood as a set of procedures to protect chain links from voluntary activities. Although it seems much less likely than theft or smuggling, it is much more acute in its effects due to its possible size or scope, and it will affect human life and health.

A producer who can supervise his supply chain and locate the location of his food products on an ongoing basis is a guarantee of safety of what arrives on our plates.

In conclusion, it should be stressed that the procedure will be effective only if it is possible to locate and withdraw food products that are likely to be contaminated. One of the ways how these measures can be effective and above all efficient is to apply standard solutions for the identification of marketed food products.

6. CONCLUSIONS

Household food expenditure in Poland is quite high compared to Western European countries and amounts to 16.9%, while it is worth noting that from year to year these quotas are decreasing (in 2017 they amounted to 17.2%, and in 2016 - 18%). In 2016, Poland was ranked 29th among 113 countries in the Global Food Security Index. The presence of food security systems (100 points) and food safety (99.7 points) was very highly rated, while Poland's position has been steadily growing in the GFSI ranking for several years. In 2018, Poland was promoted to 26th place (from 27 in 2017), with an overall result of 75.4 (in 2017 it was 74.2, and in 2016 - 74.1). Poland was particularly appreciated for its food standards, the presence of food security systems, farmers' access to financing, and food security. When it comes to the high level of food security systems in Poland, the legal obligation to implement the HACCP system, as well as numerous training actions and co-financing for implementation and certification costs, along with Poland's accession to the European Union, are indeed thought to play a significant role. Subsequently, new norms and standards, such as ISO 22000, BRC, and IFS, which indicated new opportunities for improvement of safety management systems in food production and trade, contributed significantly to the development of the systems in question. Moreover, it is believed that the standards functioning in agricultural production and in the feed industry, such as GLOB-ALG.A.P., QS, GMP+, which raise the quality and safety of raw materials and unprocessed products at the very beginning of the chain, are essential. The standards implemented in Polish maritime transport complement the food safety and defense chain. The article certainly does not exhaust all aspects related to the intentional contamination of food in maritime transport and does not cover all the issues connected with this phenomenon. The authors aimed to create a fundamental basis for further theoretical considerations and in-depth research in this field. Due to the broadly understood security threats in the context of the use of food for terrorist purposes, the subject matter raised is topical, developing and dynamic, and the suggestions put forward should be treated as pilot issues.

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CONCEPTUAL MODEL OF SUPPLY CHAIN IN RISKY ENVIRONMENT: CASE STUDY

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ABSTRACT

The supply chain faces uncertainties, especially with the flow of products and information that may affect the productivity, revenue and competitive advantages of many organizations. It is therefore necessary for these organizations to be agile and resilient enough to meet with these uncertainties so that they may be managed appropriately or even avoided. In a publication by Mensah et.al (2014), the authors introduce a theoretical approach where the 'conceptualization of risks for subsequent simulation-based analysis' is evaluated. This includes the description of 'a generic conceptual model of a retail node' followed by the introduction of performance indicators relevant for simulation base analysis. Hence, a concept for further studies from a practical point of view has now arisen. This article therefore introduces a new case study where the flow of products in a real company is conceptualized for simulation base analysis to raise the awareness of the organization in case of uncertainties.

Keywords: supply chain, uncertainties, risk impact,conceptual model, resilience

1. INTRODUCTION

According to Mensah et.al (2014), modern innovative companies are now outsourcing most of the processes within the supply chain unlike traditional companies that were 'wholly and solely responsible for supplies, manufacturing and distribution'. This outsourcing has made many innovative companies vulnerable to uncertainties including natural disasters, terrorism, cyber-attacks, credit crunch demand risks etc. In fact, Christopher and Peck (2004) support this point by expressing that 'In today's uncertain and turbulent markets, supply chain vulnerability has become an issue of significance for many companies'. An astonishing result of the survey conducted by the Business Continuity Institute (2011) undertaken in more than 60 countries globally involving over 550 organizations, shows that 'supply chain incidents led to a loss of productivity for almost half of businesses along with increased cost of working (38%) and loss of revenue (32%)' (The Business Continuity Institute, 2011). The above has also contributed to the new concept for further studies as discussed earlier in the abstract. The second chapter discuses the supply chain risks adapted from various relevant scientific publications. The third chapter emphasizes on the conceptual model and its benefits in developing a simulation base analysis study from a theoretical point of view. The fourth chapter is a case study analyzing the flow of materials and information etc., within the supply chain of a real company namely, CompanyX.The risk analysisof the supply chain of Company X is assessed in chapter five.This is followed by adeveloped conceptual model with a description of the original system of Company X with its objectives, input and output parameters in the sixthchapter,and possible further studies are discussed in the conclusion.

2. SUPPLY CHAIN RISKS

Although risks may be defined as the probability of occurrence of disruptive events, the supply chain risk is yet to be defined more appropriately. Nevertheless, March and Shapira (1987) define the supply chain risk as the 'variation in the distribution of possible supply chain outcomes, their likelihood, and their subjective values', whilst Peck (2006) states that it is 'anything that disrupts the information, material or product flows from original suppliers to the delivery of the final product to the ultimate end user'. From another perspective, Tang (2006a) classifies risks as 'high profile risks and operational risks'. The highprofile risks include natural disasters like tsunami, earthquakes, hurricane and cyclones etc., however, the more common risks are mainly operational (Tang, 2006). Additionally, Protiviti (2013), elaborates that operational risks are common and many, and they include the following:

- A variety of supply interruption risks
- Demand and supply planning and integration risks
- Purchase price risks
- Inventory and obsolescence risks
- Information privacy and security risks
- Customer satisfaction and service risks
- Contract compliance and legal risks
- Process inefficiency risks
- Product introduction and cycle time risks
- Human resource skills and qualifications risks
- Project management risks

From the above, the supply interruption risks are to be considered with 'seriousness' as they may disrupt the flow of materials and products along the whole chain stimulating a ripple effect that may result in a loss of productivity and revenue. This is followed by the 'demand and supply planning and integration risks' or forecasting techniques that may result in the bullwhip effect. Besides, Lee et al. (1997) accentuate that bullwhip effect are caused by demand forecasting, lead times, batch ordering, supply shortages and price variations. In addition, Merkuryeva et al. (2019) accentuate on the impact of demand risks on the supply chain that may stimulate the bullwhip effect.Another research by BCI involving 519 organizations from 71 countries shows that '75% of respondents still do not have full visibility of their supply chain disruption levels'(BCI,2013). Figure 1 portrays that unplanned IT or telecom outages was the primary source of disruption experienced by 55% of the respondents. Additionally, adverse weather disruption was experienced by 40% of the respondents and outsource service provision failure experienced by 37 % of the respondents. In addition, a study by Juttner et al. (2003) classifies supply chain risks sources into three categories namely; environmental risk sources, organizational risk sources and network-related risk sources as shown in figure 2.

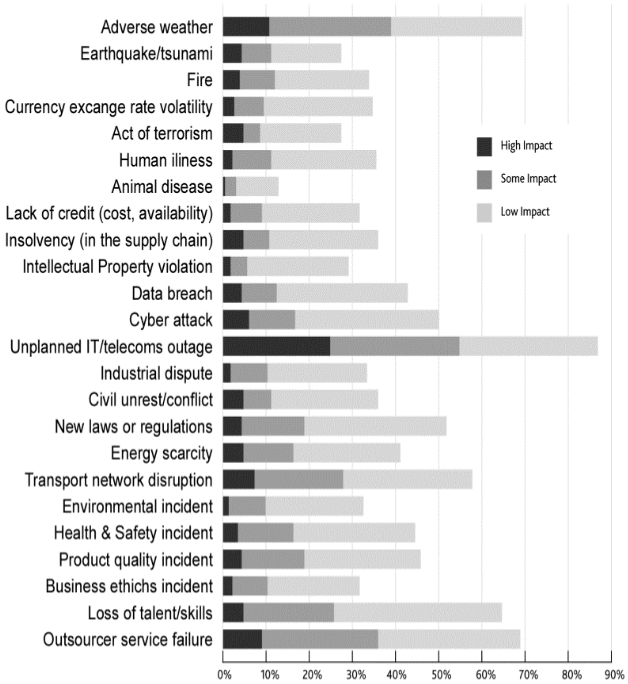

Figure 1: Source of Disruption (BCI, 2013)

The environmental risk sources are 'any uncertainties arising from the supply chain environment interaction' (Juttneret al., 2003). They include natural disasters like earthquakes and extreme weather conditions, socio-political actions like fuel protests or terrorist attacks.
The organizational risk sources are within the organization, and may include labor strikes, production uncertainties such as machine failure and IT system failures. The third category of risks given as the 'network-related risk source' arises due to uncertainties between organizations interacting along the supply chain. It is important for organizations to be aware of the potential risks they may be affected by, and the impact of these risks along their supply chain. In fact, Romanovs (2017) stresses on the importance of mitigating risks within the supply chain. Hence, with appropriate mitigation strategies,organizations will most likely be able to thwart disruptions anywhere along the supply chain.

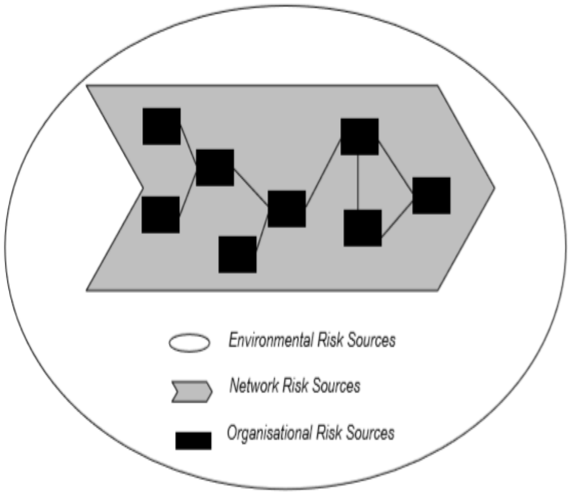

Figure 2: Risks Sources in the Supply Chain (Juttneret al., 2003).

2.1. Mitigating Risks

Organizations should to be able to analyze the uncertainties they are facing and implement adequate mitigation strategies to mange and or avoid the risks they are concerned with.Consequently, a framework for risk management process, given in figure 3, may be applied to analyze and mitigate risks. The framework is divided into three main parts; establishing the content, risk assessment and treating risks.Communicating and consulting are enforced continuously at each stage of the risk management process with the relevant stake holders. After establishing the content pertaining to risk management, the risks are then assessed. The risk assessment is in three stages; identify risks, analyze risks and evaluate risks. Upon identifying the risks, it is necessary for suitable analysis to be made, to be able to determine the impact, frequency and the risk levels. The former leads to evaluating the risks where priorities are made on which risks to manage, to share and or to avoid etc. This makes it possible for the application of resilient managerial strategies for risk treatment in the next stage which must be monitored and controlled to ensure continuous improvements (Council of Standards Australia & Council of Standards New Zealand, 2004). Another framework introduced by Hale and Moberg (2005), consists of five stages that stress on planning, mitigation, detection, response, and recovery in order to mitigate risks. A more detailed framework with nine stages, introduced by Tang (2006b), comprises of postponement, strategic stock, flexible supply base, make-and-buy, economic supply incentives, flexible transportation, revenue management, dynamic assortment planning, and silent product rollover.

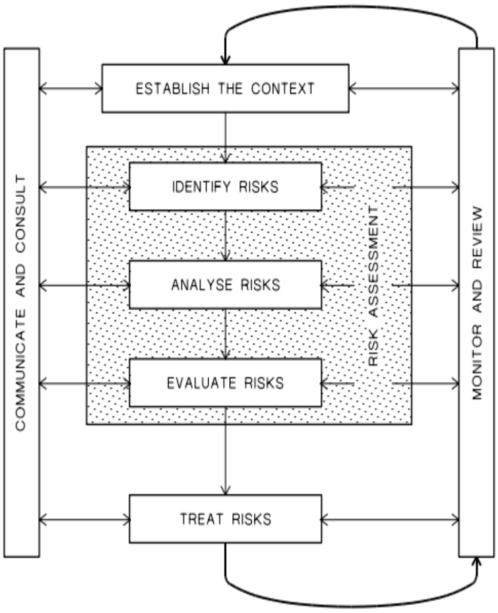

Figure 3: Risk Management Process (Council of Standards Australia & Council of Standards New Zealand, 2004)

Although some managerial strategies for mitigating risks have been discussed above, an effective way of obtaining mitigating strategies and resilience most probably is by exploiting modelling and simulation where it is possible to experiment with various scenarios. This makes it important to have an appropriate conceptual model for simulation base analysis as discussed in the next chapter.

3. CONCEPTUAL MODEL

The conceptual model, which is a ‘steppingstone’ towards developing a simulation model, is being defined by various authors form their own perspectives although they may have some overlapping contents. For instance, Wagner (2014) defines the conceptual model as a ‘ solution independent description of a real world problem domain, from which a platform independent simulation design model can be derived for a given set of research questions’ whilst Robinson (2008) states that the ‘conceptual modelling is the abstraction of a simulation model from the real world system that is being modelled’. In addition, Robinson (2004) further describes the conceptual model as ‘a non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model’. Furthermore, Becker and Parker (2011) highlight that ‘the conceptual model forms the hypothetically complete description of the original system’. Besides the definitions, Merkuryeva and Bolshakov (2015) emphasize on the importance of developing a conceptual model before translating it into a simulation model.The above given definitions synchronize with the introduction of Robinson’s (2014) ‘Artifacts of Conceptual Modelling’ framework, as shown in figure 4. The figure consists of the problem and model domain. The problem situation is within the ‘cloud’, and it is the root cause of the simulation study. After identifying and analyzing the problem, knowledge is acquired, and necessary assumptions are made especially with the absence of some data. The system is then described within the system description artifact enabling model abstraction and simplification leading to the next artifact which is the conceptual model within the model domain. The former then guides the design and development of the next artifact, followed by the model and finally the coding for the computer model (Robinson, 2014).

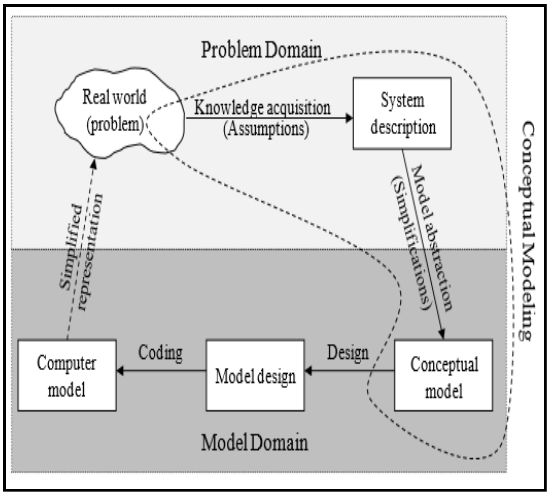

Figure 4: Artifacts of Conceptual Modelling (Robison, 2014)

One of the main benefits of the conceptual model, apart from ‘expressing the modeling objectives, and model inputs and outputs’,is to ‘determine the appropriateness of the model or its parts for model reuse and distributed simulation’ (Robinson, 2014). What is more, Birta and Arbez (2013) highlight that the ‘conceptual model ensures that the key system under investigation features evolve from discussion with all stakeholders rather than from a programming bias’. Likewise, ‘the conceptual model can help to clarify questions about the scope and purpose of a simulation project, and it is an asset that can be reused for making different solution designs for different research questions’ (Wagner, 2014). With reference to the aforementioned, a case study about the supply chain of a real company in risky environment is discussed next.

4. CASE STUDY

Company X, as portrayed in figure 4, is a major distributor for electric stoves and operates in a business to business (B2B) environment. It receives the electric stoves form three factories in Europe and distributes them to four retailers in Latvia. The stoves come in two sizes ‘a’ and ‘b’ with ‘a’ being the largest size.Company X operates under the governance of Factory A, Factory B and Factory C which belong to a Group of company.

The products are sent by trucks from the factories to Company X. Factory A is the main supplier and produces 90% of Company's X total stocks. Factory B and Factory C manufacture the remaining 10% of Company's X total stocks. All the factories are responsible for transportation and its costs from their warehouses to Company X.

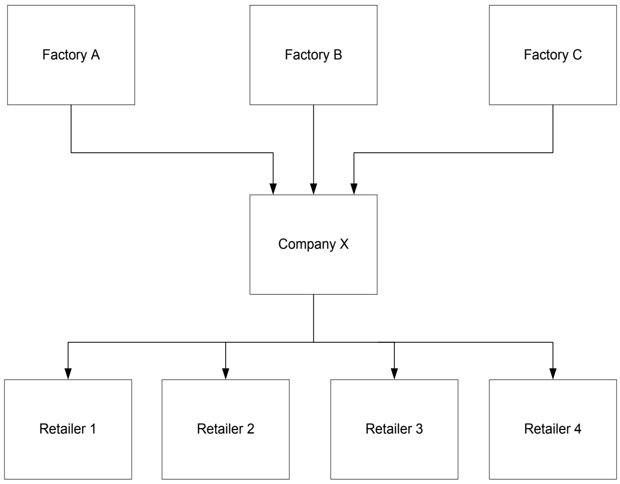

Figure 4: Company X

Factory A has a warehouse with a maximum capacity of 100,000 pieces with 52 delivery trucks with a capacity of 700 pieces per truck. One truck departs Factory A every Monday and offloads at Company X every Wednesday. The factory closes 14 days in July for the overhauling of its machines and equipment etc.

Factory B has a warehouse with a maximum capacity of 5,000 pieces with 12 delivery trucks with a capacity of 500 pieces per truck. The factory closes 14 days in July for the overhauling of its machines and equipment etc. Factory C has a smaller warehouse and suppliers only on 'Just in Time' (JIT) basis. It possesses 12 delivery trucks with a capacity of 200 pieces per truck. The factory closes 7 days in July for the overhauling of its machines and equipment etc. The warehouse at Company X has a total capacity of 8,000 pieces, however, it holds a maximum of 4,500 pieces in peak seasons and automatically orders when the stock drops to 3,800 pieces.

The four retailers place their orders daily from Mondays to Fridays. The orders are accumulated and sent to the factories every Friday. The retailers also provide their own trucks when picking up their goods from Company X.Retailer 1 is the largest retailer and constitutes 65% of Company's X sales. It collects its products every Mondays and Wednesdays and ordered a maximum of 36,000 pieces in the year 2018.Retailer 2 is the second largest retailer and constitutes 15% of Company's X sales. It collects its products every Friday and ordered a maximum of 8,000 pieces in the year 2018.Retailers 3 and 4 only are the smallest with each constituting 10% of Company's X sales. They can collect their goods any day as the number of products is relatively small. They ordered a maximum of 6,000 pieces each in the year 2018.Only Company X, Factory A and the retailers will be considered in this case study due to the limitation of data. Consequently, the supply chain operations of Company X have been developed as shown in figure 5.With reference to figure 5, Factory A receives order every Friday from Company X. After receiving the order, Factory A checks to see if the ordered products are available at the warehouse. If the products are available, they are uploaded and transported to Company X, provided the trucks are available, on the immediate Monday.

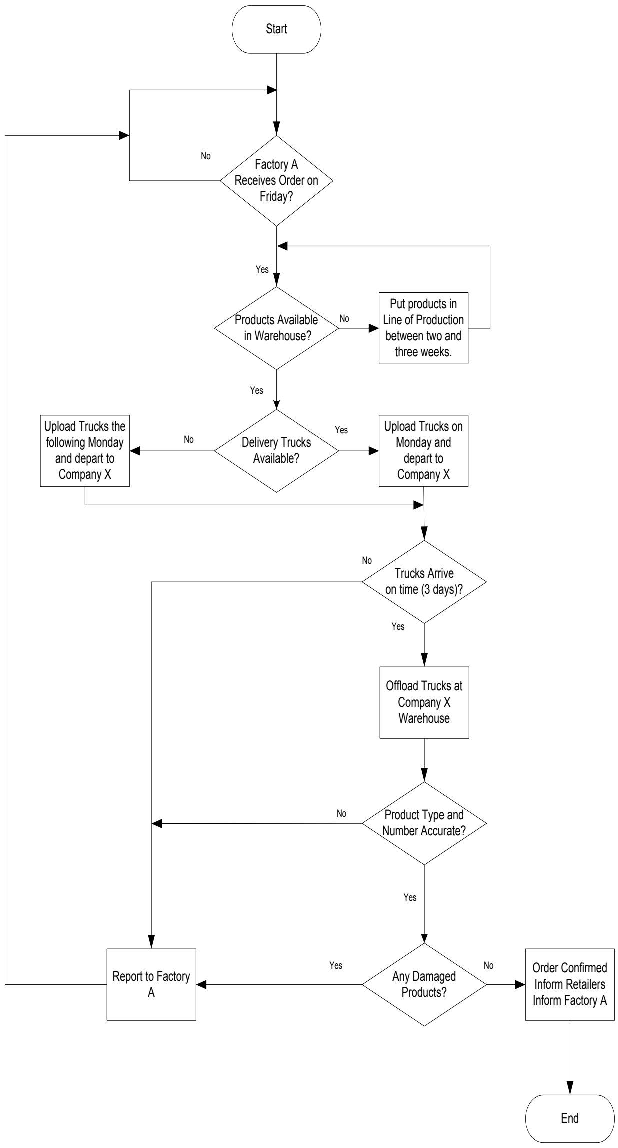

Figure 5: Company X Supply Chain Operations

On the other hand, unavailable products are put in line of production between two and three weeks and delivered to Company X the following Monday after availability. The delivery time is usually three days. On arrival, Company X offloads the goods and checks to see if the product type and number are accurate. Assuming that the product types and number are accurate with no damaged products, the delivery is confirmed, and the retailers are informed. In case ofinaccuracies with the number and or quality of products, a report is sent to Factory A.

5. RISK ANALYSIS OF COMPANY X

The risks within the supply chain of the Company X that may affect product flow are being considered in this case study. As there is only one major supplier providing 90% of Company X products, any disruption with the major supplier will create a ripple effect down to the retailers whereby the retailers are not provided with their products on time. Risks affecting Company X include demand risks, delayed delivery risks, inventory risks, IT breakdown, delayed products and damaged products etc., as shown in figure6. The demand risk most probably is due to the bullwhip effect yielding to inaccurate forecasting. Seasonality also affects demand as the high season is from May to September. Delayed delivery is mainly affected by unavailable products as they are put in line of production between two and three weeks. Additionally, transportation problems such as truck breakdown, unavailable trucks and even bad weather conditions may hinder on the time of delivery.

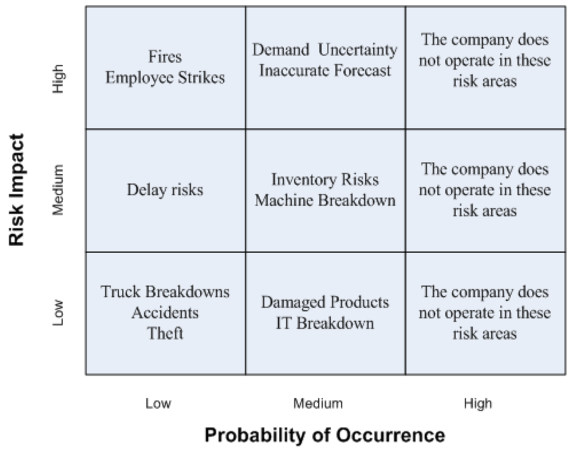

Figure 6: Probability of Risk Occurrence and Impact: Company X

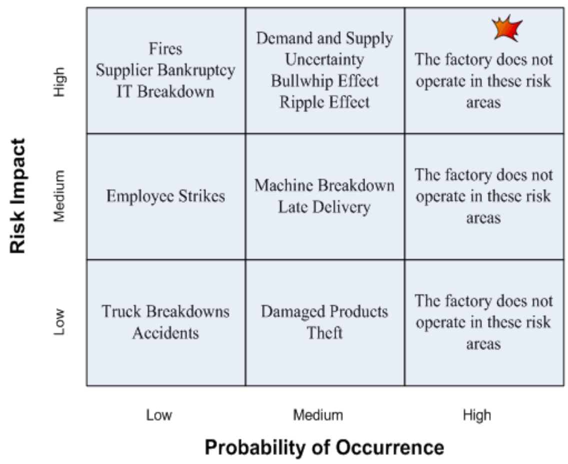

Figure 7: Probability of Risk Occurrence and Impact: Factory A

The cost ofholding inventories is mainly considered as inventory risks at Company X. Factory A, on the other hand, may face disruptions like machine breakdown, transportation risks including truck breakdowns and accidents, employee strikes, damaged products, IT breakdown and theft as illustrated in figure 7.

6. CONCEPTUAL MODEL OF COMPANY X

The conceptual model of Company X is provided in figure 8 with reference to Robinson's (2004) approach. From the figure, the input data are the experimental data and events whilst the output data are the performance measure and estimates.

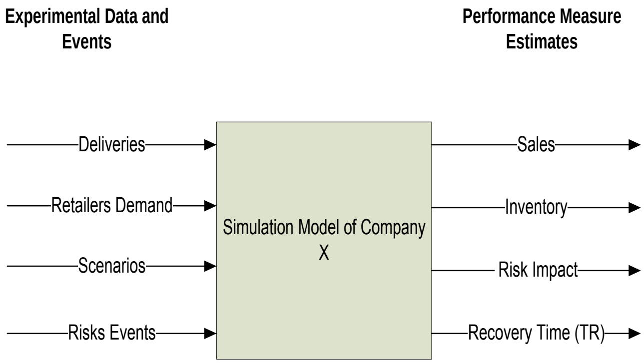

Figure 8: Conceptual model of Company X

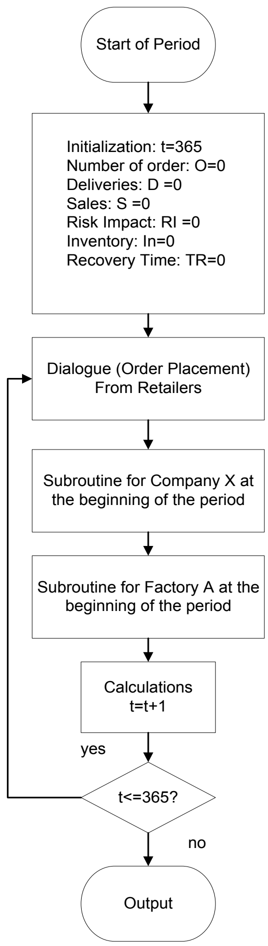

Figure 9: Basic Algorithm of the Simulation Model of Company X

The simulation model of Company X accepts input data from the left and provides output on the left. Deliveries, retailers' demand, different scenarios and risk events are the experimental data and events, and the performance measure and estimates are represented by sales, inventory, risks impact and recovery time.

As indicated earlier in chapter 4, Company X accumulates orders and sends them to the factories by email every Friday. The factories deliver available products every Wednesday and the non-available products are put in line of production between one and two weeks increasing the lead time as mentioned earlier on in the case study. A basic algorithm of the simulation model of Company X is given in figure 9. The initialization period is 365 days, but the number of orders, sales, delivery time, risk impact and time to recovery are all set to zero at the beginning of the simulation. The simulation repeats *(t=t+1)* if the time is less than 365 days and equal to zero, and ends when the time is greater than 365 days.

Further studies: Since the conceptual model is available, two simulation models have to be developed:

- simulation model without the risks
- simulation model with the risks

The simulation model with the risks is used for experimental purposes to study the ripple effect of the product along the supply chain of Company X from the upper stream down to the bottom stream of the supply chain of Company X. The study will also the examine the maximum time it will take Company X to match supply and demand after disruptions and how long it will take Company X to fully recover after disruptions.

7. CONCLUSION

A conceptual model has been developed as a novel approach to foster resilient strategies within the supply chain, whereby managers would be able to make appropriate decisions in case of uncertainties. The article has analyzed the risks and their impacts within the supply chain as well as conceptual models from both theoretical and practical perspectives. After having some dialogues with the supply chain manager of Company X about its supply chain operations and possible risks events that might hamper the flow of materials, the authors have developed a 'Flowchart of Company X Operations' and a conceptual model of Company X. The conceptual model is essential for the development of the simulation model to make it possible to study the impact of disruptions on the flow of products from the factories down to the retailers by experimenting various risks scenarios. This will make it possible for the company to be aware of the impact of the risks on sales and inventories. As a result, appropriate resilient strategies may be developed to reduce the lead times during disruptions as well as the time to recovery for normal operations. However, more historical data need to be collected on the flow of products and demand within the supply chain of Company X to make this possible. Simulation software such as AnyLogistix and or Simul8 will be used for the simulation model.

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AN ALGORITHM FOR THE CAPACITATED VEHICLE ROUTING PROBLEM FOR PICKING APPLICATION IN MANUAL WAREHOUSES

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ABSTRACT
Given that warehouses play a central role in modern supply chains, this study proposes the application of an algorithm for the capacitated vehicle routing problem (CVRP) based on the two-index vehicle flow formulation developed by Baldacci, Hadjiconstantinou, and Mingozzi (2004) for picking purposes in manual warehouses. The study of Theys et al. (2010) is first used to represent the warehouse using a Steiner traveling salesman problem (TSP). Then, a calculation of the picking tour's length is obtained applying the Manhattan distance. Finally, the algorithm for the CVRP is solved through a cutting plane with the addition of termination criteria related to the capacity of picker. The study analyzes four different warehouse configurations, processing five picking list each. The analysis is carried out exploiting the commercial software MATLAB®, to determine the solution that minimize distance of the order picking tour. The results obtained in MATLAB® show the effectiveness of the chosen algorithm applied to the context of manual order picking.

Keywords: order picking, picking distance, capacitated vehicle routing problem, manual warehouse.

1 INTRODUCTION

Warehouse management is a primary issue for logistics companies (Cheng et al. 2015). The logistics cost relating to warehouse processes, including receiving, storage, order picking and shipping, is often high (De Santis et al. 2018). Among these internal operations, order picking, i.e. the process of retrieving products from their storage locations in a warehouse in order to satisfy the requests of the customers, is an important and yet tedious task (Hsieh and Tsai 2006; Muter and Öncan 2015). To be more precise, order picking process is considered the most laborious task in warehouses accounting for up 65% of the total operating costs (Gademann and van de Velde 2005; De Koster, Le-Duc, ans Zaerpour 2012; Žulj et al. 2018). For this reason, both researchers and logistics managers consider order picking as a promising area for productivity improvement (De Santis et al. 2018).

The travel time of pickers is an increasing function of the travel distance, which was investigated in many papers and considered one of the primary optimization conditions (Karasek 2013). The travel time is influenced by order picker routing policies, which determine the sequence of item retrieval in the warehouse and the sequence in which aisles are traversed (Grosse, Glock, and Ballester-Ripoll 2014). However, the performance depends greatly on the layout and size of the warehouse, the size and characteristics of orders and the order-picker capacity (Dukic and Oluic 2007; Bottani, Montanari, and Rinaldi 2019). Sure enough, the problem becomes more complex if the carrying capacity of the order picker is limited (Grosse, Glock, and Ballester-Ripoll 2014).

The problem of picking an order is the one of determining the sequence in which locations should be visited to minimize total cost (or time), which leads to the traveling salesman problem (TSP) (Daniels, Rummel, and Schantz 1998). In particular, the generic order picking problem is configurable as a Vehicle Routing Problem (VRP), which consists of constructing a set of at most *m* vehicle routes of least total distance, according to a portfolio of capacity and time constraints, and in order to simultaneously satisfy a group of retrieval requests (Ferrari, et al. 2003).

However, according to our knowledge, the picker's capacity is rarely considered when dealing with order picking problems. A VRP algorithm (and in particular an algorthm for the CVRP problem) is expected to well capture the order picking problem in the case of capacity constraints.

These gaps will be addressed in the present study, by applying an algorithm for the capacitated vehicle routing problem (CVRP) to the manual picking process. The chosen algorithm has been proposed by Baldacci, Hadjiconstantinou, and Mingozzi (2004) and is based on the two-index vehicle flow formulation. The result of the algorithm, i.e. the estimate of the picking distance, shows the effectiveness of this algorithm to solve a manual order picking problem with capacity constraints.

The paper proceeds as follows. The next section describes the simulation strategy adopted to estimate the picking distance and provides some preliminary information about the warehouse under examination.

Section 3 details the configurations considered and the main results obtained in this study. Section 4 discusses the main findings and concludes by highlighting the main limitations of this work and suggesting future research directions.

2 METHODOLOGY

2.1 Algorithms

From a methodological point of view, the study of Theys et al. (2010) is first used to represent the warehouse using a Steiner TSP; then, a calculation of the picking tour's length is obtained applying the Manhattan distance. Finally, the algorithm for the CVRP developed by Baldacci, Hadjiconstantinou, and Mingozzi (2004) is solved through a cutting plane with the addition of termination criteria related to the capacity of picker. The analysis is carried out exploiting the commercial software MATLAB®, to determine the best solution that minimize distances of the order picking tour.
To be more precise, in the following we will present the formulation of the CVRP.
A graph G= (V', E) is given where V'={0,1,…,n} is the set of n+1 vertices and E is the set of edges. A nonnegative cost d_{ij} is associated with each edge {i, j}∈E. Let OP=={1,…,op} be the number of order picker with same capacity Q located in depot. Also, let OP(S) be the number of order picker with Q capacity required to pick up the required items in S.
The integrality constraint is defined as follows:

$$x_{ij} = \begin{cases} 1, \forall (i,j) \in E \backslash \{\{0,j\}: j \in V\} \\ 0, \quad otherwise \end{cases} \qquad (1)$$

Now, the two-index problem can be mathematically formulated as the follows:

$$minimize\ (F)\ z(F) = \sum_{\{i,j\} \in E} x_{ij}\, d_{ij} \qquad (2)$$

$$\sum_{\{i,j\} \in \delta(\{h\})} x_{ij} = 2, \forall h \in V \qquad (3)$$

$$\sum_{\{i,j\} \in \delta(\{S\})} x_{ij} \geq 2OP(S), \forall S \in T \qquad (4)$$

$$\sum_{j \in V} x_{0j} = 2OP \qquad (5)$$

where T={S:S⊆V, |S|≥2}. Constraint (3) is the degree constraints for each customer, i.e. each vertex must have an incoming and an outgoing arc. Constraint (4) is the cutting constraint which, for any subset S of customers that does not include the depot, imposes that at least OP(S) vehicles enter and leaves S. Constraint (5) states that OP vehicles must leave and return to the depot.

The solution of the problem is not unique, because of the presence of more pickers. Hence, when running the algorithm, MATLAB® returns the first solution found that satisfies constraints 2-5. A check has been set in MATLAB® to verify that the solution returned meets the capacity constraint. In the case the solution found also meets this constraint, it is considered as the optimal solution to the problem. Otherwise, the algorithm is run again to identify a new solution.

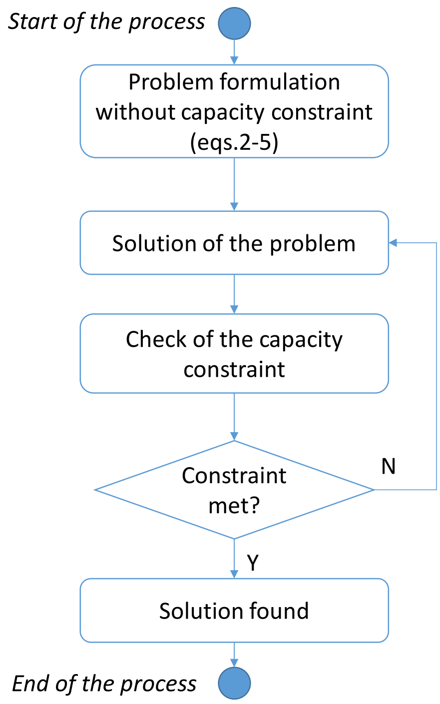

Figure 1: Flowchart of the algorithm in MATLAB®

2.2 Warehouse settings

The picking environment in this paper is as follows:

- rectangular warehouse;
- manual picker-to-parts order picking system;
- random storage of items in the warehouse;
- depot located at the top left corner of the warehouse;
- the picking area uses double-side shelves with a total storage capacity of 640 SKUs;
- each SKUs is 1.30x1.00 meter in width and depth, respectively;
- aisle width is 2.50 meters.

3 CONFIGURATIONS ANALYSIS

For the purpose of testing the algorithm in various settings, 4 different warehouse configurations are evaluated in this study:

- One block warehouses – 10 items –picker capacity = 300
- One block warehouses – 20 items –picker capacity = 600
- Three block warehouses – 10 items –picker capacity = 300

- Three block warehouses – 20 items –picker capacity = 600.

For each configuration, 5 picking lists of the same length are processed.

To model a capacity constrained problem, a weight is assigned to each item in the warehouse. The weight, expressed in kg, is generated by MATLAB® as a random number with values ranging between 0 and 100 (step 1). The picker's capacity instead, depends on the length of the order picking list: for a picking list of 10 items, the picker's capacity is set at 300, while for a picking list of 20 items, the picker's capacity is set at 600. In the picking lists with an equal number of items (i.e. 10 or 20), the same products (weights) are considered, regardless of the warehouse layout. The same consideration can be made for picking lists of 20 items. Moreover, the instances of the problem are calculated for a number of pickers equal to two and three.

In the following sections, the analysis of various configurations for the estimation of the picking distance is shown. For all configurations, an evaluation of the distance and computational time required to order picking activities is provided.

3.1 One block warehouses – 10 items – picker capacity=300

In this scenario, the configuration with one block warehouses, picking list of 10 items and picker's capacity of 300 is analyzed. The results obtained from application of the algorithm are shown in Table 1 for the five order lines for the reference configuration.

Table 1: Order picking distance for one block warehouses with 10 Items (picker's capacity = 300)

ORDER LINE	TOTAL WEIGHT [kg]	NUMBER OF PICKERS	WEIGHT FOR PICKER [kg]	DISTANCE [m]	COMPUTATIONAL TIME [s]
1	408	2	185	**326.4**	2.456
			223		
		3	21	**348.8**	2.615
			204		
			183		
2	379	2	273	**278.4**	1.278
			106		
		3	21	**319.2**	1.012
			106		
			252		
3	632	2	-	-	-
			-		
		3	260	**432.2**	0.978
			75		
			297		
4	485	2	279	**280.2**	1.322
			206		
		3	34	**306.6**	1.159
			184		
			267		
5	424	2	138	**258.6**	1.322
			286		
		3	21	**268.8**	1.021
			111		
			292		

As can be seen from Table 1, for all order lines, when increasing the number of pickers, a longer order picking distance is found. Nonetheless, it is interesting to note, that in the third order line with two pickers, the constraint of the picker's capacity is not met; for this order line, therefore, the shortest distance is obtained where the number of pickers equals 3. Whereas, the trend of the computational time generally is inverse: decreasing the number of pickers involves an increase in the computational time. For first order line only, decreasing the number of pickers generates a lower computational time.

3.2 One block warehouses – 20 items – picker capacity=600

In this scenario, the configuration with one block warehouses, picking list of 20 items and picker's capacity of 600 is analyzed. The picking distances and computational times are shown in Table 2 for the five order lines evaluated.

Table 2: Order picking distance for one block warehouses with 20 items (picker's capacity = 600)

ORDER LINE	TOTAL WEIGHT [kg]	NUMBER OF PICKERS	WEIGHT FOR PICKER [kg]	DISTANCE [m]	COMPUTATION TIME [s]
1	787	2	193	**430.4**	3.875
			594		
		3	21	**450.8**	2.273
			172		
			594		
2	1117	2	580	**496.8**	2.491
			537		
		3	580	**517.2**	2.354
			34		
			503		
3	884	2	599	**418.6**	2.532
			285		
		3	270	**428.8**	1.934
			593		
			21		
4	948	2	383	**522.2**	3.215
			565		
		3	35	**532.4**	2.773
			331		
			582		
5	1198	2	600	**525**	141.276
			598		
		3	75	**539**	211.992
			546		
			577		

As can be seen from the table above, for all order lines, decreasing the number of pickers involves a shorter order picking distance. It is interesting to note that the trend of the computational time is opposite: when increasing the number of pickers, the computational time decreases. For the last order line only, decreasing the number of pickers causes a decrease in the shorter computational time as well.

3.3 Three block warehouses – 10 items – picker capacity=300

In this scenario, the configuration with three block warehouses, picking list of 10 items and picker's capacity of 300 is analyzed. The picking distances and computational times obtained with this configuration are shown in Table 3.

Table 3: Order picking distance for three block warehouses with 10 items (Picker's Capacity = 300)

ORDER LINE	TOTAL WEIGHT [kg]	NUMBER OF PICKERS	WEIGHT FOR PICKER [kg]	DISTANCE [m]	COMPUTATION TIME [s]
1	408	2	247 161	**273.4**	3.2681
		3	21 173 214	**313.8**	1.6411
2	379	2	84 295	**263.7**	1.1561
		3	63 21 295	**304.5**	0.9844
3	632	2	- -	-	-
		3	75 297 260	**336.5**	1.6062
4	485	2	189 296	**251.6**	1.255
		3	70 119 296	**284.3**	1.6078
5	424	2	135 289	**234.6**	1.3793
		3	111 24 289	**255**	1.4678

As can be seen from Table 3, for all order lines, again the increase in the number of pickers involves a (slight) worsening of picking distance. Nonetheless, it is interesting to note that for the third order line with two pickers the constraint of picker's capacity is not respected. This result was also found in the configuration with one block warehouse and two pickers. For this order line, therefore, the shortest distance is obtained when the number of pickers equals 3. However, in this configuration, the computational time does not follow a linear trend: sometimes, it increases with the increase in the number of pickers, while sometimes it decreases.

3.4 Three block warehouses – 20 items – picker capacity=600

In this scenario, the configuration with three block warehouses, picking list of 20 items and picker's capacity of 600 is analyzed. The results obtained from application of the algorithm are shown in Table 4 for the five order lines for the reference configuration.

Table 4: Order picking distance for three block warehouses with 20 items (Picker's Capacity = 600)

ORDER LINE	TOTAL WEIGHT [kg]	NUMBER OF PICKERS	WEIGHT FOR PICKER [kg]	DISTANCE [m]	COMPUTATION TIME [s]
1	787	2	193 594	**336.1**	2.964
		3	21 172 594	**376.5**	4.147
2	1117	2	580 537	**326**	2.696
		3	34 580 503	**357.9**	2.883
3	884	2	285 599	**317.3**	19.749
		3	46 239 599	**337**	10.023
4	948	2	412 536	**342.6**	1.770
		3	35 377 536	**360.8**	1.646
5	1198	2	598 600	**361.2**	6.856
		3	75 575 548	**392.9**	1.827

The results shown in the table above confirm the trend previously observed, i.e. for all order lines, decreasing the number of pickers involve a decrease in the picking distance. However, it is interesting to note that in this configuration, the computational time does not follow a linear trend: sometimes, it decreases with the number of pickers, while sometimes it increases.

4 DISCUSSIONS AND CONCLUSIONS

This paper has proposed an application of an algorithm for the CVRP based on the two-index vehicle flow formulation developed by Baldacci, Hadjiconstantinou, and Mingozzi (2004) for the problem of minimizing the travel distance of pickers in manual warehouses. In particular, the study of Theys et al. (2010) was first used to represent the warehouse using a TSP. The estimate of the picking tour's lenght was then obtained through the Manhattan distance. Finally, the algorithm for the CVRP developed by Baldacci, Hadjiconstantinou, and Mingozzi (2004) is solved through a cutting plane with the addition of termination criteria related to the capacity of picker. The rationale for the choice of this algorithm is that the picking problem is frequently modelled as a TSP, of which the VRP is a special case; therefore, a VRP algorithm is expected to well capture the order picking problem. Moreover, CVRP model by Baldacci, Hadjiconstantinou, and Mingozzi (2004) takes into account the vehiche capacity in the problem formulation. This is an important (and innovative) point, as the picker's capacity, on the contrary, is rarely considered when dealing with order picking problems. Rather, when modelling a manual order pickng process, researchers typically assume that the picker has enought capacity to pick all the items included in the picking list.

In general terms, the best results from the proposed approach were observed with three block warehouses, in terms of the total distance covered. To be more precise, considering the first picking list of the first and third configuration (picking list of 10 items), it is interesting to note that the best solution in terms of distance travelled is returned by the three block warehouses configuration, both in the scenario with two and three pickers. The outcomes can be used by warehouse and logistics managers to identify the configuration of warehouses on which to focus with the aim to reduce the travel distance (and thus the order picking cost), considering the capacity of picker.

From a technical perspective, it should be mentioned that the results obtained with the proposed approach

cannot be compared with either the traditional heuristic routing policies (e.g. S-shape, largest gap or return) or with metaheuristic approaches available in literature, because none of these approaches takes into account the capacity of the picker when modelling the problem. Therefore, a benchmark to evaluate the performance of the proposed approach is not available (to the best of the authors' knowledge) at the time of writing. This could be seen as a limitation of the present work, as it prevents judging the performance of the proposed model. At the same time, however, as this paper takes into account the picker's capacity among the problem constraints, the results returned could represent a viable benchmark for similar studies to be carried out in the future.
A further limitation of the analysis made in this paper is that the present work does not take into account the combination of several orders into a single order to fulfill small orders (e.g., online orders directly by the final customer) in a batch picking process. Similarly, the situation with large orders, that need to be split up into smaller batches that are to be picked successively, is not taken into account in the model, as well. This could be a future adjustment to be made to the problem modelled. Finally, multiple order pickers in the same area can cause wait times due to picker blocking and increases the risk of accidents in the warehouse; these aspects are not included in the present evaluation, so they could be considered in future research activities.

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A CONCEPTUAL MODEL FOR ASSESSING THE IMPACT OF INTERNET-OF-THINGS TECHNOLOGIES FOR PEOPLE WITH REDUCED MOBILITY IN AIRPORTS

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ABSTRACT
The European Union has regulated by law the elimination of barriers to guarantee the right to free movement, freedom of choice and non-discrimination of people with reduced mobility (PRM). This regulation also affects air transport. More specifically, airports of the member states must offer a quality assistance service to PRM, with the adequate human and technical resources to guarantee their rights. The changing characteristics of the operation of an airport (delays, cancellations, breakdowns, etc.) add great complexity to the design and management of a PRM service. Internet of Things (IoT) technologies pose a unique opportunity to integrate new services and solutions to deal with these problems. This work focuses on the use of modeling and simulation techniques for the evaluation of the impact of the incorporation of new IoT-based elements (such as autonomous vehicles, smart devices and 5G-enabled systems), for the improvement of the PRM service.

Keywords: workstation People with reduced mobility, Internet-of-Things, airports, simulation model.

1. INTRODUCTION

In the European Union, as stated in Regulation (EC) 1107/2006 of the Parliament European Union (European Parlament 2006), in force since July 26, 2008, "disabled persons and persons with reduced mobility, whether caused by disability, age or any other factor, should have opportunities for air travel comparable to those of other citizens. Disabled persons and persons with reduced mobility have the same right as all other citizens to free movement, freedom of choice and non-discrimination. This applies to air travel as to other areas of life". Moreover, "in order to give disabled persons and persons with reduced mobility opportunities for air travel comparable to those of other citizens, assistance to meet their particular needs should be provided at the airport as well as on board aircraft, by employing the necessary staff and equipment. In the interests of social inclusion, the persons concerned should receive this assistance without additional charge.".

Since the entry into force of the op cited regulation, the service of attention to people with reduced mobility (PRM) in European airports has reported a significant increase in the number of attendances. Taking Spanish airports as a reference, about 1 million attendances were made, representing 0.53% of total passengers (Aena 2009), whereas in 2017, more than 1.5 million attendances were performed (0.61% of total passengers) (Aena 2017),. Around 1% of the passengers that transit through an airport require assistance from the PRM service. Large European airports record, on average, more than 500 attendances per day. For example, the London Gatwick airport transported more than 32 million passengers in 2009, and registered an average of 900 attendances per day (Reinhardt, Clausen, and Pisinger 2013),. At the Canary Islands, Tenerife Sur Airport offers assistance to approximately 1% of the 11 million passengers it serves, recording days in which more than 700 attendances were made.
The PRM service at European airports can be classified according to the passenger's flight phase in the following three types of assistance: departure, arrival and transit.

- Assistance at the airport of departure: assistance starts at one of the airport meeting points intended for this purpose. Some of the tasks of assistance to the PRM are: support in billing tasks, assistance in the displacement of carry-on luggage, support for security checks, escort to the pre-boarding area, boarding the aircraft and moving to the seat assigned
- Assistance at the arrival airport: assistance starts on the aircraft itself with the displacement from the seat to the door of the aircraft. In addition, the tasks of assisting the PRM include the disembarkation of the aircraft, travel to the baggage hall, support in security controls and accompaniment to a meeting point.
- At transit airports or connections: assistance includes all the necessary tasks to carry out with successful transit or connection of the PRM, including if necessary boarding

maneuvers, disembarkation, terminal transfer, etc.

In relation to financing, Regulation (EC) 1107/2006 of the European Parliament (European Parlament 2006), states that "Assistance should be financed in such a way as to spread the burden equitably among all passengers using an airport and to avoid disincentives to the carriage of disabled persons and persons with reduced mobility. A charge levied on each air carrier using an airport, proportionate to the number of passengers it carries to or from the airport, appears to be the most effective way of funding." Therefore, the optimization of PRM service costs becomes more relevant since it affects air transport rates in general.

Starting from the hypothesis that the management and development of the assistance service to PRM in European airports will continue to increase its complexity due to the annual increase in attendance and the higher level of punctuality and comfort of airport services. We also consider that, due to European regulation, the cost of the PRM assistance service has an impact on air transport rates in general. And moreover, taking into account that the planning of the operation of an airport can be affected by cancellations, deviations and large flight delays, as well as by many other causes such as adverse meteorological conditions, system failures, security alerts, among others.

The main objective of this research is the study of a conceptual model that allows, by means of simulation techniques, analyzing the introduction of Internet-of-Things (IoT) enabled services for the assistance to PRM in airports.

2. LITERATURE REVIEW

There is a limited amount of published papers that deal with modeling and simulation of PRMs in airports. Reinhardt, Clausen, and Pisinger (2013) present a heuristic algorithm based on simulated annealing for the planning of the assistance service for PRMs. The objective of the algorithm is finding solutions that attend to the greatest number of passengers in an optimal time. Reindhardt et al. treat this problem as a Dial-A-Ride Problem (DARP) problem, which is a generalization of the Pickup and Delivery Problem (PDP). The proposed technique is applied to an airport that employs 120 workers who perform a range between 300 and 500 attendances a day which should receive a solution in 2 minutes. The authors aim at offering fast solutions to reprogramming the PRM assistance, since there are many changing conditions of the operations of the airport due to unforeseen situations such as delays and cancellations of flights, unforeseen assistance, breakdowns, etc.

Yorukoglu and Kayakutlu (2011) present a model based on Bayesian networks of a civil aviation ground operations system, which aims to serve as a tool for making decisions that minimize delays and reduce the number of complaints of PRMs. The authors propose the use of Bayesian networks to determine the influence of the causes of delays coded by the International Air Transport Association (IATA) with the complaints factors of PRMs and vice versa.

Arcidiacono, Giorgetti, and Pugliese (2015) analyze the flow of PRMs who enter, exit and transit through a passenger terminal by means of axiomatic design techniques. They take as a reference the service assistance for PRM at an Italian tourist airport consisting of 4 terminals, as well as an additional one (T5) dedicated to the departure of particularly sensitive flights due to the risk of a terrorist attack.

Most of the found papers deal with boarding and disembarking PRMs, since these processes have a notable impact on delays and claims. Holloway et al. (2015) compare the strength and time required for two methods of boarding passengers in wheelchairs. They focus on the maneuver of boarding the wheelchair and do not include the processes of transferring the passenger to and from the wheelchair. Schultz (2017), and Molenaar, Gabrielli and Pudlo (2015) analyze different boarding strategies, with special emphasis on PRMs. While Molenaar, Gabrielli and Pudlo (2015) carry out a study of the cost of the different strategies, Schultz (2017) incorporate the use of the Side-Slip Seat technology into these strategies. This technology allows the reconfiguration of the seats of an aircraft in such a way that the width of the aisle or of some seats can be extended, thus facilitating the PRM boarding. Finally, although more generic in his approach, Schultz (2018) includes PRMs in his stochastic model of the passenger boarding process presents.

3. CONCEPTUAL MODEL FOR THE PRM ASSISTANCE SERVICE

None of the found contributions focus on assessing how PRMs can benefit from new technologies. Hence, a conceptual model that allows for the incorporation of such technologies into the PRM flows is required.

Of the possible passenger flows of the PRM assistance service at airports, five main flows stand out: departure, arrival, remote boarding, remote disembarking and transit. These passenger flows are related to each other, since they share service resources (assistants, ambulifts, among others) and the incidences of a workflow can affect the rest. However, for the sake of simplicity, it is advisable to divide the problem and study each of the flows separately to later integrate them in a global solution.

Passengers who need assistance, such as PRM, must make a prior booking both in the departure and the arrival flows. Requests without prior booking are attended anyway, but add uncertainty and complexity to the planning of the resources of the service.

The departure flow begins with the arrival of the passenger at one of the meeting points of the airport, at the time scheduled in the reservation. Then, an assistant takes the PRM to perform the check-in tasks. Subsequently, the assistant supports the PRM to pass the security controls. Depending on the type of flight, the PRM may require to pass the passport control process. Next, the assistant takes the PRM to the pre-boarding area. Finally, if the aircraf is parking in remote stand, the remote boarding flow is applied; but nevertheless if the boarding uses a finger the boarding process is performed. In the boarding process, one or more assistands (depend on the PRM) transfer the PRM from the boarding area prior to their assigned seat. In addition, it must be borne in mind that between the phases of arrival of the passenger and the pre-boarding there may be interruptions. “Interruptions” are moments in which the service is suspended at the request of the PRM to perform actions without assistance such as going to the toilet, buy or eat, among others. Figure 1 presents an outline of the departure flow.

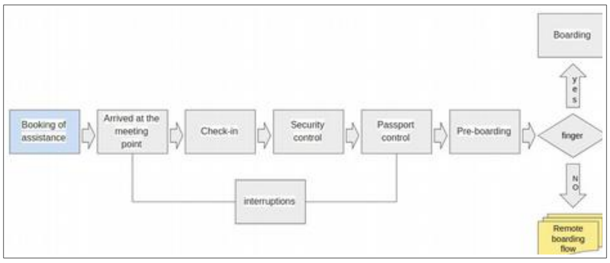

Figure 1: Departure flow

The arrival flow begins with the disembarkation process. In the case of a flight being disembarkation by finger, the disembarkation process consists of one or more attendants (depend on the PRM) moving to the PRM from the aircraft to the terminal airport. However, if the finger is not used, the remote disembarkation flow is performed. In the next step of the arrival flow, and if the flight requires it, the assistant takes the PRM to passport control. Then, the PRM should arrive at the baggage claim area. Finally, the assistant accompanies the PRM to the departure point of the airport, which may include, among others, the seat of a taxi, or a meeting point with a family member or friend who picks it up. We must emphasize that, as in the outflow, in the arrival flow there may be interruptions between the arrival phase to the terminal until it leaves the airport. Figure 2 presents a diagram of the arrival flow.

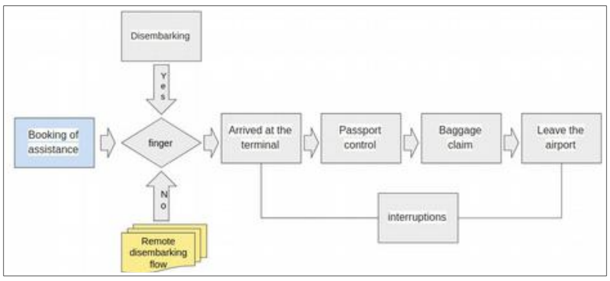

Figure 2: Arrival flow

In the remote boarding and disembarking flows, special vehicles called ambulifts facilitate the transport of the PRM to the aircraft door. The management and planning of the use of ambulifts is a key element in the optimization of the service associated with flights stationed remotely.

The remote loading flows begin at the ambulift loading docks, where the assistants ride the PRMs in an ambulift. The ambulift transport the PRMs and the assistants to the remote location where the aircraft is placed. Subsequently, Airport staff connects the ambulift to the plane and the assistant accomodates the PRM at his/her seat. Figure 3 presents a scheme of the remote approach flow.

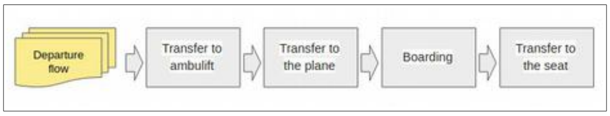

Figure 3: Remote boarding flow

In the case of remote disembarking, the flow starts with the PRM seated in the aircraft cabin. First, one or several assistants (depend on the PRM) move the PRM from his/her seat to the ambulift, then the ambulift makes the transport to the terminal building, and the assistants get the PRMs out from the ambulift to the terminal building. Figure 4 presents a diagram of the remote disembarking flow.

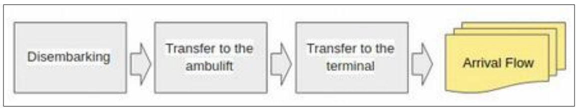

Figure 4: Remote disembarking flow

Figure 5: Ambulift

For in-transit PRMs, the basic flow begins with the disembarking process. An assistant transfers the PRM to the pre-boarding area of their departure flight and the flow terminates with the boarding. It must be borne in mind that between the phases of passenger arrival and the pre-boarding, as well as in the flows of arrivals and departures, there may be interruptions and the process of boarding and disembarking could be remote or through fingers. Figure 6 presents an outline of the basic transit flow.

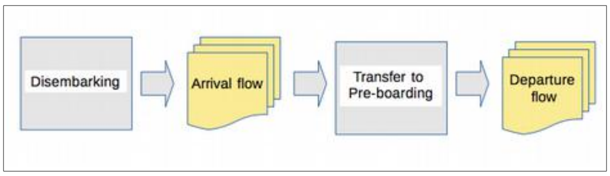

Figure 6: Basic transit flow

In the case of the in-transit PRMs, there are characteristics of the flight or the airport that may modify the basic flow of the passenger. Considering the characteristics of the airport, the flow may be modified if different terminals are available between incoming and outgoing flights for in-transit PRMs. With regards to the type of flight, transits between national and international flights require passing the passport control process. Besides, if the PRM is carrying out a link with different airlines, he/she will require the luggage collection and the check-in process, similarly to performing a combined arrival and departure flows.
The integration of arrival and departure flows requires considering that the aircraft that make a flight arriving at the airport also have a departure flight associated, unless the flight sleeps at the airport and performs the departure flight another day. The integration of arrival and departure flows requires considering that the aircraft that make a flight arriving at the airport also have a departure flight associated, unless the flight sleeps at the airport and performs the departure flight another day.
Figure 7 presents a model proposal for the airport PRM assistance service that integrates the five flows discussed above. In the model diagram, the flows of departures, arrivals and transit are differentiated, while the flows of remote boarding and disembarkation are represented as processes of the departure or arrival flows in the case of a flight associated with an aircraft with remote stand.

4. IOT TECHNOLOGIES IN THE AIRPORT

The proposed simulation model will serve to assess the impact of new technologies that should improve the assistance of PRM. The proposal of a technological framework for the management of the service of assistance to PRM in airports is based mainly on three technologies: 5G, Internet of Things (IoT) and autonomous wheelchairs.

Current services of IoT sacrifice performance to make the most of the existing wireless technologies (3G, 4G, WiFi, Bluetooth, Zigbee, etc.). Conversely, 5G networks are designed to achieve the level of performance needed by massive IoT, and to create the perception of a completely ubiquitous and connected world. Consequently, 5G is expected to become a great impulse for this technology. The 5G standard features are expected to become a great impulse for IoT since they offer low latency (1 millisecond), increased bandwidth (10 to 100x improvement over 4G), high coverage and availability (even indoors) and low power consumption (European Telecommunications Standards Institute 2018). IoT offers the possibility of creating a fully connected "things" ecosystem that will improve the user experience of passengers. At the same time, it allows the interconnection between the different stakeholders of the airport operations, facilitating the best management of the resources. In relation to the PRM assistance service, IoT techniques can be developed in different areas such as: the geolocation of PRMs, the use of autonomous wheelchairs, and the custom signage, among others.
Recently, several papers have been published to evaluate IoT platforms and their technical features. Mineraud et al. (2016) present a comprehensive gap analysis of 39 platforms and define gaps and recommendations that providers should follow to enhance the platform performance. Da Cruz et al. (2018) provide a performance evaluation of five opensource IoT platforms. Ismail, Hamza and Kotb (2018) presents an overview and comparison between the ThingsBoard (ThingsBoard Inc 2019), and SiteWhere (SiteWhere LLC 2019), platforms.
With regard to wheelchairs, there is an opportunity to have mixed fleet of manual and autonomous chairs, all of them connected through IoT to the service management framework. One of the objectives of the research is the valuation of the impact of the use of

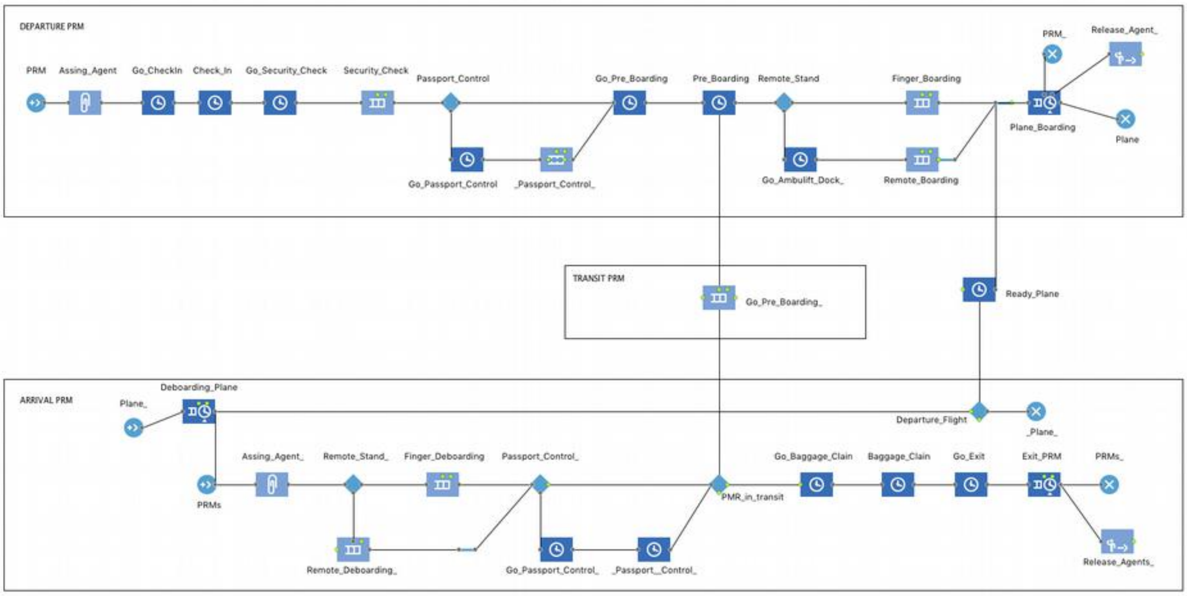

Figure 7: Model for the PRM assistance service

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autonomous chairs through simulation, as well as quantifying the optimal implantation percentage with respect to the total number of wheelchairs.

Figure 8 shows a diagram of the proposed technological framework. In this proposal, the main actors and resources of the PRM assistance service (PRM, assistants, wheelchairs and ambulifts) would be connected to the IoT platform through 5G communications and an IoT gateway. In the case of wheelchairs and ambulifts, IoT devices would be installed; the attendees would connect through a mobile application since everyone has a cell phone to carry out their work, while PRMs could be connected through a mobile application or by means of an IoT device in smart card format.

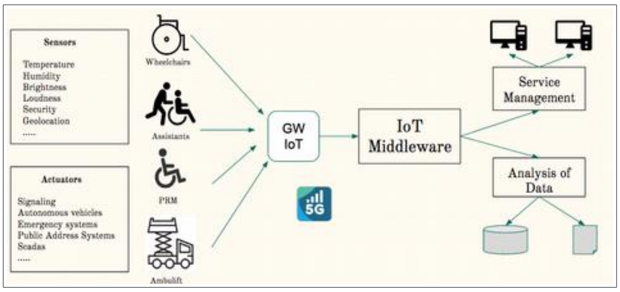

Figure 8: Proposal of technological framework

The IoT platform is responsible for organizing and processing all the data obtained from the actors and resources of the service (PRM, assistants, wheelchairs and ambulifts), and offering the information to the service management applications and data analysis systems.

This technological framework proposal will allow incorporating the management of other systems of an airport such as: parking, video surveillance, air conditioning, heating, among others. The sensors and actuators of these systems would be connected to the framework through IoT devices, which would use the IoT gateway to communicate with the IoT platform. In this way, the gateway and the IoT platform would be shared by all airport management systems and, in turn, data from a sensor or actuator could be reused in different management systems.

5. CONCLUSIONS

Airports are moving faster to adopt the latest technologies in order to improve their customer services. However, and despite the fact that current regulations highlight their importance, PRMs have not received enough attention in the design of such services. We have presented a conceptual model that will serve as a framework to assess, by means of modeling and simulation, the impact of 5G, IoT and automated wheelchairs on the assistance service of PRMs. We have also sketched the main features of a technological framework that will act as a central hub for these improvements.

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A GENERIC TERMINAL MACRO SIMULATION MODEL FOR MEASURING OPERATIONAL PERFORMANCE

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ABSTRACT

Strategic decision making linked to the development of intermodal transport terminals is marked by high complexity. Terminal operators need to cope with uncertainties and potential cascading impacts of decisions which were taken a long time ago. The aim of this paper is to present a generic System Dynamics (SD) model of a terminal's operational performance. SD is used to capture a holistic view on a dynamic system, which is characterized by complex feedback structures, nonlinear processes, uncertainties and time delays. After introducing the qualitative Causal Loop Diagram (CLD), the underlying hypotheses are transposed into a quantitative Stock-and-Flow (S&F) model. The main components and its input data are explained. The generic model can be used as a decision support tool to bridge the gap from a detailed view to an understanding of long-term consequences. It offers multiple areas of application, which are briefly discussed.

Keywords: logistics, intermodal terminals, decision support tool, strategic management

1. INTRODUCTION

Intermodal transport is defined as the combination of at least two modes of transport in a single transport chain, without handling the goods themselves (United Nations 2001). The transshipment of a loading unit is organized at intermodal freight terminals. In the European Union are more than 800 freight terminals, ranked as terminals of high relevance (European Commission 2013). Intermodal transport is of a complex nature due to the use of multiple transport modes and the necessary consideration of various stakeholders (Caris, Macharis, and Janssens 2013). In this sense, to manage the operations of intermodal freight terminals and to take strategic decisions regarding a terminal's development are characterized by high complexity. Decision makers need to cope with uncertainties and potential nonlinear consequences. The present paper aims to introduce a basic model of a terminal's operational performance. The generic model can be used as a tool, e.g. for testing different policies or for estimating the long-term impact of investment decisions. Due to the complexity of the topic and the nonlinearity of interacting parameters SD is a well suited method. The model is implemented on a high level of abstraction to allow an understanding of the dynamics (Mella 2012). The remainder of this paper is organized as follows: Section 2 offers an overview of SD methodology. Section 3 presents the first step of the modelling process, the qualitative CLD, its underlying hypotheses and the system archetype growth and underinvestment. Section 4 explains the second step of the modelling process, the quantitative S&F model, its major components and input data. Finally, Section 5 lists the model's possible scenarios and its potential areas of application.

2. METHOD

Simulation methods are often used to model container operations at terminals. SD is a simulation methodology, which allows capturing especially complex systems from a macro perspective. It offers decision-makers the possibility to compare available options and to develop their skills in understanding interdependencies. Sterman (2000) describes SD modelling as discovering and presenting feedback processes, which define the dynamics of a system. Other simulation approaches than SD take a more detailed perspective on the operational performance of terminals. Discrete-event models, for instance, often model physical processes performed at the terminal, or traffic situations, which occur at the yard with a medium time horizon. The operational flows are modelled as a sequence of events. One can, e.g. identify potential bottlenecks or evaluate the performance of different vehicle-, equipment- or routing strategies (see e.g. Gronalt et al. 2012; Schroër et al. 2014; Kavakeb et al. 2015; Cimpeanu et al. 2017). For simulating the interaction of multiple agents at a terminal, one can use agent-based models. In general, these models apply a microscale and aim at describing the effect of different agent's behavior and decisions on the entire system. Examples are Garro et al. (2015) or Sharif and Huynh (2012). In addition, hybrid approaches, e.g. combining agent-based simulation and SD, exist (see, e.g. Swinerd and McNaught 2012).
On the contrary, SD is well suited to measure the impacts on the operational performance of a terminal with a view to strategic consequences on a long time horizon. The method consists of a qualitative and a quantitative

process and uses two different types of feedback loops, i.e. self-reinforcing loops (R) and self-correcting loops (B). + and – signs at the arrowheads indicate if the effect related to the cause is positive or negative. In the qualitative process, a CLD portrays cause-and effect relationships (Morecroft 2015), thus, develop dynamic hypotheses (Shepherd, 2014). A well-known shortcoming of CLDs is their inability to capture stocks and flows (Sterman 2000). Stocks are accumulated values created by changes of its inflow and outflow over time. Valves control the flows and define the rules for the model's behavior in mathematical equations. Time delays between a decision and its actual impact on the system are rather common and in the model, they are marked by a double line "||".

In the transport sector, SD is most often used to address policy concerns or to model the uptake of alternate fuel vehicles (Shepherd, 2014). In addition, several terminal papers have been published, most of them dealing with seaports (Oztanriseven et al. 2014). Others address the capacity utilization and investment decisions (e.g. Randers and Göluke 2007; Ho, Ho, and Hui 2008).

In the present analysis, eight semi-structured interviews with respondents of five inland terminals in Belgium and Austria served as an input for the qualitative terminal model. Furthermore, the analysis uses data of detailed simulation models of inland container terminals. The simulation models map existing or planned infrastructure layouts and terminal operations and compare different settings with regard to a given scenario (Gronalt, Benna, and Posset 2006; Gronalt et al. 2011).

Then, the CLD was transposed into a quantitative S&F model, using the software Vensim 7.2. Iterative meetings with decision-makers allowed feedback during the modelling process and to integrate practical experiences, which is known to result in knowledge creation (Petty, Thomson, and Stew 2012).

3. QUALITATIVE TERMINAL MODEL

The qualitative CLD includes a handling loop (B1), a market power loop (R1), a cost loop (R2), an infrastructure investment loop (B2) and an energy loop (B3) (see Figure 1). The loops describe the basic model's behavior by guiding dynamic changes over time. The model includes several exogenous variables, which set the boundary and are input factors only: the total market demand, a perceived minimum infrastructure and equipment standard, a terminal's geographical position within the transportation network, and existing mergers and alliances, a growth limit due to space restrictions.

The handling loop describes the impact of a change in the number of incoming load units. An increase leads to a rising equipment utilization rate and longer lead times. Consequently, terminal reputation decreases, which has again an impact on the customer demand rate and the number of incoming load units. The market power loop visualizes the causalities between the costs of operation, the terminal's bargaining power and its reputation. In addition, the terminal's reputation is positively influenced by a terminal's growing energy efficiency, whilst a reduced energy consumption results in lower costs of operation (energy loop). Furthermore, if the equipment utilization rate increases, the costs of operation increase due to higher maintenance costs (costs loop). Finally, the investment loop compares the actual equipment utilization rate to a perceived standard and decides upon an investment, which, after a time delay, results in more capacity and, thus, a lower equipment utilization rate. As a measuring unit of load units, the model uses twenty-foot equivalent units (TEU). For a detailed description of the CLD the reader is referred to Gronalt, Vögl, and Protic (2018).

The terminal model contains the system archetype growth and underinvestment (Senge 2010). Archetypes are generic structures in dynamic systems. Once an archetype is identified, its impact on the behavior of a model can be analyzed.

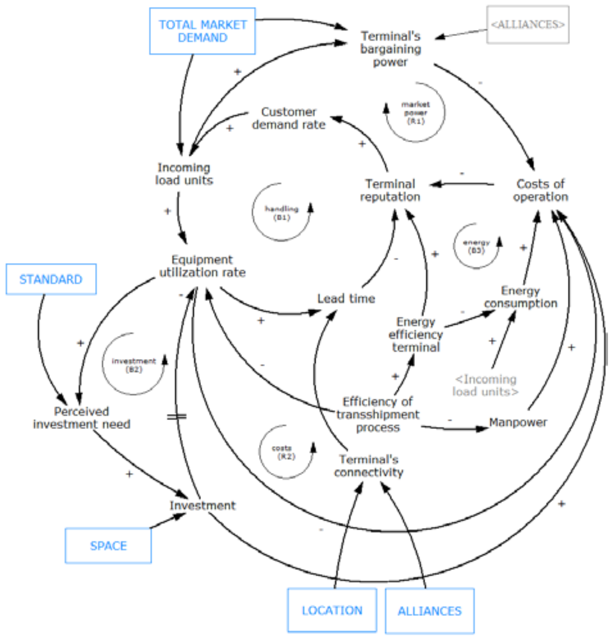


Figure 1: Qualitative Terminal Model.

The growth and underinvestment archetype consists of one reinforcing loop and two balancing loops, at present the handling loop (B1), the costs loop (R2) and the investment loop (B2). In theory, the archetype is often linked to a star-up's decision if and how much to invest in new production capacity. Due to the time lag in-between investment and an actual capacity increase, fast growing demand cannot be met. The backlog (negative performance) increases customer dissatisfaction, which lowers the new demand. As a result, the actual capacity is again sufficient. An oscillating effect of new demand and capacity may occur. We observe similar dynamics regarding terminal investment and an increase in lead times due to higher equipment utilization rates. Therefore, if decisions are made too late or too cautious, it is hard to anticipate a reduced demand. This is especially of high relevance in view to long construction periods. Figure 2 visualizes the basic dynamics of the archetype in a simple S&F model. The archetype's impact on the new demand and the capacity are exemplarily shown in Figure 3.

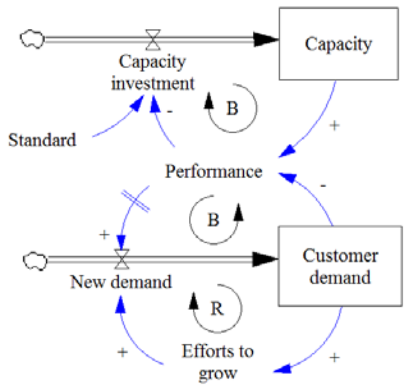


Figure 2: Archetype growth and underinvestment in a simple S&F model.

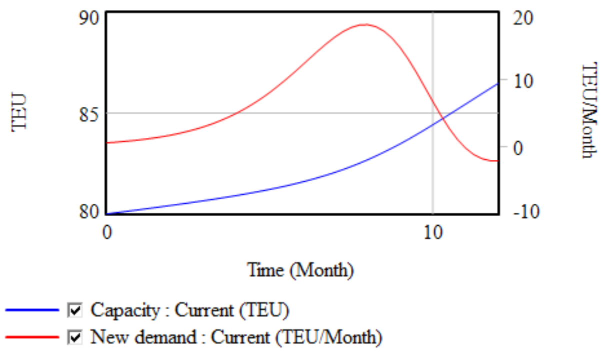


Figure 3: Dynamics of the archetype growth and underinvestment.

4. QUANTITATIVE STRATEGIC TERMINAL MODEL

The terminal model has a time horizon of 30 years, which seems an appropriate period to observe the model behavior and to link the origin and the effect of changes in the terminal performance. The length of the time horizon considers long-time construction projects and periods of depreciation for new infrastructure. The simulation applies monthly time steps.

The S&F model allows to choose several input parameters, some of which are the model's exogenous variables and, thus, time-independent and valid over the entire time horizon of a simulation, e.g. a terminal's geographic location. Others determine the initial situation of the terminal, e.g. a terminal's initial capacity. Correctly selected, the input parameters allow to adapt the generic essence of the model to reality. Table 1 and 2 list the main model variables and its definitions. Stocks are symbolized as rectangles (□), in- and outflow processes are symbolized as circles (O), and valves, which control the flows, are symbolized as crossed out circles (⊗).

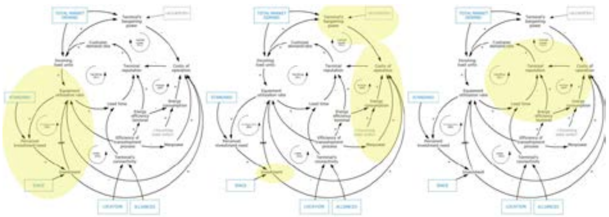
Table 1: Exogenous variables. User-defined input parameters are marked (*).

Exogenous variables		
□	Geographic location (*)	The geographic location of a terminal refers to (i) its gateway role, thus, its position in the TEN-T network. Each direct link to a TEN-T corridor increases the potential market volume of a terminal, according to estimated volumes of European Commission's corridor studies (European Commission 2014a-i). (ii) Its Loco role, thus, the number of potential customers closer than 150km (Posset et al. 2014), and (iii) the number of potential customers in the terminal's surrounding area.
□	Total market demand	The market demand is determined by a terminal's geographic location. Annual growth rates assume an increase of 2% until 2020, of 1.9% until 2030 and of 1.4% until 2050 (Enei 2010).
□	Strength due to alliances (*)	This value stands for a terminal operator's bargaining power and its role in the transport network. It ranges between 0 and 2, depending on the number of terminals, the terminal's operator is controlling.
□	Growth limit (*)	Maximum growth rate of the terminal capacity, compared to its capacity in the initial time step. The growth rate might be limited du to, e.g. space restrictions.
□	Modal share (*)	Modal share of the terminal, including road and rail transport.
□	Actual lifting factor (*)	This value can differ from the average value of 2.5, e.g. due to efficiency gains in a terminal's transhipment processes.
□	Minimum infrastructure / equipment standard (*)	This value determines, if an operator will decide to invest or not. In the model, the investment decision is linked to a maximum equipment utilization rate, calculating with a forecast of the expected handling volume.
O	Financial data and terminal operation data	Lookup functions, e.g. maintenance costs, for investment costs, for staff costs (all three depending on the terminal size), and for lead times (depending on the equipment utilization rate) are used to equate the actual input with an impact factor. They are graphical functions, which are determined by linear interpolation between known input values.

Table 2: Endogenous variables

Endogenous variables		
□	Terminal reputation	The current level of the terminal’s reputation, ranging between 0 and 1.
⊗	Reputational gains	Depending on the total reputation impact caused by the lead time - impact (O), the environmental image - impact (O), and the costs of operation - impact (O). A maximum increase is defined per time step.
⊗	Reputational losses	Depending on the total reputation impact caused by the lead time - impact (O), the environmental image - impact (O), and the costs of operation - impact (O). A maximum decrease is defined per time step.
O	Lead time - impact	Ranging between -1 and 1, depending on the dynamic change of the lead time compared to the initial year.
O	Costs of operation - impact	Ranging between -1 and 1, depending on the dynamic change of the costs compared to the initial year.
O	Environmenta l image - impact	Ranging between -1 and 1, depending on the dynamic change of the image compared to the initial year.
□	TEU at yard	Difference between incoming load units (TEU) and those leaving the yard.
⊗	New demand (TEU)	Depending on the terminal reputation and the volume handled in the previous time step. It is influenced by the actual backlog (thus, the negative performance) due to previously cancelled load units due to capacity constraints.
⊗	TEU leaving the yard	Depending on the actual transhipped volume, determined by the capacity and the lifting efficiency of a terminal.
□	Total terminal capacity	Stepwise increase in case of investments being made. Its value in time step 0 is required as an input parameter.
⊗	New equipment	Depending on the investment decision taken and considering the delay of the construction period.
O	Costs of operation	Consisting of investment costs (O), maintenance costs (O), staff costs (O) and energy expenses (O).
O	Equipment utilization rate	The rate depends on the current terminal capacity, the amount of outgoing load units (TEU) and the actual lifting efficiency of a terminal.

The computational model can be roughly structured in three major components: (i) investment decisions, (ii) costs of operation, and (iii) reputation building. Figure 4 explains the link between the three components in the S&F model and the qualitative CLD in Figure 1. To allow for a better understanding of the modelling process the three components and the input data will be explained one after the other.



(i) Investment decision (ii) Costs of operation (iii) Reputation building

Figure 4: Assignment of major components in the S&F model (see Figure 1), to the CLD.

4.1. Investment decision

In the S&F model the perceived investment need of the terminal depends on the forecasted equipment utilization rate, thus, it is a dynamic decision concerning the ratio of the forecasted handling volume and the actual capacity (Slack and Johnston 2010). If the equipment utilization rate is expected to exceed the set standard of 65 percent within the next year (t+12 time steps) and if the equipment utilization rate does not demonstrate a downward tendency, we assume that the terminal operators will invest in order to increase its capacity. The use of forecasts is a valid leveraging point to cope with a threatening decrease of new demand linked to the archetype growth and underinvestment. The total investment depends on the expected future handling volume. The decision pursues the objective of reducing the equipment utilization rate to a level of 50 percent, which is another leveraging point linked to the archetype growth and underinvestment (Mandl 2019).

In general, infrastructure construction periods last between two and seven years (Wiegmans and Behdani 2017). Nevertheless, smaller handling equipment or small-scale modifications in the terminal entrance area are realized more quickly. In the model, every decision to invest in an extension of terminal capacity is followed by a construction period, which delays the investment effect on the equipment utilization rate and pauses new investment plans. It is for this reason that the capacity in the S&F model increases stepwise. In literature, there is only little to be found about terminal capacity calculation. The present model refers to the design capacity of a terminal, defined as the maximum capacity at ideal conditions during actual operating times (Slack and Johnston 2010). The standard scenario assumes a lifting factor of 2.5, which means that each TEU is lifted 2.5 times at average (Gronalt et al. 2011). The equipment utilization rate calculates the actual output and takes into regard the difference between the assumed lifting factor (2.5) and its real value, which is an input variable. As the difference of the real lifting factor affects the equipment utilization rate, it also restricts the number of outgoing TEU, whilst the units, which can’t be handled due to low capacity remain at the terminal yard and increase the backlog. A growth limit of the terminal, e.g. due to area restrictions, can be set in advance in the model's input.

4.2. Costs of operation

The costs of operation are a sum of fixed costs, including infrastructure and equipment investment, and variable costs, including maintenance costs, energy expenses and staff costs. Furthermore, the exogenous factor, a terminal's strategic alliances (e.g. if the terminal is controlled by an operator that controls several other terminals as well) has a moderate impact on the cost structure as the negotiating power is expected to allow an operator realizing price advantages. Other variable costs such as IT systems or taxes are not taken into account due to the high level of aggregation required in SD.

Wiegmans and Behdani (2017) describe the relatively low level of variable costs compared to investment costs. Furthermore, returns on scale are reflected in the S&F model, in which the operational costs decrease with an increase in the number of transshipped containers. Following the classification of five freight terminal types by Wiegmans, Masurel, and Nijkamp (1999) we use estimated terminal realization costs and the approximate number of employees as input (Wiegmans and Behdani 2017). Another input is the average gross salary for a full time employee assuming a 40/60 mix of workers and administrative staff. The maintenance costs account for approximately 15 percent of the total investment costs (Wiegmans and Behdani 2017). In general, the equipment of a terminal is fueled either by electricity or diesel. In the following, we assume that one third of the overall energy consumption is covered by electricity and two thirds by diesel (Green Efforts 2014), which is reflected in the composition of the energy costs in the S&F model (Eurostat 2017, Weekly Oil Bulletin 2018). For an approximation of a terminal's average energy consumption we use 12,83kWh/TEU (Hong et al. 2013). Efficiency gains in the transshipment process result in energy savings.

The importance of government subsidies and tax breaks for realizing a profit is recognized by various authors, even after a terminal's start-up phase (Wiegmans and Behdani 2017, Woodburn 2007). The S&F model applies a subsidy of 40 percent of total investment in a given time period, if the total investment costs exceed a given threshold, which is comparable with the purchase price of an average reach stacker. For the remaining investment stream we use a linear depreciation over a depreciation lifetime of a reinvestment duration of 18 years. The depreciation period of infrastructure investment ranges between 13 years (office furniture) and 21 years (gantry cranes) (Bundesministerium der Finanzen 2000).

Determined by linear interpolation between these known values, the maintenance costs, the staff costs and the energy expenses for any terminal can be estimated. It is important to consider that considerable differences in the characteristics of a terminal in terms of its staff number, the price of its equipment or the energy costs are possible. For this reason, the S&F model does not aim for realistic customer prices, but calculates the dynamic changes of the operational costs per loading unit (TEU) over time. Experiences from terminal operators validate the final composition of costs, which is close to the average composition as observed in practice, i.e. 55 percent staff costs, 25 percent maintenance costs, 15 percent investment costs (taking into regard the depreciation period), and 5 percent energy costs (WienCont 2018).

4.3. Reputation building

The reputation of a terminal, i.e. it's attractiveness from a customer's point of view, is expected to increase and decrease stepwise. We assume a terminal's initial reputation equal to 50 percent, while 0 and 100 percent denote its minimum and maximum level. While several authors underline that a customer choosing a terminal is influenced by various factors, due to the required high level of abstraction in SD, the focus lies on the most important ones only. Ng (2006) carries out a survey among shipping lines to determine, which factors have an impact on a port's attractiveness. Monetary aspects and time efficiency were rated beyond the most important factors. In the model, the determined scores are translated into impact factors on a terminal's reputation. Although the survey does not list environmental concerns, the present model takes it into regard due to an observed increase of environmental public interest and its expected implications for the future transport sector (Protic, Geerlings, and van Duin 2018). Therefore, the present model includes three influencing factors, namely (i) lead time, (ii) environmental image, and (iii) costs of operation.

- The lead time refers to the time a load unit (TEU) needs from the gate-in to the gate-out. Higher equipment utilization rates are expected to increase lead times. The model considers two different lead time lookup functions, one for rail-rail transshipments and one for road-road transshipments, both using data of a terminal simulation study (Gronalt et al. 2011). It is possible to determine a terminal's average mix of transport modes, which allows taking into regard rail-road and road-rail transshipments. The average lead time is calculated as an arithmetic mean of lead times for transshipments with lorry and train. The function describes a steep rise in lead times at occupancy levels above 80 percent, due to the fact that terminals often face problems in their daily operation when their utilization rate passes this threshold (Wiegmans and Behdani 2017, Gronalt et al. 2011). A terminal's position within the transportation network, i.e. TEN-T corridor position, and its role in existing mergers and alliances affect the total lead time, due to efficiency gains or losses (Lun and Cariou 2009).
- The impact of a terminal's environmental image on its reputation is set at a rather low level

compared to the ones of lead times and costs. Nevertheless, environmental sustainability is not only an operator's tool to decrease energy costs, but is increasingly becoming a matter of societal needs and beliefs. Worldwide best practices, e.g. wind or solar power at the terminal area, measures to reduce fine dust or noise, witness to the high degree of acceptance (Protic, Geerlings, and van Duin 2018).

- The terms costs of operation and customer costs per TEU (price for a transshipment) are used synonymously. We calculate the cost level's dynamic change over time. In general, the transshipment price of a container is fixed and includes all liftings needed to handle a container. If certain in advance that only one lifting, e.g. train-train, is needed a lower price can apply. For the sake of simplicity, this was left out in the model. Nevertheless, the more favorable the prices are compared to the initial level, the higher the more likely a customer will choose the terminal for a transshipment (Ng 2006).

The impact of all three factors is a matter of dynamic changes over time. An increase of lead times or costs will decrease the reputation level. On the contrary, an increase of the energy efficiency will increase the reputation. Clearly, countervailing effects can be observed, e.g. investments increase costs, but offer the chance to decrease lead times and environmental benefits.

5. POTENTIAL AREAS OF APPLICATION

The model allows to adapt various input factors to adopt the generic model to a terminal's specific characteristics (see Table 1). Furthermore, it is possible to choose different scenarios regarding the overall handling volume of the terminal and the development of energy prices over time. Whilst (in addition to the endogenous dynamic behavior of the model) in the CR_low scenario the customer demand rate decreases by 50 percent within the next 30 years, the CR_high scenario assumes that the handling order rate increases by 200 percent. The energy price scenarios (EP_low and EP_high) allow variations of -30 percent and +30 percent within the anticipated simulation period. The basic scenarios include moderate market and price developments (business-as-usual). The holistic view of the SD model and the fact that it describes only one terminal instead of an entire network, makes it interesting for the strategic terminal management. It allows to analyze the effect of investment decisions on a long-term and to think about its underlying parameters, e.g. the time of an investment, the need of correct volume forecasts, public subsidies or the maximum utilization rate that should trigger an investment. But it is not all about an expansion of equipment capacity. Also the overall impact of an innovation, which leads to an improved process efficiency, e.g. fast lanes for lorries, or of an ICT innovation that speeds up the exchange of information between terminal operators and customers, can be analyzed. Another interesting area of application is the reputation building of a terminal, e.g. to find out how a strong environmental awareness of terminal customers would change the overall performance of a terminal. The generic model offers multiple areas of application and allows to bridge the gap from a detailed view in decision making to a holistic understanding of potential cascading effects and long-term consequences on the terminal performance.

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RESEARCH ON ONE-WAY CHANNEL CONVERSION STRATEGY OF COASTAL PORTS BASED ON SYSTEM SIMULATION

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ABSTRACT

The waterway is the necessary passage for ships to enter and leave the port. From the perspective of cost, many coastal port channels are one-way channels, it alternates as an inbound channel and an outbound channel. The one-way channel conversion strategy refers to when it is used as an inbound channel and when it is used as an outbound channel. By constructing a simulation model, this paper simulates the one-way channel conversion strategy that uses a fixed time period conversion, a conversion considering a certain number of outbound ships, and a conversion with the combination of time and number of outbound ships to achieve the best state of the port's overall operations. By comparing the port service level, traffic capacity of waterway, ships waiting time and other indicators, a one-way channel conversion strategy suitable for port operations is recommended.

Key words: One-way Channel, Conversion strategy, Port Operation, System Simulation.

1. INTRODUCTION

In recent years, with the development of economy and trade, port construction under high demand has gained a new development opportunity. At present, port construction is gradually becoming saturated. With gradually complete of port hardware facilities, under the new situation, the focus of port construction has shifted from whether infrastructure exists to how to improve the overall operation level of the port, and more attention has been paid to how to improve the port service level, throughput capacity of channel and other indicators. It brings new opportunities for port development.

At present, most of the research focuses on improving the level of port service, throughput capacity of channel, improving the navigation efficiency of ships, reducing waiting time and other indicators. Construct ship scheduling optimization model, or use system simulation method to simulate the whole process of ship entering or leaving the port under different conditions, and provide suggestions for the development of relevant waterways. On the construction of ship scheduling optimization model, Zheng(2018), aiming at minimizing the total waiting time of incoming ships, constructs a mixed integer linear programming model and designs a hybrid algorithm combining heuristic rules with simulated annealing algorithm to solve the problem. Wang(2014), designed a multi-objective genetic algorithm based on one-way channel ship scheduling optimization, which provides theoretical support and key technology for integrated scheduling of port ships. Zhang(2018), analyzed the difficulties of ship scheduling in one-way, two-way and compound channels, an optimization model of ship scheduling in one-way channel was established, which reduced the conversion of the channel and the total scheduling time. Xu(2009), based on the information provided by ship-borne AIS related to the safety of ships' passage, takes the main factors such as berth distance, ship size, ship type, draught and other sub-factors as the weights, and puts forward the optimal sequencing mode for ships entering and leaving ports in one-way waterway.

In the aspect of using system simulation method to construct ship port channel simulation model, Ning(2008), using arena simulation software, constructed a simulation system of port ship operation, comparing the throughput of port route theory with that of simulation. Zhang(2009), constructed the simulation model of the ship's inbound and outbound operation system of one-way channel in bulk port area based on different inbound and outbound rules, compared and analysed the effects of different rules on channel capacity under different conditions, and explored the contribution of different rules of inbound and outbound to throughput capacity of one-way channel. Liu (2014), analyzing the effects of first come first service rule, large vessel priority service rule and ship clustering navigation rule on port service level by using computer simulation technology and building a simulation model of ship navigation operation system. Song (2012), defined the weighted average of ship tonnage to port as the characteristic tonnage of ship type combinations, and the influence of ship type combinations on port channel capacity is studied. Guo (2011), Using Arena simulation software to build a model to study the influence of safe time interval on the passage capacity of coastal bulk port area under different conditions.

Most of the research focus on the optimization of ship scheduling and navigation rules, which improves the operation level of ports in one-way navigation environment. Most of the research on ship scheduling in one-way navigation channel are based on the construction of ship scheduling optimization model, which solves the problem through optimization algorithm. The model of ship's inbound and outbound operation based on system simulation is built, and the influence of different navigation rules on channel capacity is obtained.

On the basis of the former research, this paper considers the ship scheduling problem under the conversion of one-way channel. Under the restriction of one-way channel, the ship entering and leaving port usually needs to consider how to convert the channel at a certain stage to make the ship's traffic flow smoothly. Under the changeable rules of ship arrival and departure, the port dispatcher is required to convert the channel reasonably. It is of great value to study how to convert one-way channel reasonably and efficiently, to ensure that ships arrival on time for loading and unloading, to arrange the next voyage on time for departure.

2. ANALYSIS ON THE PROCESS OF SHIP'S INBOUND AND OUTBOUND OPERATION AND EVALUATION INDEX UNDER ONE-WAY NAVIGATION

2.1 Analysis of ship's inbound and outbound operation process under one-way navigation

The process pf ship's inbound and outbound operation in one-way channel and operation in port can be divided into :ship's arrival, anchorage waiting, condition judgment for entry, navigation in channel, arrival berth, auxiliary operation, loading and unloading operation, departure operation and ship departure. There are differences in ship's tonnage, ship's type, cargo loading and unloading type, berth demand, ship's behavior characteristics and so on. It is necessary to conduct comprehensive and meticulous operation process analysis for different ships. After arrival, the ship waits for entry at the anchorage outside the harbour. In the process of waiting for anchorage, the weather conditions, tide level of ships, whether the channel is empty, whether it is in the one-way channel converting stage, whether it meets the safe time distance with the front ship and so on are judged respectively. After satisfying all the judgement conditions, the ship enters the channel, sails into the harbour and arrives at the berth. Carrying out loading and unloading operations, after the completion of loading and unloading operations to meet all similar conditions of departure before leaving, release berth, leave the port for the next voyage operation.

2.2 Evaluation index

Aiming at the impact of conversion strategy scheme on the whole port, this paper adopts port service level as an evaluation index. The port service level (AWT/AST) directly reflects the degree of service received by ships. AST indicates the average time of ships which required for loading and unloading in a port under normal conditions. The AWT indicates the average waiting time of the ships. AWT/AST reflects the proportion of waiting time to berth operation time. The better the service level of the port, the better the service of the ship and the reasonable utilization of the resources in the port.

Aiming at the influence of conversion strategy scheme on ships, this paper introduces the average waiting time of ships as an evaluation index. The average waiting time of ships is divided into waiting time of ships for waterway and waiting time of ships for berthing. The waiting time of ships for berthing refers to waiting time due to the lack of reliable berthing, which reflects the waiting time period. The matching relationship between the berth and the arriving ship shows that the longer the waiting time is, the more tense the berth is, the shorter the waiting time is, the lower the cost of the ship and the better of the economy. The longer the waiting time is, the more congestion the current traffic is. In this paper, the waiting time of large ships under the influence of conversion strategy is also considered, and the waiting time of large ships is introduced as one of the evaluation indexes.

3. ONE-WAY CHANNEL CONVERSION STRATEGY

In port operation, the ship dispatcher monitors the state of ships entering and leaving the port and the operation process in real time. Judging the flow direction of inbound and outbound channel ships, which gradually forms an empirical value for the work of converting the flow direction of inbound and outbound under the heavy workload. However, under the influence of uncertain factors, the conversion of one-way channel can not be achieved by relying on the empirical value alone, and unreasonable conversion strategy will make the waiting time of ships too long, the service level of the whole port decreases, and the throughput capacity of channel decreases. Based on the above problems, this paper proposes three conversion strategies for one-way channel.

3.1 Scheme 1: One-way channel conversion strategy according to fixed time

Converting the one-way channel according to the fixed number of hours. For port dispatchers, this conversion mode is based on the accumulated experience of a certain amount of work. When the law of ship's arrival is known According to the arrival time of ships, a reasonable fixed conversion time can be deduced as a method of converting one-way channel periodically to allow different traffic flows to carry on the traffic. Converting according to fixed time can make the port dispatching easy to manage. Under this converting decision, the number of ships in formation does not take into account the inbound or outbound flow direction. However, when the converting time is too long and the number of ships passing through the waterway is small, it is easy to form the situation that the waterway is idle and still open to navigation, resulting in the reduction of waterway utilization rate and the long waiting time of the opposite ships.

3.2 Scheme 2: One-way channel conversion strategy based on the number of outgoing vessels

Converting the one-way channel according to the number of ships coming out of port formation. This plan focuses on the number of ships coming out of the port formation. Under the navigable condition of ships with normal inbound and outbound directions, when the ship's operation in the port has been completed and meets the conditions of departure and in the state of imminent departure, it will become one of the fleet ships to depart from the port. When the number of ships in the departure formation accumulates to a certain number, the converting channel is in the state of departure navigation. This scheme considers that in the case of limited resources in the harbour, ships that have completed berthing operations are still waiting for departure from the harbour, and excessively use of resources in the harbour results in unreasonable utilization of resources and delays caused by the inability of incoming vessels to obtain berthing resources in time. In order to improve the utilization rate of resources in port and enhance the function of port service, this paper adopts the rule of priority of departure for outgoing ships. Priority rules for departure form the core of this scheme. However, considering the idea of priority for ships leaving the port formation, in the case of extremely number of ships arriving at the port, the "critical value" of ships leaving the port formation is too small to form a single channel state for too long, resulting in large waiting time for ships to depart and unreasonable control of channel converting time in the continuous state of departure. The changeover of converting time is not fixed, which will affect the waiting time of ships and may result in poor overall navigation condition of waterway.

3.3 Scheme 3: One-way channel conversion strategy considering converting time and number of outgoing vessels

Under one-way navigation, the conversion strategy considering the combination of converting time and the number of fleets of ships leaving port is proposed. Based on the analysis of the two conversion strategies, considering the converting time or priority of departure, the number of ships leaving the port formation is slightly thin. Therefore, scheme 3 combines the number of ships leaving port with the converting time to form a comprehensive conversion strategy. Under this conversion strategy, we can simultaneously pay attention to the converting time and the number of fleets of ships which leave the port, and synthetically analyze the optimal converting strategy, so as to make the port and channel state optimally, make the waiting time of ships shortest, and improve the level of port service. Based on the above three decision-making schemes, the simulation models of ship's inbound and outbound and inbound operations are established by means of system simulation, and the one-way channel converting operation flow under the three decision-making schemes is simulated respectively.

4. ESTABLISHMENT OF SIMULATION MODEL FOR SHIP'S INBOUND AND OUTBOUND AND OPERATION IN PORT.

System simulation is widely used in various fields as a safe, economical, controllable and efficient technical means. Anylogic simulation software is used to build simulation models. Anylogic is a simulation tool for modeling discrete events, system dynamics, multi-agent and hybrid systems. Its object-oriented modeling characteristics and visual development are discussed. The environment makes the modeling operation convenient and concise. The channel simulation model in this study is based on discrete event simulation under anylogic system. The simulation model of ship's inbound and outbound and operation in port under one-way navigation based on anylogic system simulation is established.

The simulation model established in this paper can be divided into: ship generation sub-module, anchorage waiting sub-module, entry judgment sub-module, ship navigation sub-module, ship operation sub-module, departure judgment sub-module. Six sub-modules constitute the whole process of ship entry and exit and operation in port under one-way navigation.

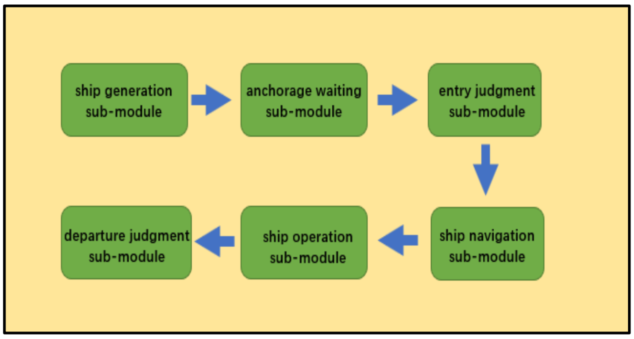

Figure 1. The whole process simulation sub-module of ship entry and exit and operation in port under one-way navigation

Ship Generation Sub-module: Generate ship entity resources, simulate ship's arrival process, and input ships' parameters in ship generation module, including: ship attributes, ship's arrival rules and other actual ship-related data.

Anchorage waiting sub-module: In order to allocate berth resources for the generated ship resources, berth allocation is carried out by flexible berthing, and berth resources are occupied by ships.

Entry judgment sub-module: Judgment of various conditions for ship resources, It is necessary to judge the wind, current and extreme weather before actual ships enter the harbour. For large ships or special ships, it is necessary to judge whether the tide level meets the requirements of the harbour entry. Based on the particularity of the ships which need to tide riding, the rule of tide priority is introduced into the sub-module. After satisfying the natural conditions, it is necessary to judge the phase of one-way channel converting. The three conversion decision-making schemes proposed above will be added to the judgment module for multiple simulations. When the ship is in the entry stage of one-way channel converting, it can enter the port. Otherwise, the ship should wait. Finally, the condition of collision avoidance is judged. The distance between the vessel and the front vessel must meet the safety distance before entering the channel.

Ship navigation and ship operation sub-module:
After satisfying the judgment of the entry conditions, the vessel sails in one-way channel according to the

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corresponding navigation time and enters the corresponding berth in the port to carry out the loading and unloading operation.

Departure judgment sub-module: After the completion of berth operation, it is necessary to judge whether the berth meets the exit conditions before leaving the port. The judgment of the exit conditions is similar to the judgment of the entry conditions.

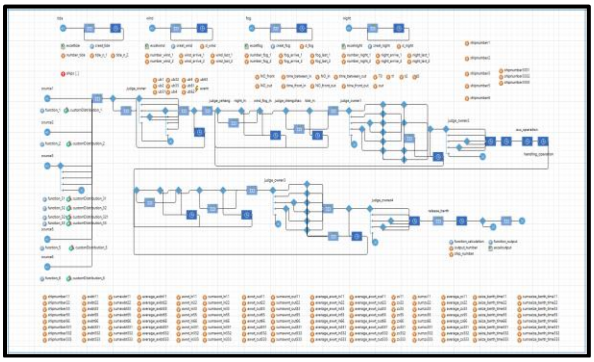

Figure 2. Schematic diagram of simulation interface

5. CASE STUDY

This paper chooses a coastal port and waterway as an analysis. The port area has multi-port and multi-junction points. Because of environmental restrictions and other factors, the one-way navigation rules are adopted. As shown in Figure, this paper establishes the whole process simulation of ship's inbound and outbound and operation in the port under one-way navigation. The conversion strategies are simulated separately, and the relevant evaluation indexes under the three conversion strategies are compared.

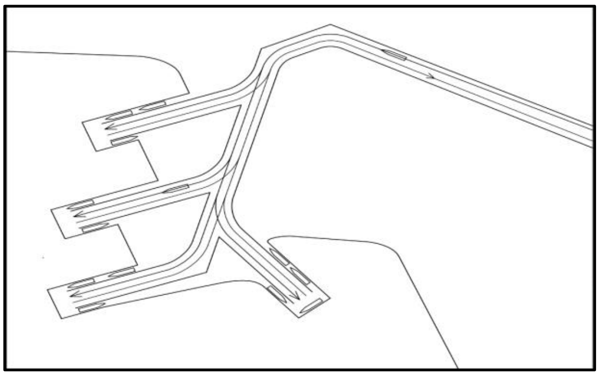

Figure 3. Schematic diagram of one-way traffic flow in a port area

5.1 Parameter selection

The data of a certain harbor basin is selected as input parameters and input into the model. The data include the number of ships arriving at the harbor, the types of ships arriving at the harbor, the speed of ships, the time of ships sailing and loading and unloading time, the time interval of ships arriving at the harbor which obeys Poisson distribution, etc. Input natural condition data, including extreme weather time and tidal value in the harbor. Input berth data, including berth attributes, berth number and so on. The rules of navigation, tide priority, ship departure priority and first come first serve should be determined.

Table 1. Simulation Model Input Parameters

Name of input parameters	Input parameter values
Ship's tonnage	The tonnage of ships is between 1,000 tons and 50,000 tons, and the ships are mostly around 10,000 tons.
Types of ship's cargo	All incoming goods are summarized in 8 categories , such as petroleum, natural gas and products, liquid chemical products, wood, mining materials, vehicles, containers and other goods.
Auxiliary, loading and unloading operation time	Calculate and select values in accordance with the specifications
Vessel Speed	8 knots.
Safety distance of ships	Calculating safety spacing value from 8 knots speed.
The tonnage of Berths	11 berths of 5000 tons, 6 berths of 30,000 tons, and 28 berths of 50,000 tons.
Waterway conditions	The main waterway is 29.8 km in length and has 3 branch waterways, 3 junctions.

Running simulation model 10 times, three one-way channel conversion strategies under one-way navigation are simulated respectively, and the optimal conversion decision quantification values under the scheme are obtained, and the optimal values of the three schemes are compared by using different evaluation indicators.

5.2 Impact of different schemes on port service level

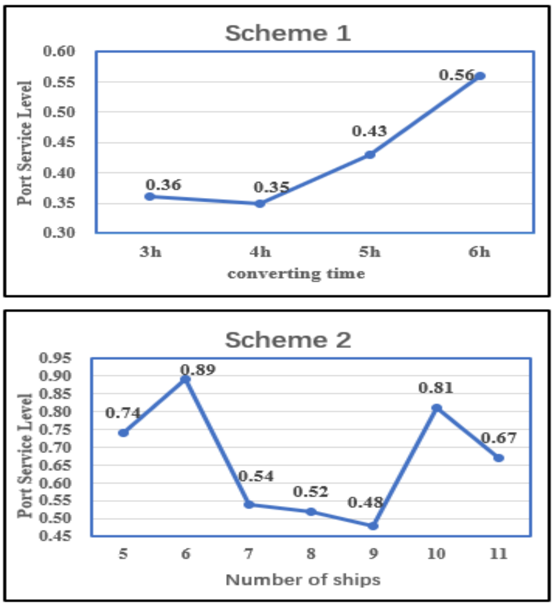

Figure 4. Port service level under different converting times or number of ships in departure formation

Scheme 1: Considering the reasonable one-way channel converting time, this paper takes 3 hours, 4 hours, 5 hours and 6 hours as one-way channel converting time, and carries out system simulation under four kinds of one-way channel converting time. As shown in Fig.4, scheme 1 shows that different one-way channel converting time has a significant impact on port service level, the port service level under four-hours converting one-way channel is lower and the port service level is better. Therefore, it is better to choose four-hour converting one-way channel as conversion strategy in scheme 1.
Scheme 2: Considering the distribution of the number of ships leaving the port, this paper takes 5-11 as the cumulative value of the number of ships leaving the port. Under normal navigation conditions, when the cumulative value of ships leaving the port is reached, the one-way channel is in the state of outgoing navigation., the port service level under scheme 2 is in the optimal state when nine ships are about to leave the port. Therefore, it is reasonable to select the one-way channel converting strategy when nine ships are about to leave the port

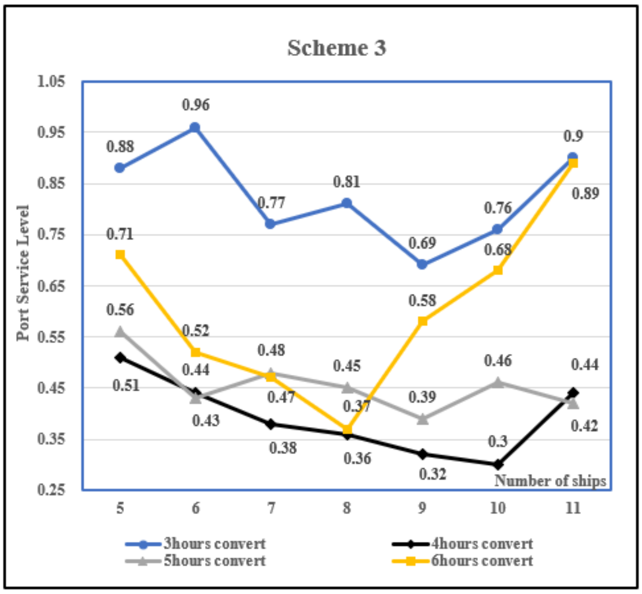

Figure 5. Port Service Level under Scheme 3

Scheme 3: Combining the converting time with the number of ships coming out of port, considering the rule of priority of departure, when any conditions of the converting time or the cumulative value of the number of ships in the departure formation are satisfied, the converting channel is in the state of outbound navigation. As shown in Fig.5, the port under scheme 3 is in the state of outbound navigation. The service level is in the optimum state when the converting time is 4 hours and the number of ships coming out of the port reaches 10 as the cumulative condition of the converting. Therefore, the combination of 4 hours converting and 10 ships coming out of the port is chosen as the one-way channel conversion strategy in the third scheme.

5.3 The influence of different schemes on the average waiting time of ships

Considering the obvious influence of one-way channel converting strategy on ships, this paper also selects the average waiting time of ships and the average waiting time of large ships as the evaluation index. A reasonable one-way channel converting strategy can reduce the waiting time of ships and make ships more efficient in entering and leaving ports and loading and unloading operations. Therefore, considering the effect of one-way channel converting strategy on the average waiting time of ships and large ships, this paper defines a ship which tonnage reaches 50,000 tons as a large ship.

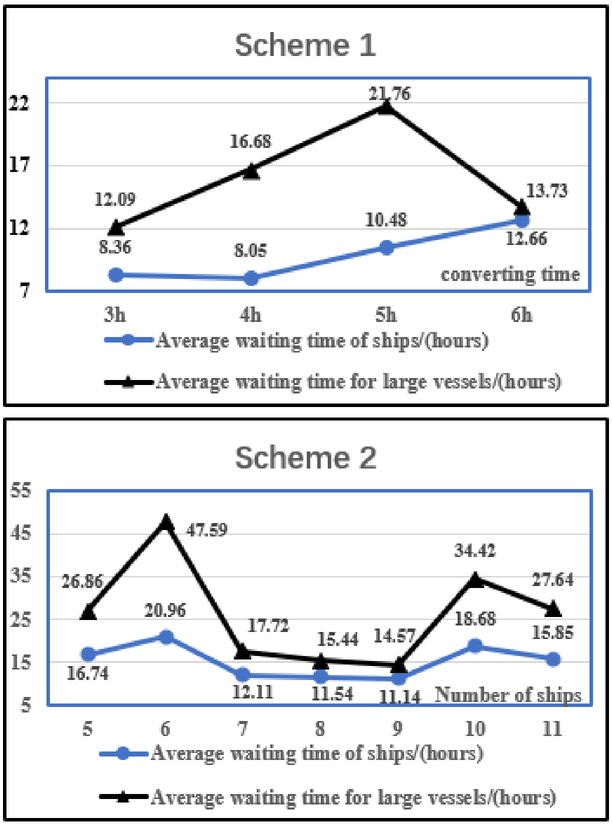

Figure 6. Average waiting time of ships under different converting times and number of ships in departure formation

Scheme 1: According to the reasonable one-way channel converting time, select 3, 4, 5, 6 hours as the time of converting one-way channel for system simulation, and compare the average waiting time of ships under different converting time. As shown in Fig.6, different converting time have obvious effects on the average waiting time of ships and large ships. It is more reasonable to choose 4 hours to convert one-way channel when considering the average waiting time of ships. It is more reasonable to choose 3 hours to convert one-way channel when considering the average waiting time of large ships. Therefore, when comparing the average waiting time of ships and large ships, different converting time are selected respectively. As a reasonable choice of scheme 1.
Scheme 2: According to the reasonable number of ships

leaving the port, 5-11 ships are taken as the cumulative value of the number of ships leaving the port. When the ships leaving the port reach the critical value, the one-way channel is in the state of departure and navigation., when the number of ships coming out of the port formation reaches 9, the one-way channel will be switched. At this time, the waiting time of ships and large ships can reach the shortest time. Therefore, when comparing the average waiting time of ships and the average waiting time of large ships, when the number of ships coming out of the port formation reaches 9, converting one-way channel is a reasonable choice for scheme 2

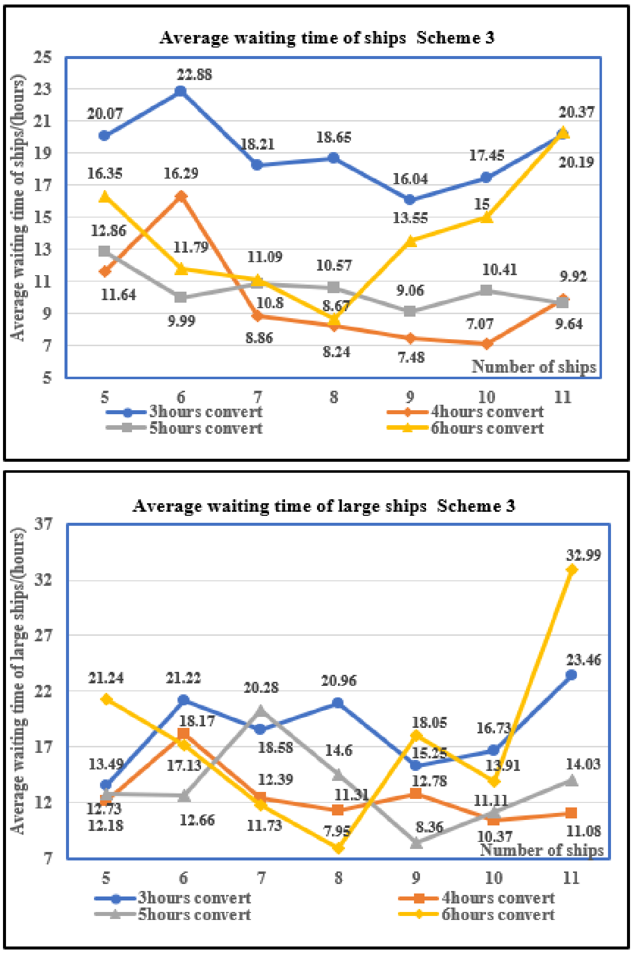

Figure 7. Average waiting time of ships and large ships in scheme 3

Scheme 3: Combining the converting time with the number of ships leaving port, considering the rule of priority of departure, referring to Figs.7, it can be analyzed. In Scheme 3, considering the average waiting time of ships and large ships, the converting time of 4 hours is chosen to be connected with the converting when the number of ships coming out of port formation reaches 10. Considering the average waiting time of large ships, it is more appropriate to choose a combination of 6 hours converting time and 8 ships in the port when the number of ships in the departure formation reaches 8. Therefore, when comparing the average waiting time of ships and the average waiting time of large ships, the best choice of scheme 3 can be obtained separately.

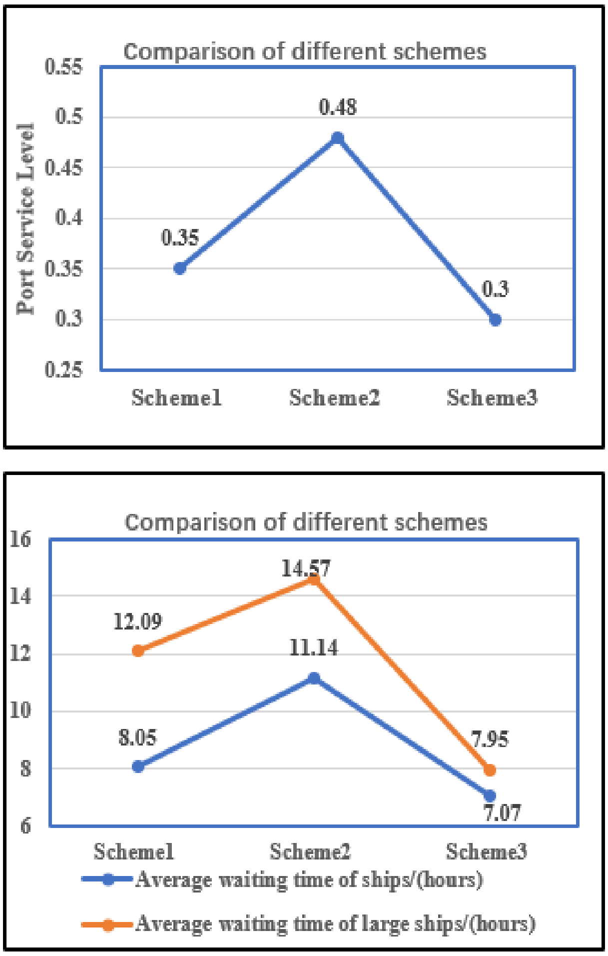

Figure 8. Average waiting time and port service level under different schemes

Considering the actual situation of the port and referring to Fig.8, we can conclude that under the same ship arrival distribution, the service level of the port under the one-way channel converting strategy of scheme 3 is better than that of the other two schemes, which shows that the one-way channel conversion strategy under scheme 3 is better for the whole port. It is more advantageous to upgrade the operation status. The average waiting time of the ships and the large ships under the one-way channel converting strategy of the third scheme is smaller than that of the other schemes, which proves that under the third scheme, the channel converting strategy can reduce the waiting time of ships and improve the efficiency of ships' entry and exit and operation in the harbor.

6. CONCLUSION

By putting forward three kinds of one-way channel conversion strategies, considering the influence of one-way channel conversion strategy on port service level, average waiting time of ships and specific large ships under the same ship-to-ship distribution, this paper uses system simulation method to input the same arrival data and analyses three different ways. The optimal situation of one-way channel conversion strategy is discussed, and three kinds of one-way channel conversion strategies are compared according to different evaluation indexes. From the data of system simulation, it can be concluded that only considering the converting time of one-way channel or the number of ships coming out of port formation is too limited, whether it is all of scheme 1 or scheme 2. In this case, it is particularly necessary to consider the combination of converting time and the number of ships leaving the port. Based on this item, the third one-way channel conversion strategy under comprehensive consideration is put forward. Through simulation analysis and data comparison, the scheme is proposed. Three one-way channel conversion strategies have reached the best state in comparison of several schemes under several evaluation indexes. Therefore, considering the converting time and the number of ships coming out of the port formation, this one-way channel conversion strategy is the best conversion strategy for this certain port basin under the three schemes proposed in this paper.

At present, affected by the actual environment and navigation rules of the port channel, some ports still use one-way navigation mode. In order to ensure that the overall operation level of the port is in good condition and the operation efficiency of arriving ships reaches the best level, one-way channel conversion strategy is one of the most important factors. How to deal with the one-way channel conversion strategy is one of the most important factors. A reasonable planning of the conversion strategy of the one-way channel still needs to be further studied.

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STOCHASTIC FLOATING QUAY CRANE SCHEDULING ON OFFSHORE PLATFORMS: A SIMHEURISTIC APPROACH

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ABSTRACT
The scheduling of quay cranes is a core logistics challenge that affects significantly the loading and unloading time of a vessel berthed at a container terminal. In this paper, we study the Stochastic Floating Quay Crane Scheduling Problem involving cranes situated on the quay of an offshore modular platform. Specifically, we consider the case in which each crane is situated on a different module of the platform, thereby confining its operation range. Additionally, we assume stochastic crane productivity rates due to the effect of the offshore wind. To tackle the problem, we propose a simheuristic framework, which combines Iterated Local Search with Monte Carlo Sampling into a joint collaborative scheme. The main objective is to minimize the expected completion time of the loading and unloading process taking into account precedence, non-simultaneity, non-crossing, and spatial constraints of the problem at hand. The performance of the proposed simheuristic is investigated on a set of established problem instances across different configuration parameters and under various real-world environmental scenarios offering insightful conclusions.

Keywords: quay crane scheduling, optimization, simulation, offshore platforms.

1. INTRODUCTION
Maritime transport has always been the backbone of international trade and it is expected to maintain its prevailing position in the foreseeable future (Christiansen et al. 2007). Currently, more than 80% of global trade with respect to volume is transported by sea and is handled by seaports. In 2017, world seaborne trade attained a number of 10.7 billion tons of goods and recent predictions have revealed a raise of 3.2% between 2017 and 2022 (UNCTAD 2018). This on-going world transport maritime development has already begun to alter significantly the shape of the contemporary seaports, which require now more than ever sustainable solutions to increase their size. The extension of the port area is not considered as a straightforward task, especially in the case that the land available onshore is

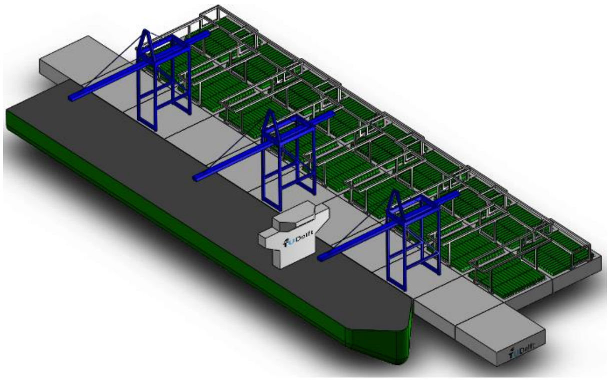

Figure 1: A conceptual design of three quay cranes situated on the quay of the offshore modular platform (Gideonse 2018).

fully exploited by the existing facilities. For this reason, an alternative option suggests the expansion of the port towards the sea by adopting new technological developments (Lamas-Pardo et al. 2015).
Based on this suggestion, recent technological concepts include the extension of ports via the construction of floating platforms. In this direction, the European project Space@Sea (https://spaceatsea-project.eu/) proposes and investigates the implementation of an offshore modular platform in the proximity of the port of Antwerp. The platform acts as an additional offshore terminal with the major objective of extending the capacity of the port. Under this premise, all operations that occur at a typical terminal may also take place on the floating platform, but with increased complexity due to two main causes. The first cause is that offshore logistics activities are required to respect specific limitations of the platform structure such as the constrained movement of the cranes on the modules of the platform. The second one is that operations on the platform are affected by severe weather phenomena, which are more intense in the open sea. This fact is corroborated by a relevant study which reveals that wind speed offshore is at least 20% higher than onshore (van den Bos 1995).
One of the most essential logistics operations within a terminal that affects significantly the time required for a vessel to stay in the port area is the loading and unloading

of its containers. The efficiency of this operation depends critically on the way and the order in which the quay cranes transfer containers, named *crane scheduling*. The so-called Quay Crane Scheduling Problem (QCSP) has received considerable research attention for over than three decades (Daganzo 1989). Up-to-now, a multitude of mathematical formulations along with numerous solution methods have been proposed mainly to tackle deterministic QCSPs (Bierwirth and Meisel 2009, Bierwirth and Meisel 2015, Daganzo 1989, Kim and Park 2004, Legato et al. 2012, Sammarra et al. 2007). In these works, deterministic settings for the involved problem parameters are assumed and, therefore, the uncertainty and dynamics related to container handling operations is not investigated (Al-Dhaheri et al. 2016). Hence, more research studies are needed to further enhance the so-far limited algorithmic artillery on stochastic QCSPs (Al-Dhaheri et al. 2016, Legato et al. 2008).

To the best of our knowledge, in research works that consider stochastic QCSPs, stochasticity is treated as a general concept modelled via arbitrary probability distributions. Even though current research has identified several sources of stochasticity for the QCSP (Chhetri et al. 2016, Tabernacle 1995, Zeng et al. 2011), the impact of any particular uncertainty factor on problem parameters or algorithmic performance still remains unexplored. Besides that, existing studies follow the assumption that the cranes are situated on the quay of onshore terminals, hence the increased complexity and relevant limitations of offshore paradigms are not taken into account. For this reason, the applicability of the proposed QCSP models seems to be questionable in the case that the quay is situated on an offshore floating structure. Additionally, none of the existing studies investigates the impact of environmental conditions on crane productivity rates and in turn how this affects the solution quality of the QCSP.

In this paper, we study the Stochastic Floating Quay Crane Scheduling Problem (SFQCSP) where each crane is situated on a different module of an offshore platform as shown in Figure 1. To perform the loading and unloading operations, the cranes are able to shift in parallel alongside the vessel by using a dedicated rail-track system. Additionally, we make the hypothesis that the platform is equipped with a fully autonomous crane system similar to that used at the Pasir Panjang terminal in the port of Singapore (Gustafsson and Heidenback 2002). Therefore, only unmanned (un)loading operations are performed on the platform. Moreover, we assume stochastic crane productivity rates due to the variability in offshore wind speed. To tackle the problem, we propose a simheuristic framework that combines metaheuristic optimization and simulation into a joint collaborative scheme. Simheuristics have recently emerged as an interesting approach to cope with stochastic combinatorial optimization problems (Juan et al. 2015). Up-to-now, they have been used to provide solutions for several stochastic combinatorial optimization problems (Juan et al. 2014, Michalak and Knowles, 2016).

The proposed simheuristic framework consists of a established local search algorithm, called Iterated Local Search (ILS), which offers high-quality solutions at low computation times (Lourenço et al. 2003). So far, the ILS has been successfully used to tackle combinatorial optimization problems in different application domains (Lourenço et al. 2003). However, to the best of our knowledge, this is the first study where the ILS is applied to the considered problem or any other quay crane scheduling challenge. Additionally, the proposed simheuristic integrates a Monte Carlo Sampling (MCS) approach used to compute the stochastic objective function of the considered stochastic crane scheduling problem (Shapiro 2003). The goal of the developed framework is to minimize the expected (un)loading times of the vessels that berth at the platform under the presence of precedence, non-simultaneity, non-crossing and spatial constraints. Different parameter configurations and various real-world environmental scenarios generated in accordance with the wind state at the location of the platform are used to investigate the performance of the proposed simheuristic.

The remainder of the paper is structured as follows. Section 2 formally defines the considered problem while the employed simheuristic framework is presented in Section 3. The results of the simulation experiments are displayed in Section 4. Conclusions and directions for future research are given in Section 5.

2. STOCHASTIC FLOATING QUAY CRANE SCHEDULING PROBLEM

The studied Stochastic Floating Quay Crane Scheduling Problem (SFQCSP) is considered as a modification of the problem introduced in (Monaco and Sammarra 2011). We assume a set of handling tasks $\Omega = \{1, 2, \ldots, n\}$ and a set of quay cranes $Q = \{1, 2, \ldots, q\}$. A task stands for loading or discharging a group of containers from the arriving vessel to the offshore floating platform or vice versa. Containers within a group share the same destination and are located at adjacent positions within the same compartment of the vessel, called a bay. Each task $i \in \Omega$ has a specific handling time, p_{i}, and the group of containers of the task are located in a particular bay of the vessel, l_{i}. For the sake of mathematical convenience, but without loss of generality, the beginning and the end of the container service are represented by the dummy tasks 0 and $T = n + 1$, respectively, with $p_0 = p_{\mathrm{T}} = 0$. Based on these tasks, sets $\Omega^0 = \Omega \cup \{0\}$, $\Omega^T = \Omega \cup \{T\}$, and $\bar{\Omega} = \Omega \cup \{0, T\}$, are additionally defined.

Precedence constraints are specified between pairs of tasks located within the same bay. Such constraints are used to determine the ordering of task execution by ensuring that (i) unloading tasks must be performed before loading ones, (ii) loading tasks on the deck must be carried out after those in the hold, and (iii) unloading tasks on the deck must be completed before those in the hold. Also, there are tasks that cannot be processed simultaneously because the containers involved in the tasks are located at adjacent bays which cannot be accessed by quay cranes for safety reasons. Let Φ be the set of task pairs for which a precedence relation exists and let Ψ be the set that includes the task pairs that cannot be processed simultaneously, defined as,

$\Phi = \{(i,j) | i,j \in \Omega : i \text{ has to be completed before } j\}$
$\Psi = \{(i,j) | i,j \in \Omega : i \text{ and } j \text{ cannot be processed simultaneously}\}$.

We assume that the quay cranes are of the same type sharing identical technical characteristics (e.g. dimension, speed) and can move between adjacent bays within $\hat{t} > 0$ time units. Therefore, the required travel time for a crane from the bay position of task i, l_i, to the bay position of task j, l_j, is computed as $t_{ij} = \hat{t}\,|l_i - l_j|$, whereas the time for crane k from its initial bay position l_0^k to the bay position of task j, l_j is equal to $t_{0j}^k = \hat{t}\,|l_0^k - l_j|$. Moreover, each crane $k \in Q$ adopts an initial bay position l_0^k and a ready time $r^k \geq 0$. All cranes are allowed to preserve a single moving direction (i.e., unidirectional movement), either always handling the task located at the higher-indexed bay or the lower-index bay with respect to their current bay position. Multiple tasks can be processed sequentially by each crane, but each task must be assigned and completed by a single crane, therefore preemption between tasks is not permitted.

As quay cranes are rail mounted on the offshore platform, two crane interference constraints are considered in the SFQCSP. The first one is called the *non-crossing constraint* and prohibits crossing of cranes as they move from one bay to another. The second one is named the *safety constraint* and states that a certain safety distance δ expressed in bay units has to be maintained between any two adjacent cranes. Additionally, a *spatial constraint* is taken into account to reflect the fact that each crane is situated on a different module of the platform. This constraint confines the operation range of a crane, thereby limiting its access to specific groups of bays.

Typically, vessel (un)loading times exhibit different levels of volatility. Stochasticity may originate from various factors such as diverse weather conditions (Chhetri et al. 2016), deviations among operators experience and skill levels (Tabernacle 1995) as well as equipment failure (Zeng et al. 2011). In this study, only unmanned (un)loading operations are performed, hence operators experience and skill is not considered as a factor of uncertainty. Moreover, we do not take into account operation disruptions due to crane breakdowns. Therefore, in this work, weather conditions and specifically the wind speed at the location of the platform is the studied source of uncertainty rending crane productivity rates highly stochastic. To represent the uncertainty in the studied model, we first define crane productivity coefficients, denoted by $\alpha^k \in [0,1]$, $k \in Q$, following the approach in (Legato et al. 2012). The productivity coefficients are determined by sampling crane productivity rates from real-world wind speed/crane productivity data. Then, the handling time of task i assigned to crane k is set to $p_i^k = p_i \backslash \alpha^k$, where p_i is the individual handling time of task i. The objective of the SFQCSP is to determine the expected completion time $E(c_i)$ of each task $i \in \Omega$, such that the expected completion time of the final task T, $E(c_T)$, (i.e., the expected makespan) is minimized. Therefore, the objective function value of the problem solution corresponds to the time required for the entire (un)loading process to complete.

3. SIMHEURISTIC FRAMEWORK

Simheuristics are algorithmic frameworks that combine optimization algorithms and simulation approaches into joint collaborative schemes (Juan et al. 2015). Such frameworks usually employ metaheuristic optimization to tackle the deterministic version of the problem at hand, whereas the computation of the stochastic objective function value is performed through simulation. In this study, the Iterated Local Search (ILS) algorithm (Lourenço et al. 2003) is used as the main optimization method, whereas we employ the Monte Carlo Sampling (MCS) approach (Shapiro 2003) to approximate the value of the expected makespan. Additionally, the proposed simheuristic framework is based on the assumption that high-quality solutions of the deterministic version of a problem are probable to be high-quality solutions also for the stochastic version (Juan et al. 2014). This section presents the employed simheuristic framework by providing details on its optimization and simulation counterparts as well as giving information on their integration.

3.1. Iterated Local Search

ILS is an established metaheuristic algorithm mainly used to tackle combinatorial optimization problems (Lourenço et al. 2003). The algorithm is based on the observation that the iterative application of local search (LS) does not always result in solution improvement. This is because the LS procedure is usually trapped at specific points of the search space, called *local optima*. To mitigate this issue, instead of starting the search from randomly generated solutions, ILS makes use of a specialized mechanism, called *perturbation*. Perturbation involves generating a new solution by applying proper modifications to the incumbent local optimum with the aim of exploring regions beyond the current basin of attraction. In this way, it is possible to probe neighborhoods that the LS heuristic cannot easily reach, thereby amplifying the exploration capabilities of the algorithm.

The algorithm comprises four main components, which are defined prior to its execution. These are a method that generates an initial solution, a perturbation mechanism, a local search heuristic (i.e., neighborhood operator), and an acceptance criterion. The solution generation method creates an initial solution s_0 either randomly or by employing a problem-specific heuristic technique.

Perturbation is applied to the current solution s leading to a modified solution s'. Then, the LS heuristic comes into play and generates a local optimum s'' based on s'. Finally, the acceptance criterion determines which solution will be given as input to the perturbation mechanism in the next cycle of the ILS. The algorithm is executed repeatedly until a predefined termination criterion is satisfied. In this study, the employed termination criterion is the number of local searches applied by the algorithm. Pseudocode of ILS is presented in Algorithm 1. Specifically, the provided pseudocode except for lines 3, 7, and 9 refers to the execution of the employed solution method. For more details on the ILS, the reader is referred to (Lourenço et al. 2003).

In this study, we incorporate the ILS into the proposed simheuristic framework with the aim of determining high-quality solutions for the deterministic version of the problem at hand. To this end, we design the four main components of ILS tailored to the requirements of the considered problem. Next, detailed information is provided on the development of each one of these algorithmic components.

3.1.1. Generation of initial solution

To generate an initial solution for the considered problem, a two-step technique is incorporated into the ILS. In the first step, each crane is assigned the tasks that are within its operation range and cannot be allocated to other cranes. The second step involves distributing the remaining tasks uniformly at random among cranes that are allowed to work on the bays where the containers of the considered tasks are situated. Therefore, the employed generation technique makes certain that the initial solution satisfies the spatial constraints of the SFQCSP. However, it does not guarantee that the solution will respect the other constraints of the problem. To ensure that, the generation procedure is executed repeatedly until the new solution is feasible with respect to all other constraints of the SFQCSP.

3.1.2. Perturbation mechanism

Typically, the design of this mechanism is not a straightforward task as the perturbation has to guide the search away from the current basin of attraction, but not too far leading to a random restart. For the considered problem, the mechanism is developed on the swap of several tasks between each crane and its adjacent ones. The number of tasks swapped between two cranes, called the perturbation step and denoted by p_{st}, plays a significant role in the success of the method. For this reason, its configuration is properly investigated in the experimental part presented in Section 4. The perturbation mechanism is executed repeatedly until it leads to a feasible solution with respect to the constraints of the SFQCSP.

3.1.3. Local search heuristics

For the considered problem, two local search heuristics are developed. The first one, called *shift* heuristic, works on the redistribution of tasks between adjacent cranes.

Algorithm 1 Generic Simheuristic Framework

Input: Problem and algorithm parameters
Output: Solution and its objective function value for the deterministic and the stochastic version of the considered problem

1: $s_0 \leftarrow$ `GenerateInitialSolution()`
2: $s \leftarrow$ `LocalSearch`(s_0)
3: $ms \leftarrow$ `MonteCarloSampling`(s)
4: **repeat**
5: $\quad s' \leftarrow$ `Perturbation`(s)
6: $\quad s'' \leftarrow$ `LocalSearch`(s')
7: $\quad ms'' \leftarrow$ `MonteCarloSampling`(s'')
8: $\quad s \leftarrow$ `AcceptanceCriterion`(s, s'')
9: $\quad ms \leftarrow$ `BestSolution`(ms, ms'')
10: **until** termination criterion is satisfied

The second one, named *swap* heuristic, interchanges tasks between cranes located in neighboring bays. Assuming an assignment of tasks per crane $\sigma_k,\ k \in Q$ and a unidirectional schedule $\sigma = (\sigma_1, \sigma_2, \dots, \sigma_q)$, the shift heuristic reassigns each task of crane k to cranes $k+1$, $k-1$, located in the upper and lower bays of the current bay, respectively. In the case that any of these cranes is not present, the task is shifted to the existing one. As for the swap heuristic, each task of crane k is assigned to crane $k+1$ and each task belonging to crane $k+1$ is assigned to crane k. For both heuristics, special attention is paid to make sure that each inserted task is placed at the correct position, respecting the lexicographical order within $\sigma_k,\ k \in Q$.

3.1.4. Acceptance criterion

The acceptance criterion determines which solution will be forwarded to the perturbation mechanism at the next cycle of the ILS. Two alternative solutions are compared at each cycle: the local optimum s'' generated by the LS procedure in the current cycle of the algorithm and the local optimum s produced in the previous one. Between these, the solution with the higher quality with respect to the value of the objective function is accepted and used at the next cycle of the algorithm.

3.2. Monte Carlo Sampling

MCS is a computational method that can be used to approximate the objective function value of a stochastic optimization problem (Shapiro 2003). Given an objective function $F(\cdot)$, a probability distribution P and a random sample $\{\omega^1, \omega^2, \dots, \omega^m\}$ of size m drawn from P, a Monte Carlo estimator (also called expected objective function value) of $F(\cdot)$ denoted by $\hat{f}_m(\cdot)$ is defined as:

$$\hat{f}_m(x) = \frac{1}{m}\sum_{i=1}^{m} F(x, \omega^i). \quad (1)$$

Note that the computation of $\hat{f}_m(\cdot)$ results in a numerical value whose precision depends on m. Typically, samples of larger size (i.e. more observations) lead to more accurate computations of $\hat{f}_m(\cdot)$.

The MCS is employed within the proposed simheuristic framework to compute the value of the expected makespan, which is the used objective function for the SFQCSP. Specifically, the local optimal solution generated by each LS procedure is given as input to the MCS, which is executed until a predefined stopping rule is satisfied. The employed stopping rule is presented in the Section 3.2.1. Lines 3 and 7 of Algorithm 1 refer to the execution of the MCS method. Note that this method is always applied after LS taking into account the hypothesis that there is a relation between high-quality solutions of the deterministic and the stochastic version of the considered problem. Furthermore, a so-called best solution procedure is developed (line 9 of Algorithm 1) to compare the solution for the SFQCSP of the current cycle (ms'') with the solution that was generated in the former cycle (ms). Finally, the solution that achieves the lowest expected makespan is identified as the best solution.

3.2.1. Stopping rule

Determining the exact number of observations needed by MCS to achieve a specific level of precision is considered an intricate task. For this reason, instead of defining a specific sample size, we set a limit on the number of required simulations by computing the relative error of the generated sample. Following the study in (Ata 2007), the relative sampling error is defined as:

$$\text{RSE} = z_{\alpha/2}\sqrt{S_m^2/m}, \quad (2)$$

where $z_{\alpha/2}$ is the z value of the confidence interval at significance level α, m is the number of already performed simulations, and S_m^2 is the variance estimator of the sample. Then, the current simulation is terminated when:

$$\text{RSE} \leq \mu_\varepsilon \bar{X}_m, \quad (3)$$

where $\bar{X}_m$ is an estimator of the sample mean over m observations and $\mu_\varepsilon \in [0,1]$ is the given error threshold, which represents the level of precision. Eq. (3) acts as the stopping rule used to terminate any MCS conducted within the developed simheuristic framework. The benefit from employing this stopping rule is twofold: it enables the simulation to achieve the desirable level of precision while it also averts long and unnecessary simulations, thereby reducing considerably the execution time of the simheuristic.

4. EXPERIMENTAL EVALUATION

The goal of the experimental evaluation is to study the effect of different configurations of the developed approach on the solution quality. To accomplish this, we have conducted extensive simulation experiments adopting the set of instances introduced in (Kim and Park 2004) and also used in (Bierwirth and Meisel 2009, Monaco and Sammarra 2011, Sammarra et al. 2007).

Table 1: Characteristics of the used problem instances including bay ranges per crane (Kim and Park 2004, Monaco and Sammarra 2011).

Set	Instances	$\lvert\Omega\rvert$	$\lvert Q\rvert$	Bays	Bay ranges per crane
A	k13-k22	10	2	1 to 10	[1,7], [3,10]
	k23-k32	15	2	1 to 15	[1,10], [5,15]
B	k33-k42	20	3	1 to 20	[1-10], [5-15], [11-20]
	k43-k49	25	3	1 to 25	[1-12], [8-20], [13-25]

Table 2: Parameter configuration of the developed approach.

Parameter	Description	Value(s)
N_{LS}	Number of applied LS	{51,101}
p_{st}	Perturbation step	{1,2,3}
m_{max}	Max sample size per MCS	2 x 10^4
μ_ε	Error threshold	{1 x 10^{-2}, 5 x 10^{-3}}
α	Significance level	0.95

Characteristics of these instances including limitations imposed on the operation ranges of the quay cranes are shown in Table 1. In this table, note that the number of considered tasks and available cranes are denoted by $|\Omega|$ and $|Q|$, respectively.

Our experimental study comprises two phases. In the first phase, the focus is on determining the best ILS variant with respect to the solution quality for the deterministic version of the problem. In the second phase, we incorporate the best algorithmic variant derived from the previous step into the simheuristic framework. During this step, our aim is to minimize the time required to (un)load a vessel (i.e., expected makespan) under different wind speed/crane productivity scenarios. The parameter configurations used in the experiments are displayed in Table 2.

The simheuristic approach has been developed in Python 3.7.0 using the Anaconda 1.8.7 framework. We performed the experiments on a Windows workstation consisting of an Intel© Xeon 3.70 GHz processor with 32GB of RAM.

4.1. Deterministic case

As described in Section 3.1.3, two specialized neighborhood operators, called shift and swap heuristics, are used by the ILS. Moreover, we consider a low and a high computation budget with respect to the number of applied local searches in order to evaluate the performance of the algorithm under different computation scenarios. Specifically, the low budget case involves carrying out 51 local searches, whereas the high budget case refers to the application of the local search heuristic for 101 times, namely $N_{\text{LS}} \in \{51,101\}$. Note that one local search is performed during the initialization phase of the algorithm whereas the remaining local searches are consumed by the main execution of the ILS. Also, we investigate the performance of three perturbation step values, namely $p_{\text{st}} \in \{1,2,3\}$. Overall, we experiment with 12 different configurations that correspond to an equal number of ILS variants. A number of 10 independent experiments per algorithmic variant and problem instance was conducted

Table 3: Results for the deterministic FQCSP - shift heuristic.

	Low comput. budget			High comput. budget		
Inst.	$p_{st} = 1$	$p_{st} = 2$	$p_{st} = 3$	$p_{st} = 1$	$p_{st} = 2$	$p_{st} = 3$
k13	453.0	453.0	453.0	453.0	453.0	453.0
k14	546.0	546.0	569.4	546.0	546.0	563.1
k15	513.0	513.0	520.2	513.0	513.0	517.8
k16	312.0	326.4	316.8	312.0	319.2	316.8
k17	453.0	453.6	464.1	453.0	453.6	455.7
k18	375.0	379.5	382.2	375.0	380.4	387.6
k19	552.0	556.8	556.8	552.0	562.8	558.0
k20	399.0	399.0	399.0	399.0	399.0	399.0
k21	465.0	465.0	489.0	465.0	481.2	496.8
k22	540.0	540.0	540.0	540.0	540.0	540.0
k23	576.3	576.0	581.1	576.0	576.0	581.4
k24	666.0	666.0	667.8	666.0	666.0	669.6
k25	741.0	742.8	746.4	741.0	741.0	743.7
k26	642.0	642.0	642.3	642.0	642.0	643.2
k27	660.0	660.0	667.5	660.0	660.0	663.9
k28	531.0	531.0	534.9	531.0	531.0	538.8
k29	807.0	813.6	816.0	807.0	807.0	813.0
k30	891.0	895.8	893.4	891.0	900.6	894.6
k31	570.0	570.0	576.0	570.0	570.0	573.0
k32	597.0	597.0	612.3	597.0	597.0	612.3
k33	642.0	642.0	642.0	642.0	649.8	642.0
k34	741.0	741.0	741.0	741.0	741.0	741.0
k35	687.9	686.4	718.2	688.8	684.0	697.8
k36	729.0	729.0	729.0	729.0	729.0	729.0
k37	510.0	510.3	530.7	510.0	510.6	525.3
k38	650.4	651.9	666.3	640.5	648.3	658.2
k39	526.8	525.0	535.5	525.0	525.0	538.2
k40	567.0	567.0	574.8	567.0	567.0	585.0
k41	588.6	589.8	629.7	588.0	589.2	630.9
k42	578.7	591.9	606.3	573.0	573.0	589.2
k43	876.3	899.7	896.4	876.0	888.3	912.9
k44	823.5	835.8	849.9	822.6	830.1	849.0
k45	837.6	840.0	841.2	836.4	839.4	842.4
k46	720.9	723.6	721.8	712.5	717.0	708.0
k47	792.6	793.8	793.2	794.1	793.2	793.2
k48	666.0	670.2	666.0	666.0	666.0	666.0
k49	896.1	902.7	903.3	894.6	898.5	899.4
Mean	625.0	627.7	634.4	**624.2**	626.7	633.2

Table 4: Results for the deterministic FQCSP - swap heuristic.

	Low comput. budget			High comput. budget		
Inst.	$p_{st} = 1$	$p_{st} = 2$	$p_{st} = 3$	$p_{st} = 1$	$p_{st} = 2$	$p_{st} = 3$
k13	453.0	453.0	453.0	453.0	453.0	453.0
k14	546.0	567.0	602.7	546.0	567.0	608.1
k15	531.6	536.4	541.2	543.3	552.6	555.3
k16	312.0	321.6	315.3	312.0	326.4	316.2
k17	453.0	453.9	468.9	453.0	453.6	469.8
k18	375.0	387.6	384.0	375.0	384.9	385.8
k19	552.0	558.0	579.9	552.0	571.8	598.2
k20	399.0	399.0	426.0	399.0	399.0	429.0
k21	465.0	476.7	486.9	465.0	495.6	508.8
k22	599.4	567.0	606.6	568.8	590.4	588.6
k23	576.0	576.0	588.0	576.0	576.0	588.0
k24	670.2	670.2	729.6	669.6	668.4	683.4
k25	741.0	741.0	758.7	741.0	741.0	767.1
k26	642.0	642.0	642.9	642.0	642.0	661.8
k27	660.0	661.2	663.9	660.0	661.8	662.1
k28	531.0	548.7	552.9	531.0	544.8	552.9
k29	807.0	831.3	825.9	807.3	829.8	822.9
k30	891.0	921.6	951.6	891.0	928.2	937.2
k31	570.0	641.7	644.7	570.0	645.0	654.9
k32	597.0	597.3	609.3	597.0	597.3	637.5
k33	642.0	665.4	688.8	642.9	642.0	677.1
k34	756.0	793.5	765.9	756.3	783.0	807.0
k35	690.6	686.7	731.4	688.2	684.0	730.8
k36	729.0	729.0	729.0	729.0	729.0	729.0
k37	510.6	513.9	539.7	510.0	513.0	538.8
k38	647.1	667.5	689.7	640.2	660.0	684.0
k39	528.6	552.9	555.6	528.3	556.8	566.4
k40	567.0	598.5	611.1	567.0	590.7	611.4
k41	593.7	634.2	665.1	588.6	636.3	673.5
k42	580.5	623.7	683.1	573.0	640.2	647.1
k43	936.0	918.6	1056.9	915.0	935.7	957.3
k44	825.9	877.5	832.8	823.2	850.2	864.3
k45	839.4	843.6	842.7	835.2	842.4	837.6
k46	835.5	769.8	854.7	806.7	774.6	807.9
k47	971.7	950.4	983.4	1003.8	918.9	943.8
k48	801.6	747.9	778.5	788.4	740.1	768.6
k49	906.0	927.3	963.3	906.3	930.3	960.6
Mean	641.4	650.0	670.4	**639.3**	650.2	667.2

resulting in 4.440 independent experiments in total. For each experiment, we recorded the best objective function value, which provides an estimate on the time units required to (un)load a vessel that arrives at the offshore platform.

Tables 3 and 4 present the results for the application of the shift and swap heuristics, respectively. To compare the different approaches, we compute the mean value per variant over all considered problem instances. Regarding the shift heuristic, in Table 3 we find that the setting $p_{\mathrm{st}} = 1$ is the best configuration choice for both low and high computation budgets. On the contrary, higher p_{st} values result in worse performance. This leads to the conclusion that mild perturbations should be applied when the considered problem is tackled by the ILS. An additional conclusion is that the high computation budgets exhibit better performance than the low budgets. This result was anticipated since by applying a higher number of local search procedures, usually solutions of better quality are detected. Overall, the best configuration choice combined $p_{\mathrm{st}} = 1$ with the high computation budget scenario achieving a mean objective function value of 624.2.

As for the swap heuristic, in Table 4 we again observe that lower perturbation steps along with higher computation budgets lead to results of higher quality.

This outcome is in line with the best configuration choice that was identified for the shift heuristic. Specifically, we see that using $p_{\text{st}} = 1$ and the high budget choice, the best objective function value for the swap heuristic is attained, which is equal to 639.3. Comparing the shift and swap heuristic, we find superior the performance of the shift heuristic under all considered configurations. This can be attributed to the fact that the swap heuristic works in a similar way to the employed perturbation mechanism. Therefore, there is the risk that the perturbation reverts moves that already applied the swap heuristic, thereby reducing significantly the exploration dynamics of the ILS.

4.2. Stochastic case

In this section, we provide results for the SFQCSP, assuming that the crane productivity rates exhibit uncertainty. Our goal is to minimize the expected time required to (un)load a vessel from/to the offshore platform under different wind conditions. To accomplish this, we use the simheuristic framework that employed the best ILS variant of the previous experimental phase consisting of the shift heuristic and adopting the parameter values $p_{\text{st}} = 1$, $N_{\text{LS}} = 101$. Regarding the simulation component of the framework, we assume a maximum sample size of $m_{max} = 2 \text{ x } 10^4$ simulations per application of MCS. Additionally, the stopping rule presented in Section 3.2.1 is used to terminate the MCS when the desired level of precision is attained. To this end, two different error threshold values, $\mu_\varepsilon \in \{1 \text{ x } 10^{-2}, 5 \text{ x } 10^{-3}\}$ and a significance level of $\alpha = 0.95$ are considered.

To solve the SFQCSP under realistic wind conditions, we have gathered real-world wind data and computed their impact on crane productivity. Specifically, environmental data from years 1979-2017 containing hourly average wind speeds at a height of 10m at the platform location have been obtained from the DHI MetOcean (http://www.metocean-on-demand.com). In order to provide accurate computations, the wind speed should be measured at the height of 40m (i.e., the crane top level) instead of the height provided in the data. Furthermore, according to (PIANC 2012), the calculations should be based on the 3-second gust speed and not on the typical wind speed. Therefore, the provided hourly average wind speed is converted to a 3-second gust speed at the platform location. Following both suggestions, the required transformation has been performed as follows:

$$U_{40} = U_{10} \text{ x } \left(H_{10}^{40} + F_w^g\right) = U_{10} \text{ x } 1.45, \qquad (4)$$

where U_{10} is the average wind speed at 10m and U_{40} is the 3-second gust speed at 40m. The transformation from 10m to 40m, denoted by H_{10}^{40}, is computed according to the power law relationship $(40/10)^{1/7}$and is equal to 1.22. F_w^g represents the conversion from the average wind speed to the 3-second gust speed and is equal to 1.23 taking into account that the platform is situated more than 20 km away from the coast.

Table 5: Characteristics of the scenarios regarding the wind speed and its impact on crane productivity.

Sce-nario	Wind speed	3-second gust speed	Crane productivity rate %
1	13.34-14.00	20.00-20.99	[80.00, 100.00)
2	14.01-14.67	21.00-21.97	[60.00, 80.00)
3	14.68-15.33	22.01-22.99	[40.00, 60.00)
4	15.34-16.00	23.00-23.99	[20.00, 40.00)

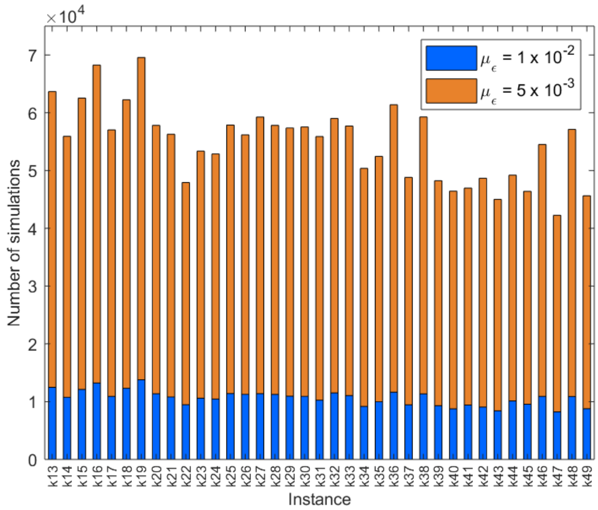

Figure 2: Number of simulations per instance for the used error threshold values for Scenario 1.

Typically, a 3-second gust speed below 20m/s is assumed to enable full crane productivity (100%), while rate values exceeding 25m/s force the crane equipment to cease its operation (PIANC 2012). In this study, we only consider gust speeds between 20 and 24m/s and therefore productivity rates between 20% and 100%. This is because rates equal to 100% imply a deterministic crane scheduling problem while the focus of this section is on stochastic crane scheduling challenges. Additionally, we consider productivity rates less than 20% as an extreme case where crane operations are infeasible, hence obviously the crane scheduling problem is not required to be assessed under these scenarios. Given these assumptions, from the available dataset, we have extracted data items that correspond to gust speeds in [20.00,24.00), resulting in 12612 data points. To compute the crane productivity per data item, we make the hypothesis that productivity rates decrease linearly with respect to the 3-second gust speeds. To study the impact of wind speed variability on crane operations in more detail, we divide the total crane productivity operation range into disjoint groups resulting in four main wind speed/crane productivity scenarios. Information per scenario with respect to the wind speed at 10m, the corresponding 3-second gust speed at 40m along with the corresponding crane productivity rates is shown in Table 5.

Tables 6 and 7 in Appendix A presents the results for the SFQCSP using the four scenarios and the error threshold value $\mu_\varepsilon = 1 \text{ x } 10^{-2}$. Specifically, for each instance, we report the best solution of the deterministic version, c_T, the best solution for the stochastic version of the problem, $E(c_T)$, along with the confidence interval, CI,

at significant level $\alpha = 0.95$. Note that there is only one column for the c_T value as the simheuristic detected the same best solution regardless of the employed wind speed/crane productivity scenario. This is because the wind variability does not affect the solutions of the deterministic problem. On the contrary, for each scenario, we see that the higher the wind speed, the lower the crane productivity rate and thus, the less the expected time of the (un)loading process.
Finally, we experiment with the sample size of the MCS for each of the considered error threshold values. Indicatively, Figure 2 reports the total number of simulations performed by the simheuristic per error threshold value regarding Scenario 1. Interestingly, we notice that in order to double the level of precision (i.e., halve the error threshold), the number of simulations has to be increased by about four times. Determining the exact trade-off between precision and execution time depends significantly on the time frame according to which the SFQCSP is required to be solved.

5. CONCLUSIONS AND FUTURE RESEARCH

In this paper, we studied the Stochastic Floating Quay Crane Scheduling Problem in which each crane is situated on one module of an offshore platform. Moreover, we explicitly took into account that the speed of the offshore wind influences the productivity rates of the quay cranes. To address the crane scheduling challenge, we proposed a simheuristic framework that combines the Iterated Local Search algorithm and the Monte Carlo Sampling method into a joint collaborative scheme. The Iterated Local Search algorithm was used to tackle the deterministic version of the problem whereas the Monte Carlo Sampling method was employed to compute the value of the stochastic objective function. Two different local search heuristics, called shift and swap heuristic, were incorporated into the Iterated Local Search algorithm. Experimental results showed the superiority of the shift heuristic under all considered configurations. Additionally, we concluded that only mild perturbations are required when the particular problem is confronted. We have used the developed simheuristic to minimize the time required to (un)load a vessel from/to the platform under different wind speed/crane productivity scenarios. The scenarios were generated by using a specialized approach that quantified the impact of wind speed on crane productivity rates. Future research will involve the application of the simheuristic to larger problem instances including a higher number of cranes and tasks. Additionally, different methods that enhance the efficiency of this framework will be proposed and evaluated on environmental data considering both wind and wave conditions.

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APPENDIX A

In the Appendix, Tables 6 and 7 present detailed results for the SFQCSP under the considered four wind speed/crane productivity scenarios.

Table 6: Results for the SFQCSP under Scenario 1 and Scenario 2.

		Scenario 1		Scenario 2	
Inst.	c_T	$E(c_T)$	CI	$E(c_T)$	CI
k13	453	492.5	[487.6, 497.4]	636.8	[630.5, 643.2]
k14	546	604.1	[598.0, 610.1]	781.9	[774.1, 789.7]
k15	513	566.8	[561.1, 572.4]	733.2	[725.9, 740.5]
k16	312	339.3	[335.9, 342.7]	438.6	[434.2, 443.0]
k17	453	498.2	[493.3, 503.2]	642.7	[636.3, 649.1]
k18	375	413.0	[408.9, 417.1]	535.1	[529.8, 540.5]
k19	552	601.8	[595.8, 607.8]	776.7	[768.9, 784.4]
k20	399	442.4	[438.0, 446.7]	572.1	[566.4, 577.8]
k21	465	520.3	[515.1, 525.5]	673.6	[666.9, 680.3]
k22	540	597.9	[591.9, 603.8]	774.9	[767.2, 782.6]
k23	576	644.6	[638.2, 651.0]	834.0	[825.7, 842.4]
k24	666	744.7	[737.3, 752.1]	964.8	[955.2, 974.5]
k25	741	822.3	[814.1, 830.5]	1067.6	[1056.9, 1078.3]
k26	642	714.7	[707.6, 721.8]	926.3	[917.1, 935.6]
k27	660	733.6	[726.3, 741.0]	949.5	[940.0, 958.9]
k28	531	588.7	[582.8, 594.6]	763.2	[755.6, 770.8]
k29	807	904.7	[895.7, 913.7]	1170.2	[1158.5, 1181.9]
k30	891	1003.2	[993.2, 1013.2]	1303.3	[1290.3, 1316.3]
k31	570	627.7	[621.4, 633.9]	812.5	[804.4, 820.6]
k32	597	661.0	[654.4, 667.6]	858.1	[849.5, 866.7]
k33	642	702.2	[695.2, 709.2]	910.8	[901.7, 919.8]
k34	741	823.1	[814.9, 831.4]	1072.5	[1061.8, 1083.2]
k35	684	777.0	[769.3, 784.8]	1012.7	[1002.6, 1022.8]
k36	729	796.6	[788.6, 804.5]	1034.8	[1024.5, 1045.1]
k37	510	579.0	[573.2, 584.8]	755.3	[747.8, 762.9]
k38	636	716.5	[709.5, 723.6]	927.0	[917.8, 936.3]
k39	525	582.7	[576.9, 588.5]	759.0	[751.4, 766.6]
k40	567	636.8	[630.5, 643.2]	827.1	[818.9, 835.4]
k41	588	671.9	[665.2, 678.6]	873.5	[864.8, 882.2]
k42	573	639.7	[633.3, 646.1]	835.5	[827.1, 843.8]
k43	876	993.3	[983.4, 1003.2]	1298.2	[1285.3, 1311.1]
k44	822	936.5	[927.2, 945.8]	1224.1	[1212.0, 1236.3]
k45	834	954.8	[945.3, 964.3]	1244.5	[1232.1, 1256.9]
k46	705	795.7	[787.8, 803.6]	1033.4	[1023.0, 1043.7]
k47	792	901.9	[892.9, 910.8]	1178.1	[1166.3, 1189.8]
k48	666	731.8	[724.5, 739.0]	948.5	[939.0, 957.9]
k49	894	1016.8	[1006.7, 1026.9]	1321.5	[1308.4, 1334.7]

Table 7: Results for the SFQCSP under Scenario 3 and Scenario 4.

		Scenario 3		Scenario 4	
Inst.	c_T	$E(c_T)$	CI	$E(c_T)$	CI
k13	453	891.7	[900.9, 919.1]	1537.9	[1522.5, 1553.2]
k14	546	1110.5	[744.9, 760.0]	1946.9	[1927.5, 1966.4]
k15	513	1038.3	[1081.2, 1103.1]	1822.8	[1804.5, 1841.0]
k16	312	613.9	[796.9, 813.0]	1066.7	[1056.0, 1077.4]
k17	453	910.0	[947.6, 966.7]	1586.7	[1570.8, 1602.6]
k18	375	752.5	[1081.7, 1103.5]	1318.2	[1305.0, 1331.4]
k19	552	1092.2	[1159.6, 1183.0]	1907.9	[1888.9, 1927.0]
k20	399	805.0	[1350.4, 1377.6]	1414.5	[1400.3, 1428.6]
k21	465	957.2	[1487.1, 1517.1]	1676.1	[1659.4, 1692.9]
k22	540	1092.6	[1295.7, 1321.8]	1919.4	[1900.2, 1938.6]
k23	576	1171.3	[1324.4, 1351.1]	2051.8	[2031.3, 2072.3]
k24	666	1364.0	[1063.4, 1084.8]	2377.4	[2353.6, 2401.1]
k25	741	1502.1	[1636.7, 1669.7]	2631.7	[2605.4, 2658.0]
k26	642	1308.7	[1823.4, 1860.2]	2290.5	[2267.6, 2313.4]
k27	660	1337.7	[1130.4, 1153.2]	2348.7	[2325.2, 2372.2]

k28	531	1074.1	[1196.2, 1220.3]	1863.0	[1844.4, 1881.7]
k29	807	1653.2	[1276.1, 1301.9]	2899.2	[2870.2, 2928.2]
k30	891	1841.8	[1513.2, 1543.7]	3231.0	[3198.7, 3263.3]
k31	570	1141.8	[1434.1, 1463.0]	1991.5	[1971.6, 2011.4]
k32	597	1208.3	[1444.1, 1473.3]	2117.7	[2096.5, 2138.9]
k33	642	1289.0	[1064.8, 1086.3]	2303.1	[2280.1, 2326.1]
k34	741	1528.5	[1300.3, 1326.5]	2735.9	[2708.5, 2763.2]
k35	684	1448.6	[1060.7, 1082.1]	2599.7	[2573.7, 2625.7]
k36	729	1458.7	[1167.0, 1190.5]	2610.7	[2584.6, 2636.8]
k37	510	1075.5	[1233.7, 1258.6]	1926.8	[1907.5, 1946.1]
k38	636	1313.4	[1169.8, 1193.4]	2324.4	[2301.1, 2347.6]
k39	525	1071.4	[1826.9, 1863.7]	1914.2	[1895.0, 1933.3]
k40	567	1178.7	[1720.1, 1754.8]	2119.6	[2098.4, 2140.7]
k41	588	1246.1	[1747.7, 1782.9]	2234.7	[2212.4, 2257.1]
k42	573	1181.6	[1453.4, 1482.8]	2124.5	[2103.2, 2145.7]
k43	876	1845.3	[1660.4, 1693.9]	3321.5	[3288.3, 3354.7]
k44	822	1737.5	[1332.0, 1358.8]	3115.8	[3084.7, 3146.9]
k45	834	1765.3	[1874.2, 1912.0]	3164.8	[3133.2, 3196.4]
k46	705	1468.1	[900.9, 919.1]	2621.2	[2595.0, 2647.4]
k47	792	1677.2	[744.9, 760.0]	3018.2	[2988.0, 3048.4]
k48	666	1345.4	[1081.2, 1103.1]	2400.6	[2376.6, 2424.6]
k49	894	1893.1	[796.9, 813.0]	3384.4	[3350.5, 3418.2]

SIMULATION BASED EVALUATION OF THE CAPACITY OF LIUHENG LNG TERMINAL

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ABSTRACT

Liuheng LNG (Liquified Natural Gas) terminal is proposed to serve LNG carriers and LNG tank container ships. However, the capacity of this terminal may be limited by the long entrance channel and traffic rules for LNG transportation. Therefore, to evaluate the capacity of Liuheng LNG terminal, we establish an agent-based microscopic simulation model for ship operation (AMic-SMSO) to simulate the whole process of ship operation in and out of a port. We undertake a series of experiment scenarios to identify the bottlenecks and assess the throughput capability by analyzing waiting times, berth occupancies, and explore the effect of modifying the traffic rules on these indicators. The results show that this simulation model is a useful tool in determining whether traffic rules works well actually, especially for LNG terminal berth configuration plan.

Keywords: LNG terminal, one-way channel, ship traffic simulation, service level

1. INTRODUCTION

Fierce competition hastens port operators' efforts to enhance the capacity and efficiency of channel while maintaining a required service level. However, the terminal capacity is closely related to a great amount of uncertain factors and may be limited by the long entrance channel. Liuheng LNG (Liquified Natural Gas) terminal is proposed to accommodate LNG carriers and LNG tank container ships. So, traffic rules for LNG transportation also need to be considered. For example, the traffic rules such as one-way traffic, moving safety zone and no transit at night may lead to more waiting time and decrease the capacity of an LNG terminal. Therefore, the objective of this study is to identify the capacity and bottlenecks of Liuheng LNG terminal by analyzing waiting times, berth occupancies and LNG throughput.

At present, few works study the throughput capacity of LNG terminals, and most studies concentrate on the capacity in container terminals and bulk terminals. Lin et al. (2014) got the annual throughput of container terminal considering equipment types and berth allocation. Longo et al. (2015) investigated the effect of throughput capacity on the implement of green practices in container terminals. Huang et al. (2013) presented a capacity-assessment simulation system for complex waterway networks. Tang et al. (2014) optimize the channel dimension to improve the capacity and navigation efficiency of channel. Sun et al. (2012) developed a real-time system to determine the container throughput. Meanwhile, some studies devoted to analyze the capacity of bulk cargo terminals using mathematical methods and artificial neural network model (Yan and Zhou 2014, Dragovi et al. 2012). However, different from the container ships and bulk ships, LNG carriers should set up a mobile safety zone and implement traffic control when sailing in the waterway considering the safety requirement of its navigation. Liu et al. (2016) considered the additional security zones of LNG ships and waterway conditions. Then a dynamic ship domain model was created to guarantee the safe navigation of ships. Wen et al. (2013) defined the width of a moving safety zone around LNG carriers based on a quantitative probability model. Lisowski (2014) presented a computer simulation model for ship collision avoidance at sea. It's clear that the high safety requirement make entry and exit of LNG carriers exclusive, which will have a great impact on the entry and exit of ships in the relevant port areas, especially in the case of one-way long channel. As described above, at present, there are little studies have been conducted to evaluate the capacity of LNG terminal considering the navigation safety of LNG carriers simultaneously.

Due to complex interactions between ship entities, combined with special navigation rules of LNG carriers, random factors and uncertainties of port operation, it is difficult to use traditional mathematical models to analyze port service level quantitatively. This necessitates the development of traffic flow simulation models to estimate the port capacity (Moran et al., 2014). Simulation technology is often used to study the characteristics of ship traffic flow. Xiao et al. (2015) introduced a multi-agent simulation model to describes the nautical traffic of autonomous ship. Li et al. (2015) constructed a one-way waterway transportation simulation system and analyzed the ship traffic smoothness and traffic efficiency in the waterway. Chen et al. (2018) established a full mission model to simulate the operation of terminals and ships in consideration of the operational safety of LNG carriers during berthing.

Therefore, considering the one-way long channel and complex operation system in Liuheng LNG terminal, this paper establishes an agent-based simulation model to study the capacity of the LNG terminal.
The remainder of this paper is organized as follows. The study case is presented in Section 2. The simulation model is implemented in Section 3 in detail. The simulation results are analyzed in Section 4. Finally, the main conclusions are drawn in Section 5.

2. PROBLEM DESCRIPTION

Due to the dimensions of shoreline and water area, Liuheng LNG terminal could accommodate 4 berths at most as shown in Figure 1, which comprise two 20000-DWT (Dead Weight Tonnage) LNG container berths (B2 and B3) and two 150000-GT (Gross Tonnage) LNG berths (B1 and B4). According to the capacity of the landside LNG handling system on each berth, the annual capacity of this LNG terminal is estimated to reach 10~20 Mt. However, the actual capacity of a port system is dependent on not only LNG handling system, but also the capacity of wet infrastructure (e.g., entrance channel, turning basin, et al.) and traffic rules for ship navigation and maneuvering.

2.1. Wet infrastructure

As shown in Figure 1, the wet infrastructure consists of a very long entrance channel (24.5 km) to the LNG terminal and 2 turning basins (TB1 and TB2). The entrance channel provides two-way traffic only for less than or equal to 20000-DWT container ships loaded with LNG tank containers, but one-way traffic for larger than 20000-DWT LNG tank container ships or LNG carriers. One-way traffic means that this channel allows ships to move in the same direction, while ships moving in the opposite direction have to wait until the channel is evacuated (McCartney et al. 2005, Tang et al. 2013). When one-way entrance channel is too long, the situation becomes more serious (Tang et al. 2013). With the increase of traffic volume, unacceptable wait will definitely lead to poorer port performance and capacity.
In addition, as shown in Figure 1, the turning basins TB1 and TB2 occupy part section of the entrance channel, which causes hindrance to ship traffic. When an LNG ship is maneuvering in turning basin, no other ship is allowed to be in this channel section for safety, which also increase waiting time of LNG carriers.

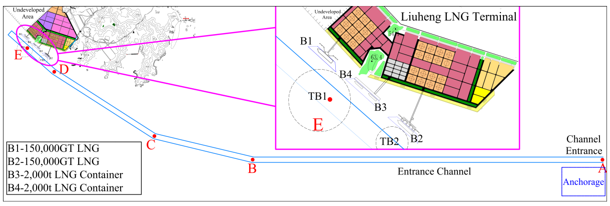

Figure 1: Schematic Diagram of the Proposed LNG Terminal with Its Wet Infrastructure

2.2. Traffic rules

To ensure the safety of LNG carriers and LNG tanker container ships, more management measures (e.g., one-way traffic, moving safety zone and no transit at night) are taken during LNG carriers or LNG tank container ships transit from the open sea to its terminal berth and return to sea.

1. **Traffic rules for LNG carriers**
   a) One-way traffic: Encounters and overtake maneuvers with vessels are prohibited during LNG carriers transiting through the channel area.
   b) Moving safety zone: No other ships are permitted to enter the safety zone around a transiting LNG carrier. From the practice of existing Chinese LNG terminals, the recommended size of safety zone is 1 n mile distance in front and behind, and 150 m from port side and starboard side.
   c) No transit at night: Entry and departure commence only during daylight hours.
2. **Traffic rules for LNG tank container ships**
   a) Two-way traffic: Less than or equal to 20000-DWT LNG tank container ships are allowed to pass each other.
   b) One-way traffic: Encounters and overtake maneuvers with vessels are prohibited when larger than 20000-DWT LNG tank container ships are transiting through the channel area.
   c) Safety zone: Its size varies with ship speed and ship length and determined based on the fuzzy quaternion ship domain theory (Chen P et al., 2018).
   d) No transit at night: Entry and departure commence only during daylight hours.

In conclusion, these traffic rules will cause more waiting and complicate the navigation system of wet infrastructure in Liuheng LNG terminal. Moreover, ship arrivals and ship unloading/loading time are also stochastic. Therefore, a traffic flow simulation model is developed to estimate the port capacity.

3. METHODOLOGY

In this study, we define the capacity of Liuheng LNG terminal is the annual LNG throughput with complex traffic rules dependent on the required service level in terms of acceptable average waiting times and berth occupancies. Therefore, we establish an agent-based microscopic simulation model for ship operation (AMic-SMSO) to simulate the whole process of ship operation in and out of a port. The objective of the traffic flow simulation study is to identify the bottlenecks of Liuheng LNG terminal by analyzing waiting times, berth occupancies and LNG throughput.

3.1. Logical model

The whole process of the ship in and out of a port is illustrated in Figure 2. Ship operation begins with an inbound ship's arrival. The ship may or may not have to wait in anchorage area, depending on the congestion at the berth and traffic rules for LNG transportation in Section 2.2. If all these states are favorable, the ship is assigned to a berth, and transit to berth via entrance channel and turning basin. After berthing, the LNG or LNG tank container are unloaded to storage tanks or container yards, and the outbound ship travels through the entrance channel and leaves the port when the channel is accessible.

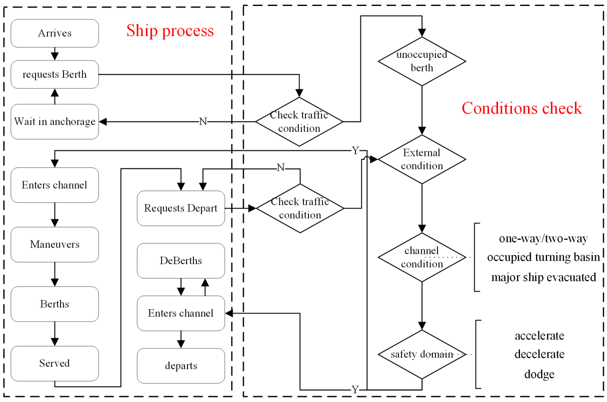

Figure 2: Logic Flowchart of Ship Operations

1. **Ship arrivals**
   Ship arrivals occur at random times (PIANC 2014), and the inter-arrival times between successive ship arrivals are exponentially distributed with $1/\lambda$ hours. Thus, the probability density function is:

$$f(t) = \lambda e^{-\lambda t} \quad (1)$$

   where λ = ship arrival rate, i.e., the number of arrival ships per hour from historical data.
2. **Requesting berth and checking channel availability**
   After inbound ship arrives, it requests the quay master for a berth first. Then the VTS (Vessel Traffic Services) checks currents, water levels and traffic situation based on traffic rules in Section 2. The ship enters and berths on days with good weather in case no problem exists. Otherwise, this ship waits in the outside anchorage until all these states are favorable.
3. **Ship sailing/maneuvering**
   When the ship is sailing in the channel area, it checks whether its safety zone meets the requirements, and then accelerate, decelerate according to the separate distances between ships. Then it arrives at the turning basin and maneuver to berth with tugs, and no other ship is allowed to enter this channel section.
4. **Ship loading and unloading**
   The berth service time includes auxiliary operations time, loading and unloading operations time. According to the statistics of neighboring port, berth service time follows an exponential distribution with $1/\mu$ hours per ship. Its probability density function is as follows:

$$f(t) = \mu e^{-\mu t} \quad (2)$$

   where μ is the service rate, i.e., the number of ships serviced per hour.
5. **Ship mooring and departure**
   After finishing unloading/loading operation, the VTS is again asked for permission to leave the port. If no problem exists, the outbound ship leaves berth, enters channel and leaves port.

3.2. AMic-SMSO Simulation

Using AnyLogic, we revised a verified and validated ship operation system (Tang et al. 2013), establish AMic-SMSO to fulfil the precise simulation of ship operation in Liuheng LNG terminal. The AMic-SMSO comprises five agents including Main, Ship, VTS, PortOperation and QuayMaster. How these agents be organized and what things they are responsible for are contained in Figure 3. The detail description of agents is as follow:

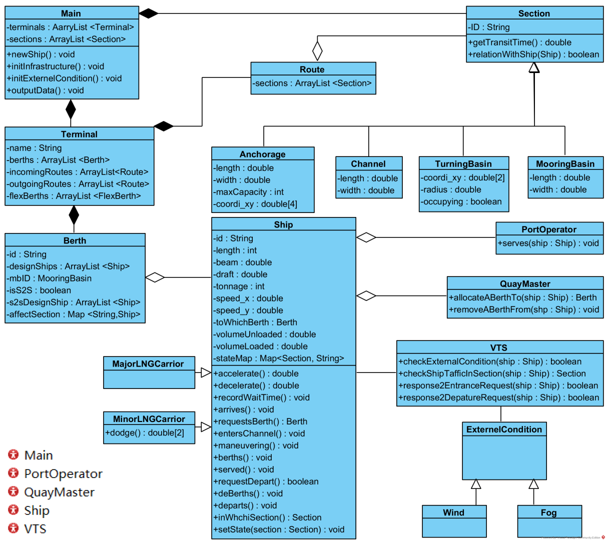

Figure 3: Static Class Diagrams of AMic-SMSO Framework

1. **Main Agent**
   Main Agent as the basis of the simulation model, is responsible for initializing simulation parameters (ship traffic volumes, the number of ship arrivals), port infrastructure (berths and water area) and traffic rules and generating ship agents according to ship arrival pattern. Also, Main agent controls the whole simulation process and outputs simulation results once the simulation run is finished.
2. **Ship Agent**
   Once the ship agent is generated by Main Agent, the ship process is activated and performs the ordered activities in Figure 2. The ship operation is simulated by states and transitions in AnyLogic. The states of a ship agent include

arrival, mooring, waiting, navigation, operation, etc., which corresponds to the process of ship operation in Section 3.1. As illustrated in Figure 4, the ship agent changes from one state to another and modifies speed avoiding collision dynamically based on the distance between the ship and the facilities in the water area or when some conditions are met.

3. **VTS Agent**
   This navigation channel, mostly one way, is subject to traffic rules, therefore a VTS service controls all the inbound and outbound traffic of Liuheng port. The VTS agent interacts with Main Agent, Ship Agent to check ship traffic in wet infrastructure. To check ship traffic, the VTS component uses the ship traffic rules, specified for each port section.

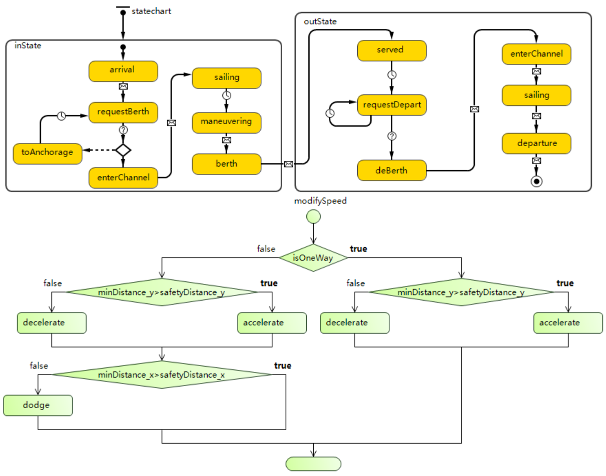

Figure 4: State Diagram of Ship Agent Implemented by AnyLogic Software

4. RESULTS AND DISCUSSIONS

4.1. Berths and traffic volumes scenarios

Before running the simulation model, baseline studies of environmental conditions were performed, and there are 43 days/year with adverse weather that are uniformly distributed over the period of 1 year in the simulation experiment. The berth service time follows an exponential distribution, and $1/\mu$ for 10000 and 20000-DWT LNG tank container ships are 10.7 hours and 12 hours, and for 100000 and 150000-GT LNG carriers are 51 hours and 56 hours respectively.

This study first evaluates 4 options for berth combination of LNG berths (n_{lng}) and LNG tank container berths (n_{con}), i.e., $\mathbf{B}(n_{lng}, n_{con})$= {{2, 2}, {2, 1}, {1, 2}, {1, 1}}, to evaluate the capacity of LNG terminal, then to identify the bottlenecks of Liuheng LNG terminal by analyzing waiting times and berth occupancies.

To explore the actual annual throughput capacity (ActT) for different berth combinations, we evaluate a series of scenarios of estimated annual number of ship arrivals and their responding estimated LNG throughputs (EstT) as shown in Table 1. And the inter-arrival times between successive ships are exponentially distributed with 1/ λ hours, which is determined by the number of ship arrivals.

In general, the acceptable waiting times vary with the cost of a vessel, but no exact accepted criteria are available (PIANC 2014). To investigate the effect of long channel and traffic rules on ActT, we adopt the waiting time for berth and channel as port performance indicators, not considering the constraint of transit at night in this case study. Besides, the adopted average waiting time for each type of ships should be lower than the predetermined value, as follows: a) Container ships: 5-10 % of the service time (1.5 h); b) Gas carriers: 10 % of the service time (6 h).

Table 1: The Scenarios of Number of Ship Arrivals and Their Estimated Throughputs

Ship type and size		Estimated number of ship arrivals			
		No.1	No.2	···	No.15
Container ship (DWT)	10,000	5	8	···	70
	20,000	10	16	···	130
Estimated LNG tanks throughput (10^4 tons)		20	50	···	400
LNG carrier (GT)	100,000	19	30	···	270
	150,000	1	2	···	14
Estimated LNG throughput (10^4 tons)		140	220	···	1900

4.2. Simulation results

We run the simulation experiments for 60 scenarios (15 EstT for 4 options) for one year, and the simulation results including average waiting time (AWT), ActT are shown in Figure 5 and Figure 6 respectively. The berth occupancies of the expected EstT are listed in Table 2.

1. **Waiting time and actual throughputs**
   As shown in Figure 5 and Figure 6, AWT of LNG carriers go beyond the acceptable waiting time (about 6 h) when its EstT is larger than 780 $\times 10^4$ t and the AWT for all scenarios of LNG tank container ships far exceed the acceptable value (about 1.5 h), which shows that Liuheng LNG terminal provides poor service under expected EstT. When n_{lng}=1, the maximum throughput capacity is 1090×10^4 t for **B**(1, 2) and 1145×10^4 t for **B**(1, 1**)**. Moreover, the ActT of LNG carriers will decrease when LNG berth increases from 1 to 2. The reason for this is that there are more LNG tank container ships in channel and LNG carriers must wait until it is cleared. Similarly, the ActT of LNG tank container ships will also reduce with one more LNG berth.
2. **Berth occupancies**
   From the viewpoint of berth occupancies of LNG berths, if two berths are planned for LNG

carriers or LNG container ship, the occupancy of one is too low (0.9~24.9% as shown in Table 2), which means it is a waste of berth resources. Therefore, the long one-way channel and traffic rules indeed limit the capacity of LNG terminal.

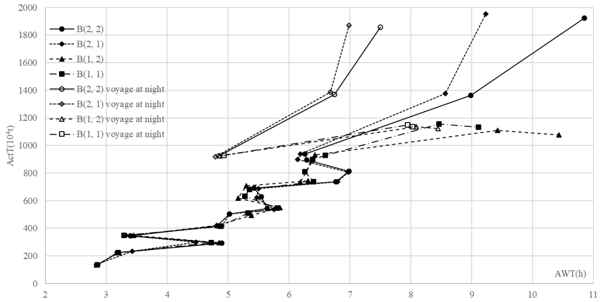

Figure 5: AWT and Actual Throughputs Diagram of LNG carriers

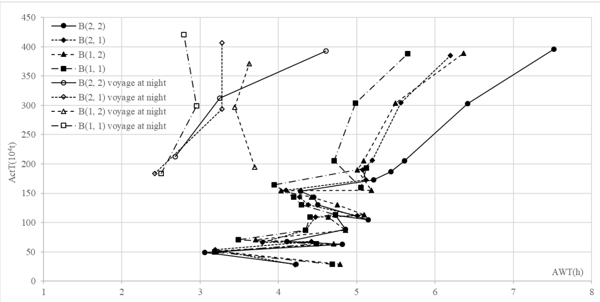

Figure 6: AWT and Actual Throughputs Diagram of LNG tank container ships

Table 2: The Simulation Results of Berth Occupancies (%)

No.	B(2, 2)		B(2, 1)	
	LNG	Container	LNG	Container
1	5.2	0.9	5.3	1.9
2	8.4	1.5	8.8	3.0
3	11.2	1.9	11.5	3.9
4	13.1	2.1	13.2	4.2
5	15.8	2.8	15.7	5.5
6	19.2	3.3	19.2	6.5
7	20.5	3.3	20.4	7.1
8	23.7	3.9	23.6	7.8
9	26.2	4.4	26.2	8.8
10	27.7	4.9	27.8	9.8
11	30.7	5.3	30.6	10.6
12	33.9	5.9	33.9	11.7
13	35.4	5.9	35.4	11.7
14	51.9	9.3	52.0	18.5
15	73.2	12.5	74.0	24.9
No.	B(1, 2)		B(1, 1)	
	LNG	Container	LNG	Container
1	10.5	0.9	10.5	1.9
2	16.9	1.5	16.9	2.9
3	22.6	1.9	22.5	3.9
4	26.4	2.1	26.4	4.2
5	31.7	2.7	31.5	5.5
6	38.1	3.2	38.5	6.5
7	41.0	3.6	41.0	7.1
8	47.0	3.9	47.4	7.8
9	52.8	4.4	52.1	8.8
10	55.8	4.9	56.3	10.0
11	55.7	4.9	62.3	10.7
12	67.7	5.9	65.9	11.5
13	70.7	5.9	70.5	11.7
14	83.7	9.3	87.4	18.5
15	81.6	12.5	86.1	24.9

3. **LNG tank container ships voyage at night**
   Considering LNG tank container ships make only a small contribution to throughput, deregulate the night voyage to alleviate LNG carriers' waiting for long channel and to meet the expected throughput of port owners is worth a trial. As can be seen from the Figure 5 and Figure 6, the relationship between AWT and actual throughputs varies greatly at No.13~15. So, the results of these scenarios deregulating the night voyage constraint are shown in these two figures and the berth configuration for 4 options for are shown in Figure 7.
   According to Figure 5 and Figure 6, the waiting time reduces significantly by 15.1% of LNG carriers and 82.3% of LNG tank container ships on average, compared to the scenarios with night voyage constraint. Meanwhile the waiting time is lower than the acceptable time of LNG carriers when Est lower than 1200×10^4 t. But the AWT of LNG container ship still does not meet the requirement. It can also be seen that the ActT keep invariant when we deregulate the night voyage, because the increase in the number of small ships offsets the reduction in the volume of large ships.
   Figure 7 shows that two LNG berths or two LNG tank container berths will also result in the resource waste of one berth in case of cancelation of no transit at night rules for LNG container ships. The berth occupancies of LNG container berth are too low (1.4%~29.5%) to spend money to build.

In summary, it's not worth to construct the LNG container berth if there is no mandatory demand and it can be built in adjacent container ports. Considering acceptable ships' waiting time and berth occupancy, **B(**1, 1**)** is suitable for this port.

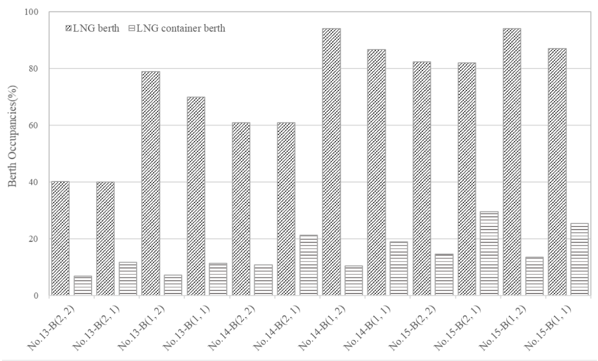

Figure 7: Berths Occupancies for Deregulating Night Voyage of LNG Container Ships

5. CONCLUSIONS

To provide decision support for berth configuration of Liuheng LNG terminal, this paper focuses on the ship traffic simulation problem and aims to determine the throughput capacity under acceptable the service level requirement. To better simulate and analyze the port operation system, we consider the LNG carrier traffic rules, long one-way channel which occupied by the turning basin and try to find out the balance between the capacity and the service level.

A simulation model is then proposed based on AnyLogic software, all parameters of which is based on historical statistics provided by the operator of Liuheng Port area. We undertake total 44 experiments to identify the bottlenecks of Liuheng LNG terminal by analyzing waiting times, berth occupancies and LNG throughput and explore the effect of modifying the traffic rules on waiting time and berth occupancies. The results allow us to affirm that simulation has good performance and can effectively determine the optimal terminal size under acceptable port service level. Moreover, this simulation model is a useful tool in determining whether traffic rules works well actually, especially for LNG terminal berth configuration planning.

However, the handling technology of LNG carriers is not be considered in-depth and the operation in port land area is at an early stage. Also, more valuable and feasible measures such as adding a buffer area in entrance channel or selecting priority rules will be taken in the future study.

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A MULTI-AGENT SYSTEM WITH BLOCKCHAIN FOR CONTAINER STACKING AND DISPATCHING.

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ABSTRACT
Port Logistical Supply chains play a very important role in society. Their complex and adaptive behaviours promote the suggested applications of combining a multiagent system with blockchain for solving complex problems. Several technologies have been proven positively to work in logistics, however the concept of combining converging technologies such as blockchain with deep reinforcement multi agent is viewed as a novel approach to solving the complexity that is associated with many facets of logistics. A simulator was developed and tested for the problem of container stacking. The simulation results indicate a more robust approach to currently used tools and methods.

Keywords: Multi Agent, Blockchain, Multi-agent Simulation, Container Stacking Management

1. INTRODUCTION

Papers that don't adhere to the guidelines provided in this Coupled with the growth of global trade and containerisation is the emergence of new technology paradigms, such as Cloud Computing, BigData, A.I. (Artificial Intelligence), Machine Learning and IoT (Internet of Things), which leads to questions on how to develop and operate automated or autonomous systems that can be applied to logistics systems, such as those found in container terminals and port logistics.

Ports and terminals as nodes in a supply chain occupy a very important position in global trade (Stahlbock and Voß, 2007). Their complexity promotes the suggested use of applications that are drawn from distributed artificial intelligence, such as a multi agent systems and deep reinforcement learning for efficiency (Henesey, 2006). Several technologies have been proven positively to work in logistics - individually, however the concept of combining converging technologies such as blockchain with deep reinforcement and multi agent systems is viewed as a novel approach to solving the complexity that is often associated with many facets of port logistical operations. Furthermore, the use of Blockchain in ports is still deemed a novel solution as very little research is published on this subject as it was identified from a literature survey performed by Mahwish et al (2019). et. al. (20019)

In this paper a simulator is developed and tested. One of the port logistical operations tested is the stacking of containers in a container yard. The simulation results indicate a more robust approach to currently used tools and methods is achieved. The port maximises throughput, while still maximising contract-price. In combining the port's objectives with the customers' objective functions into a Multiple Objective Optimization Problem (MOOP) system provides a Pareto set of solutions for the port with regards to a container picklist.

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2. BACKGROUND

Since port, seaport, terminal and container terminal are terms often used interchangeably in research papers and discussions, an attempt is made to clarify the terminology. A *port* can be seen at first hand as a place to or from where goods may be shipped. The use of ports has long been associated with maritime trade and the use of ships to carry cargo. The advent of rail roads, automobiles, and airplanes associates the mode of transport using the port, i.e. airport, seaport. A *terminal* is a specialized part of the port that handles a particular type of goods, e.g. cars, containers, wood, people, etc. The situation today must reflect the change in institutional structures where port authorities are granting concessions to stevedoring companies to operate terminals (e.g. container terminals: CTs) independently and competitively within the port area.

The primary aim of port and terminal managers is to develop strategies that improve customer satisfaction and the terminal's competitive position. The main functions of the terminal management are the *planning* and *controlling* of operations. Terminal management is often driven by tradition rather than theory, thus being conservative with respect to adopting new ideas or technologies. The management of a terminal can affect the choice of ship lines to use a particular terminal. Thus, it is imperative that the terminal management is able to satisfy its customers, such as minimizing the time that a ship spends berthed at a terminal. To shorten this time, terminal managers spend special effort in increasing the productivity in terms of container crane moves per hour, which is regarded to be one measure of CT performance.

The increasing complexity of terminal operations requires management to decide allocation of resources but also the sequence and timing of operations. Due to tradition and outdated practices, the management of a CT or port is often fragmented, with differing organizations handling specific tasks within the terminal. Through interviews and port visits we observed that many terminal managers are often faced with these types of problems, which are further supported in research articles, e.g., Rebollo et al. [5], Gambardella et al. [6], and Frankel [7]:

- lack of planning
- not enough delegation
- ad hoc planning
- little insight in terminal operations
- lack of unity of control

The choice of organizational structure has been observed by Cullinane et al. [8] to affect the efficiency and ultimately performance of a terminal. The most common structure in port and terminal management is a ‘unity of command’, where key decisions are made by a single manager or group of terminal managers [9]. The development of specific departments leads to specialists in planning, e.g., ship planners, yard planners, and resource planners. The decisions made by port and terminal management demands an understanding of customer service requirements, such as:

- *Performance* – fast ship service (‘turn-around’) time,
- *Reliability* – predictable performance,
- *Cost* – desired to be competitive and predictable,
- *Quality* – no waste or damage during operations, and
- *Adaptability* – capacity of CT operators to implement solutions, i.e., changes to shipping line schedules and fulfil other customer requirements.

Additionally, terminal managers must understand their resource availabilities, operating costs, and other constraints, such as schedules, budgets, regulations, and the objectives of the terminal [7]. The main objective for many terminals is cost leadership and terminal competitiveness. Through improving productivity, many terminals seek to gain cost leadership, since terminal costs according to Persyn [10], are significant to the total costs of shipping goods. According to Frankel [7], port costs can be in excess of 50 percent of the total costs and where 55 percent of these port related costs are the result of poor ship turn-around times and low cargo handling speeds, which are strong determinants for consideration on using Blockchain solutions. In this study, the following types of ports are studied: Container, Bulk/ Liquid Bulk, Multipurpose, RoRo and Ferry.

With the increasing cargo shipments every year, the container terminals have had to keep up with the demands. The container terminal is viewed not as a passive point of interface between sea and land transport but as the natural point of intermodal interchange. They have become logistic centres acting as 'nodal points' in a global transport system. This means efficient container terminal logistic operations and processes are a need for every container terminal to maintain the business (Voss et al., 2004). Ports such as Antwerp, Rotterdam, and Hamburg are expanding their terminals or creating new terminals to accommodate the projected rise in number of containers. Due to increases in speed and volume, the operations of a container terminal require a better regulating systems approach. Research results in AI, Blockchain and IoT, could answer some of the container terminal challenges, enabling a sustainable improvement of the terminal’s capacity and performance, e.g. increasing the performance without large investments for terminal expansion and new equipment.

Congestion and increasing cargo dwell times is a common scene in many of the world’s ports. Government authorities such as customs and health may delay containers from reaching their destinations due to inspections. Shipping lines are unconcerned if there is a poor terminal productivity, as long as their vessel sails on time. Terminal operators are trying to reduce or stabilize the cost per TEU (twenty-foot equivalent unit: container) handled and thus maximize profit. Complications in container terminal systems arise in having the various computer systems work together, ad hoc planning, ill-defined data and poor information. Currently, ports are seeking better ways in improving their productivity and offering logistical solutions to shippers of cargo. No longer are ports handling just cargo, but more and more they are becoming “*information handlers*”, (Henesey, 2002).

2.1. Container Terminal

In viewing a container terminal as a system, the following operations exist and are illustrated according to their location in Figure 1; Vessel; Berth, Intralogistics, Yard, and Gate. For a more detailed Account of container terminal operations research, c.f. (Stahlbock and Voß, 2007) and (Henesey, 2006).

Container Terminal Operations. A description of the following operations that exist in the movement of containers in and out of the container port is given as follows:

Vessel: Synonymously used as the maritime interface where cranes handle vessels. Terminal operators experience problems in reducing the unproductive and expensive container moves. The number of cranes used to perform the operation varies depending on the size of the containership and the volume of containers to be handled. The vessel planning is typically executed 24 hours before a vessel call by the ship line. The plan includes a manifest, list of containers to be loaded or discharged.

Berth: Each containership that arrives at a terminal will be assigned a berth and a location where a vessel can dock. The characteristics of a container berth are the length, depth, equipment (i.e. cranes), handling capacity, and service facilities.

Intralogistics: Containers are moved from berth to the yard to be stacked or placed in an area for dispatch, or containers from the stack are delivered to the gantry crane at the berth to be loaded on a vessel. The import container information such as its number, weight, seal number, and other information are recorded along with the location identification to a central database, such as a yard system in the terminal. Depending on the operations, either yard tractors, front loaders, or straddle carriers are employed as transport in this operation. The export containers are transferred from a location in a stack, thus notifying a yard system that the location is free and will be given to a gantry crane to be loaded on a vessel.

Yard: There exist three main types of storage systems: short term, long term, and specialized. Specialized storage is reserved for refrigerated, empty, liquid bulk, hazardous materials. The container storage system uses stacking algorithms in assigning a space for the container till it is loaded or dispatched.

Gate: The interface to other modes of transport lies in this system. The managing of the gate is to obtain information of containers coming into the terminal so as to be properly physically handled before ship arrival and to release import containers before the arrival of trucks or rail. Controlling this access to the terminal is important in that it affects other parts of the container terminal system. The data collected for example are; container number, weight, port of destination, IMO number if hazardous, reefer, shipper, ship line, and seal number are used in deciding where to place containers for storage and later for loading.

2.2. Container Processes

In the operations of ports there exist many processes that are required in the execution of operations. The major processes that are identified to be important for the efficient handling of containers are the following:

Documentation. During freight transport verification and validation of the status of the shipments, handover of responsibility, custom documents etc. are exchanged.

Tracking and Tracking. The location and identification of assets is equally important to the location of cargo itself. Improved visibility of assets, such as the equipment to handle the cargo/containers and people leads to higher productivity when such information is considered in moving containers

Sorting and Processing. As a system, the ports and terminals are constantly sorting incoming and outgoing containers and cargo based on defined criteria and rules. To enable the port and terminal management to efficient control the various operations, a number of processing tasks are required that demand expert knowledge and/or the use of computer systems in executing desired decisions.

Resource Management. Various specialized equipment types are used to handle containers and cargo. For many operators the objective is the efficient of use of equipment, number of workers and other resources in order to minimize costs whilst obtaining high performance.

Scheduling. It is an ongoing process in ports affected by many variables that are often not controllable, such as weather, strikes, congestion or traffic. For instance, the scheduling of arriving cargos with vessel calling requires coordination with the schedule of related yard operations and availability of the labour for moving cargo and containers.

Integration of Process Optimization. Often viewed by port and terminal as a "holy-grail" is the decision making that takes into account the multitude of actions and processes to decide on the physical movement of a cargo by a PHE from one location to another with minimal costs. Various IT systems are deployed in assisting port and terminal management in trying to integrate the processes with the operations.

The described operations and processes often characterize the activities existing in major container terminals and ports worldwide. As a result, many major ports and container terminals often have dedicated IT staff or departments, this provides advantages in terms of being more competitive than smaller ports. In the distribution of digital technologies for transport, such as Blockchain and IoT, small and medium ports and their service portfolios are argued to be very limited, not shared and not integrated on the cross-border level. A recent European Union financed study that was conducted, the Connect2SmallPorts project, generated results that concluded very differing levels and meanings of digitalization in ports, e.g. ports of Wismar - Germany, Karlskrona - Sweden and Klaipeda- Lithuania. Most of the small and medium ports still pursue the classical infrastructural path without any clear vision and digitalization strategy. The development for future port and container transportation is a big challenge for such small and medium size ports.

3. WHAT IS BLOCKCHAIN

Since its inception by a person or perhaps a group of people by the name of Satoshi Nakamoto in 2008, the use of Block and Chain have been popularized as Blockchain. Satoshi Nakamoto improved the design of Blockchain by introducing technological solutions, such as a *hashcash*-like method in which Blocks could be added to a Chain without requiring them to be signed by a trusted party. A very well – known example of Blockchain is the cryptocurrency known as Bitcoin, which possess a public ledger for all transactions in the network

The current literature does not provide any clear definition of Blockchain, since the technology is presented in several variances and applications. A Blockchain solution can be public and private, anonymous or based on user's reputation with a validation mechanism that can be centralized or decentralized. These are just few examples that show the broad spectrum of different technologies identified with the word "Blockchain". This confusion on the technology definition generates lack of understanding on the potential uses of Blockchain in port logistics as well as its real benefits. The first scientific problem in the field of the research is the evaluation of the fundamental Blockchain's properties that can be turned into applications in the field of logistics. The idea at the base of the technology is the concept of "distributed transactional database" spread into different nodes of the network (Morabito, 2017). These nodes, which identifies different users, work together in the creation and storage of an encrypted sequence of transactional records, which is defined as "block" (Lemieux, 2016). The technology is expected to bring a substantial transformation in the logistic sector, based on the following characteristics:

Transparency: Blockchain may prevent the creation of organizational silos within existing parties of the supply chain, enabling the different actors involved in the process to access the information. This feature leads to univocal, shared and real-time accessible pieces of information. Instead of having data buried in legacy silos, ERP or TMS, data are accessible in a distributed and decentralized way to supply chain members;

Traceability: Blockchain is able to keep track of the different processes so that every supply chain member is able to produce or collect information about the product's lifecycle (supplier information, the manufacturing process information, logistics information and others). This not only provides a guarantee over the product's origins, but it also offers information about the requirement for the product's handling, transportation and storage. Finally, this feature enables an easier traceability of the causes and responsibilities for problems occurred in the process;

Security: The information is stored in a ledger, which is a distributed data structure where transactions are organized in blocks (Kiayias et al., 2016). Each block is secure by encryption based on a hash mechanism so that the ledger becomes a proof-of-work puzzle. The access to information is based on a key system. Therefore, every member of the Blockchain, the so-called "node", is provided with a private key and a public key, which enable him to access the private information and the Blockchain respectively;

Built-in-trust: The feature of encryption on which Blockchain is based represents the guarantee of trust towards the system. This enables the members of the Blockchain to bypass the third parties that serves as a guarantee of financial, physical and information transaction in today's supply chain. In logistics, this leads to the elimination of documents such as Bill-of-Landings, Letter-of credits and middlemen such as Freight forwarder and banks.

Real-time accessibility: Blockchain provides to every user with authorization a real-time access to the information. This faster and broader access to information leads to speed-up the logistic processes and avoid bottle-necks. Benefits are not only related to the information flow, but also to the financial flow.

The implementation of Blockchain on port logistics opens the discussions on the efficiency and efficacy of the current port inter-organizational information systems. The implementation of Blockchain implies a change in the architecture from centralized to a distributed type. By using a decentralized approach, which modifies the current processes, proposes a new set of possibilities and business opportunities (Subramani, 2004).

In work by Mattia Francisconi (2018), he states that "Blockchain is a relatively new technology and there is still misunderstanding on the potential applications and impact in the field. In this study, we adopt the concept of Business Model (BM) and Business Model Innovation to evaluate small ports in the South Baltic region on impact of technology, such as Blockchain. These concepts assist in evaluating ports by analysis of a Business Model Stress Testing, which is a tool to evaluate the robustness of a company's BM to external factors. This tool was introduced for the first time by De Vos (2012) as a tool to evaluate the robustness of a company's BM by evaluating the impact of a collection of alternative environments

4. METHODOLOGY

Literature survey was performed to pinpoint areas of interest in which Blockchain could be applied and to identify any gaps in research. The data used was obtained from a small terminal in west coast US and the methodology employed is known as simulation method. A prototype that was initially developed in NetLogo® is further developed and written in Python language so that it is supported by Ethereum® for the testing and evaluation on the concept of crypto-currency in coordination and control of container stacking operations. At this time, the incorporation of ML – Machine Learning algorithms is considered but not yet implemented for further development so as to build "deep learning" Multi Agent systems.

4.1. Literature survey on Digitalisation on Ports

A comprehensive survey was conducted by Mahwish et al, (2019) and by (Heilig et al., 2017b) in which both identified areas for growth for digitalisation, such as AI, IoT, and Cloud Computing. However, there is a lack of papers on the subject of Blockchain with ports and container terminals, with Mahwish et al (2019) pointing to that only 3 papers were published.

4.2. Artificial Intelligence

Though, the reception of digital technologies, such as those highlighted in this study, in the container port domain, has been slow, but it has been steady and evolving. In the end of 1990s, the researchers cantered their work on different issues faced by the planners and managers of the container port using different approaches. For example, for the issue of container stacking (Itmi et al., 1995) advocated the concept of a society of agents that are essentially entities or processes with goals. The authors suggest a cooperative mechanism whereby; the agents achieve container stacking via N-puzzle game. (Gambardella et al., 1998) dealt with the allocation of yard and cranes to the container by proposing a decision support tool for planning purposes. The authors used simulation to test the decision policies and compared with actual experiences. (Lee, 1999) contributed with a successfully implemented automatic character recognition system for identification of vehicle and container numbers.

4.3. Internet of Thing and Cloud Computing

With the progress from barcode and magnetic strip, now the radio-frequency identification (RFID) tag is used at container terminal gate to Check-in the truck and container (Yoo et al., 2009) (Lee et al., 2011). The RFID tag refers to the digital encoded label, which is linked with a software system that records the data. In the survey, papers are classified in the context of AI and IoT, as it lays foundation for Internet of things and enables automation. (Lee et al., 2011) refer to the use of smart RFID labels to track container journey in the terminal and suggest it being linked to the overall information workflow to assist in the documentation.

When it comes to use pervasive technologies like IoT and Cloud computing in container terminal, very few research work has been proposed in literature, e.g. (Lee et al., 2011), (Ngai et al., 2011), (Shi et al., 2011), (Chen et al., 2013), (Choe et al., 2016), (Huang and Zheng, 2016), (Tsertou et al., 2016), (Li et al., 2018), (Heilig et al., 2017b) and (Ndraha et al., 2018). All of the studies are theoretical, such as reviews on potential application of IoT in Port (Shi et al., 2011), (Lee et al., 2011) or in cold food chain shipment (Ndraha et al., 2018).

During the investigation, Cloud technology was found to be discussed more of an enabler for IoT and Blockchain. (Tsertou et al., 2016) emphasized for a cloud-based information portal for the stakeholders linked with IoT sensors for real-time information analytics. (Heilig et al., 2017c) shares an idea of having an integrative mobile cloud platform for real-time inter-terminal truck routing. (Costa et al., 2007; Heilig et al., 2017b; Heilig and Voß, 2014; Ndraha et al., 2018) relay the same concept of real-time information access from people to people and machine to people.

4.4. Blockchain

Three articles were located, all from 2018 that touched upon the concept of distributed ledger, Blockchain technology. One of them (Kearney et al., 2018) attempts to set up the framework for seaport stakeholders and policymakers for to enable innovation, such as by Blockchain, in the seaport sector. Also observed, is research in the cold food chain direction where use of Blockchain could help with temperature monitoring (Ndraha et al., 2018) of containers carrying fruits or vegetables. The authors bring into the limelight the demand of having centralized information platform for communication between people and containers and refer to the Blockchain technology to fulfil the requisite whereby making the information exchange between all objects (human and machines) more secure, fast and transparent. It is worth mentioning to point out the recent academic work (Sturmanis et al., 2018) around the challenges faced by the logistic community by the implementation of Blockchain technology.

5. SIMULATION EXPERIMENT

Port logistics chains occupy a very important position in global trade. Their complexity promotes the suggested use of applications that are drawn from distributed artificial intelligence, such as a multi agent systems and deep reinforcement learning for efficiency. Several technologies have been proven positively to work in logistics - individually, however the concept of combining converging technologies such as blockchain with deep reinforcement and multi agent systems is viewed as a novel approach to solving the complexity that is often associated with many facets of port logistical operations. In this paper a simulator is developed and tested.

One of the port logistical operations tested is the stacking of containers in a container yard. The simulation results indicate a more robust approach to currently used tools and methods is achieved. The port maximises throughput, while still maximising contract-price. In combining the port's objectives with the customers' objective functions into a Multiple Objective

Optimization Problem (MOOP) system provides a Pareto set of solutions for the port with regards to a container picklist. In Figure 1 is an example of containers stacked, but are identified by owner (e.g. Amazon, Walmart)

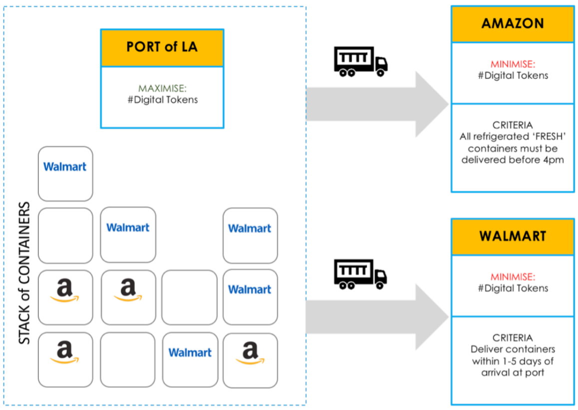


Figure 1. Container Stacking Example

The scenario evaluated in the simulation model is that of a port with a container stack consisting of 400 containers arranged in a 10x10x5. In a typical day, the crane operating on this stack can move 100 containers – a single move is defined as either moving a container within the stack to another coordinate or removing a container from the stack and delivering it to the port's customers (via a 3rd party carrier, who has a truck at the port). Each container belongs to a specific carrier, and each carrier has their own set of delivery goals related to the number, type and importance of the containers they own. Various rules concerning the container stack have been included and are obtained from experts. Rules for the container stack includes: Each container resides within a specific x,y,z coordinate; The maximum x coordinate that containers can be placed in is 10, the maximum y coordinate is 10 and the maximum z coordinate is 5; In any given column, the container with the highest z coordinate is the only container that can be moved; Containers can't 'float' in the air, e.g. a container can only be placed on (5,2,5) if a container is already placed on (5,2,4).

Every container in the stack has been assigned a *contract price* between 1 and 50, reflecting the amount of money that the customer has contracted the port for delivery of this container. The port has a single objective function; maximize the total contract price of containers delivered in a day. The output from simulation considers the Pareto Front and provides a set of moves that maximizes the total contract-price achieved by the port and the number of containers delivered, by splitting the allocation of extra moves across a number of customers.

5.1. Objective of the model

In the context of port logistics systems, how can combining blockchain with crypto currency be used as a standard transactional mechanism is modeled in to Multi-Agent system for faster means of enabling transactions amongst interested actors. The simulation results of the modeled container stacking management yield a number of solutions that satisfies all actors. The blockchain smart contracts enable elements in the process, such as containers and trucks, or applications like the port scheduling system to swiftly define and execute secure transactions between each other.

5.2. Simulation Model

The simulation model presents a means of evaluating various actor's criteria and objectives by automating the decisions, based on auctions, for the picking process for the port, choosing when to rearrange stacked containers, and when to deliver them to transportation. The actors' decisions on the optimal cryptocurrency price to set in order to achieve their goals and satisfy their constraints. In addition, the simulation model shows how the multi agents continually adapts to the changing conditions, and dynamically determines the Pareto frontier, to give the highest benefits to each participant, even as the system is being disrupted or as participants alter their goals. Finally, it is suggested that multi-agent solution helps in efficient use of cryptocurrency in to minimize costs and maximize earnings for each participant, by automatically balancing conflicting priorities. In Figure 2 we present a diagram of the containers stacked in. which an English Auction was conducted for the container customers coupled with a Dutch Auction for crane allocation.

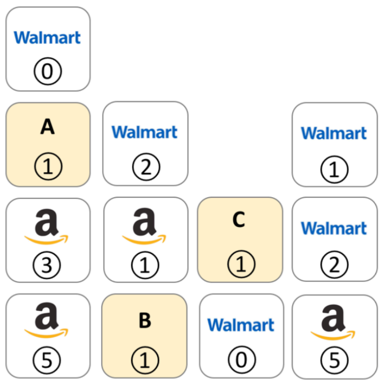


Figure 2. Containers stacked by customer

The prototype was written in NetLogo® a programming language that is supported by JAVA. Test and evaluate the concept of crypto-currency in coordination and control of a container terminal operations (explained in paper 2). At this time, the incorporation of ML – Machine Learning algorithms is not expected but is considered for further development so as to build "deep learning" Multi Agent systems. Simulation of Multi Agents Systems (MAS) in a Container Terminal. Coordination via cryptocurrency platform (e.g. Ethereum: https://www.ethereum.org) provides a new approach that is novel (1). Ideally, the prototype will seek to test and evaluate the work described. Development and test of MAS coordination was performed. Testing of Auction or other "market driven" approaches for control was conducted in the prototype.

6. SIMULATION RESULTS

The agents were bidding in the simulated model programmed in. NetLogo®, a screen shot is provided in Figure 3 that shows the construction of the simulation model.

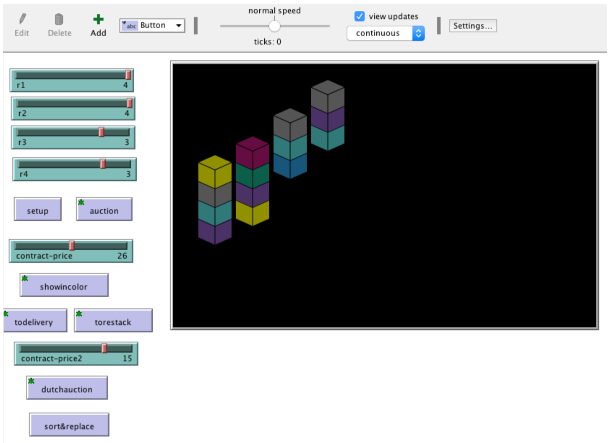
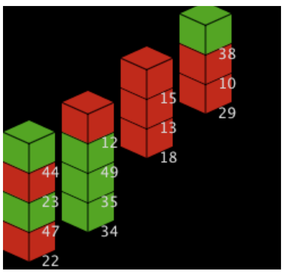


Figure 3 Simulation Model programmed in NetLogo®

From the assignment of containers to customers, the customers will begin bidding on when they would like to have their containers delivered, which will influence stacking in the container terminal. The following steps will be performed within the simulation

1. Summarize the contract price of all the containers.
2. Divide this number by the quantity of containers in the port.
3. Divide that number (2) by the total number of moves that we have (that we call move worth).
4. Multiply move worth with number of moves required to pick up the container
5. Sort and pick bigger containers without considering their positions.



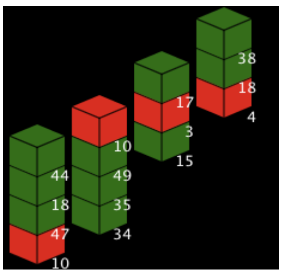
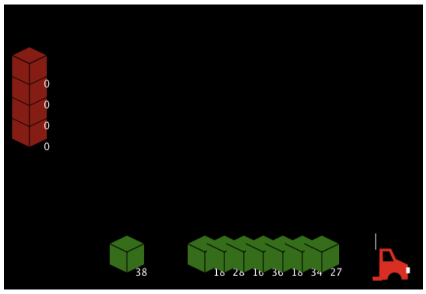


Figure 4. Stacking Figure 5. Crane Assignment

In Figures 4 and 5, the stacking of containers is generated, based on the bidding performed by the agents yielding to a plan on how the containers ought to be stacked. In Figure 5, the containers are organised based on crane assignment. The following figure, Figure 6 shows the containers being dispatched to be delivered to their owners.

Figure 6. Containers being delivered

The results highlight a novel approach in which container customers can bid via a Blockchain to stack and deliver



containers. For example:
We have these containers in three stacks:

5	10	1
15	55	5
5	2	100

1. Total price = 193
2. 193 / 9 = 21,4
3. 21,4 / 4 = 5,3

-0,3	4,7	-4,3
4,4	44,4	-5,6
- 10,9	- 13,3	84,1

Thus, in this case, with 4 moves, we will pick the containers with updated prices: 4,1 -5,6 -4,3 4 ,7

We start by picking 84,1 and the containers on top of it: -4,3 and -5,6. And then we pick 4,7. This performed by using a list that contains the containers in sorted order based on the updated price.

7. CONCLUSION AND FUTURE WORK

In this paper is on how complex systems, such as those found in supply chains and logistics would be more efficient and operational process improved. The solution that we have defined and developed is based on a multi agent systems tool encompassing elements of crypto-currency for conducting transactions in a digitalized supply chain would improve the performances of. The concept of digitalized supply chains is considered partially as a result of the digital transformation of physical global supply chains in which technologies, such as blockchain, cloud computing, machine-learning and deployment of IoT (Internet of Things) are causing disruption on many facets of transportation and trade. According to a report by Gartner, the estimate market for Supply Chain Management is to exceed by $19 billion by 2021(reference). Obviously, this is a large amount of investment on IT systems that are helping with decision making on many levels of transportation, logistics and supply chain itself.

Unfortunately, the supply chains and their management systems are viewed in this research to be inefficient due to the objectives that these solutions are often developed, which are to optimize a particular part or process of the supply chain. These inefficiencies are manifested by sub-optimal performance in specific functions, i.e., container terminal management or observed in the holistic flow of cargo goods through the entire chain. Currently, over 450 million TEU globally yearly, which has been identified in many research papers as to be complex.

The suggested solution proposed in this paper and. Partially simulated by a multi-agent system approach using. NetLogo® is specifically designed to optimize complex processes, such as the example of stacking containers to deliver a higher performance than current solutions. Due to its inherent characteristics, a multi-agent system is by its nature to be distributed, leading to synergies with blockchain, and utilization of cryptocurrency to provide a robust mechanism that is standardized for the exchange of value throughout a post logistics system. This allows the port logistics to run at an extremely high level of efficiency and gives each actor in the port logistics chain the ability to optimize their own function(s), yet still maintain a holistic balance. Multi-agents are programmed to run in a virtual, edge-based, or hybrid environment and are used to simplify deployment through a supply chain. By using cryptocurrency, such as Ethereum® it assists in establishing a standard transactional language across the port logistics chain, the suggested solution solves the multi-objective optimization problems, e.g. container stacking management by modelling a dynamic pareto frontier that maximizes value for each actor.

Future work would be to further improve the model and consider using Python in order to work with many libraries and APIs found in Ethereum organization.

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EXTENDED REALITY, INTELLIGENT AGENTS AND SIMULATION TO IMPROVE EFFICIENCY, SAFETY AND SECURITY IN HARBORS AND PORT PLANTS

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ABSTRACT
The paper introduces a new project devoted to develop a simulation-based solution for improving emergency planning and crisis management in critical infrastructures such as seaports and related terminal. The research aims to investigate the use of Artificial Intelligence and Simulation jointly with Extended Reality in this framework.

Keywords: Modeling, Simulation, AI, Seaport safety

1 INTRODUCTION

Seaports are critical infrastructures and have significant impact on economy and people's life. Indeed, nowadays they manage huge flows of goods and passengers, create numerous work opportunity and are essential parts of economy of countries where they are located. Unfortunately, such environments are characterized also by high risk of accidents; for instance, handled materials could be dangerous (e.g. toxic products, explosives) while heavy, huge and cumbersome equipments and ships might collide each other or with goods and port structures.
In general, analyzing the statistical data, it is possible to conclude that number of accidents in seaports is constantly growing despite continuous improvements in safety procedures, even due to a constant increase in flows and operations; in facts this could be explained by continuous increasing sea traffic (Darbra & Casal, 2004). In the same time, frequency of domino effect accidents is decreasing, even if their occurrence is still quite high (Clini et al., 2010). In order to identify main safety issues in seaports, it is necessary to analyze existing situation as well as past events.

2 PAST CASES OF INTEREST

In the past many notable accidents in seaports occurred, which should be used to identify some of main issues related to safety, crisis prevention and management of emergencies in ports. Indeed, these examples provide insight in most important causes of casualties and economical damage, as well as some clues regarding how to mitigate them. Hereafter it is presented a brief analysis of some cases in chronological order.

Halifax Explosion

One of the most notable explosions of the beginning of the past century happened during WWI, in the port Halifax, Canada, 1917, where collision of two ships, one of which loaded of explosives, caused fire and subsequent explosion, which devastated a large area of the city killing circa 2000 persons (Lilley, 2013). The cause of explosion was a navigation error of the two ships; as proved during the investigation, a lot of safety regulations were "relaxed" due to the war, while only few persons of the port personnel were aware about explosives on board of one of the ships. Indeed, such event caused revision of handling procedures for dangerous materials as well as more strictly checks.

Chicago Port Disaster

During WWII, improper handling of ammunition by not qualified personnel caused explosion of almost 2000 tons of TNT in the port of Chicago (Allen, 1982). Similarly to the case of Halifax, personnel was not properly informed about properties of the cargo neither prepared enough to handle it.

Moby Prince Disaster

In 1991 in the harbor of Livorno, Moby Prince ferry collided with the Agip Abruzzo tanker, leaving only one survivor among passengers and crew aboard (Cigolini & Rossi, 2010). In this case, first several hours passed with almost no actions from the port management. This particular case shows how important is a proper emergencies management; indeed, according to some evidences, many passengers could have been saved with adequate interventions timing.

Chlorine Leak in Mumbai Port

Although explosions and fire cause typically the biggest damages, lack of containment is much more frequent accident (Darbra & Casal, 2004). Indeed, nowadays transportation of potentially dangerous materials in gaseous and liquid forms is very diffused, while in some cases related risks are not assessed properly and safety procedures are not sufficiently applied. For instance, one of such cases happened in Mumbai in 2007, where old tanks with chlorine were abandoned and eventually leaked; due to negligence more than 100 people were hospitalized (Sharma et al, 2010).

Tianjin Explosion

One of the biggest explosion of the last years happened in the port of Tianjin, China, in 2015 and it caused many fatalities and injuries (Fu et al. 2016). Analyzing its details, several issues raise, mostly related to the crisis management as well as urban area planning. For instance, firefighters were not informed about presence of calcium carbide and tried to extinguish fire by water, which is considered as one of main cause of the explosion. Furthermore, distance between the storage of hazardous materials and nearby houses was less than one km, which caused additional casualties (Iyengar, 2015).

3 PROBLEM IDENTIFICATION & POSSIBLE SCENARIOS

Based on presented cases, it is evident that ports, especially that ones nearby residential areas, are potentially very dangerous. Considering the urbanization of coasts and increase of logistics flows this issue is expected to growth in terms of impact. Indeed, fire, explosions and leakage of materials might easily create casualties and severe economic damage. For instance, in case of release of contaminant agent and certain wind direction, big number of people could be at risk of poisoning in only a couple of minutes after leakage (Pastorino et al., 2014).

Analyzing historical data, it is possible to identify most frequent types of accidents in seaport as well as main causes (Darbra & Casal, 2004). Indeed, in the following are listed main types of accidents, in descendant order based on frequency of occurrence:

- Loss of containment;
- Fire;
- Explosion;
- Gas cloud.

Similarly, principal causes are the following:

- Impact;
- Mechanical malfunction;
- External factors;
- Human factors.

Obviously, this data are not complete and could be updated, but they provide an insight into the seaports safety situation.

After problem identification, it is possible to perform preliminary risk assessment and identify potential scenarios of interest, which could be used for developing a simulation-based solution. In this case, it should be considered possibility of multiple types of accidents (e.g. fire with subsequent explosion) and causes. In the same time, the model should take into account the external conditions, such as presence of personnel, proximity of residential areas, meteorological conditions and configuration of the port. Indeed, it is possible to develop different realistic scenarios which would include multiple interconnected causes and effects. As an example, possible scenario could include leakage of toxic material from tanks in the port while ferries are docked in proximity. In such case, analysis of the possible outcomes should include such factors as weather conditions (e.g. wind, fog, temperature, even time of the day) passengers' behavior (e.g. organized evacuation, panic) logic and actions of personnel and first responders (e.g. strategy, delays in decision making), impact on port structures and nearby urban zones (domino effect, evacuation of urban areas). Obviously, based on combination of such factors it is possible to observe completely different outcomes, from fast suppression of the cause of accident without any significant damage up to complete chaos and mass casualties; evaluation of possible outcomes in terms of probability of occurrence and impact could be very difficult.

4 SIMULATION FOR EMERGENCY MANAGEMENT

Modeling and Simulation reproduce reality in interactive virtual worlds. Indeed, simulation is a strategic science, capable to analyze existing or future complex systems through experimentation over models, which makes it a perfect tool to be applied to the context of interest (Bruzzone et al.2011a). In facts the interactions among different actors in ports and different concurrent operations represents a major challenge and issue in this context (Bruzzone et al.2008, 2012). Crisis management and prevention are very important tasks for administrators of complex systems. Indeed, a complex system such as a city or a seaport could be difficult to keep under control in regular conditions, while in case of emergency it is even harder to create good preventive and operational plans. In order to succeed in such critical tasks, it is essential to have proper support tools, which could be used to evaluate alternative solutions and foresee how decisions affect the scenario in different conditions (Bruzzone et al., 2018). In previous works, the authors developed multiple models devoted to emergency management, as well as crisis prevention and decision support (Bruzzone et al., 2000; Bruzzone et al., 2014; Bruzzone et al., 2019). Such models, based on Intelligent Agents (IA) are capable to reproduce human behavior and social interactions; this approach allows to extend model capabilities in predicting scenarios outcomes. Indeed, in the scenarios of interest, human factors might introduce even fear or aggressiveness, so that the scenario evolution being more realistic.

For example, Augmented Reality (AR) applications could be used to support such activities (see fig. 1). As shown, the 3D terrain and port infrastructure overlapping the real nautical map of the zone of interest; such technology allows to extend information provided by "hardcopy" map. In this example, it adds information regarding hazardous materials, security systems and adjacent zones (Bruzzone et al.2011b, 2011c).

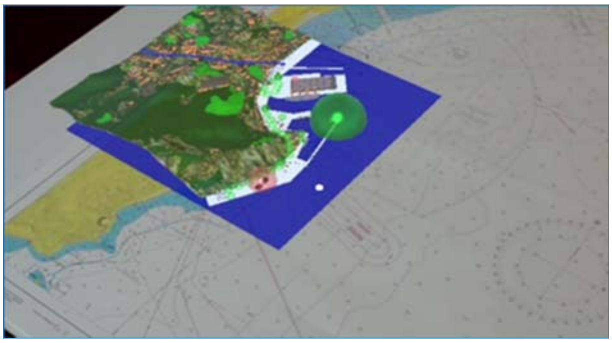
Figure 1: Augmented Reality demonstration

Hereafter, several interesting projects about simulation for critical events are presented.

T-REX: Critical Infrastructures Security
T-REX (Threat network simulation for REactive eXperience) is a simulator for evaluation of impact of different parameters on critical infrastructures. For instance, it allows to analyze consequences of hybrid attack on a port area including a Tank Farm, Oil Terminal, Power Plant and Desalination Facilities.

PONTUS: Urban Disaster Management
PONTUS (Population Behavior, social Networks, Transportations, Infrastructures and Industrial & Urban Simulation) is a city model, which simulates the entire population along with social activities and its behavior in case of critical events. For example, it allows to calculate flooding zones caused by rain (see fig. 2) and analyze impact of such dangerous situation on population in the areas at risk, with particular attention to the situation in the points of interest near to the seaport (e.g. schools, big shops, cinemas and malls).


Figure 2: PONTUS Flooding Simulation

5 CREATING A VIRTUAL LAB FOR PORTS

To address port safety, the authors propose innovative modeling & simulation solutions, capable of predicting outcome of different scenarios in various initial conditions. The idea is framed within an international project named ALACRES2 (Advanced Simulation Based Lab for Port Crisis and Emergency Management over Tyrrhenian Sea Area) carried out among different Universities and Institutions that foresees identification of scenarios of interest for port safety and their application to several ports of interest in order to create a virtual lab able to support definition of policies and guidelines as well as to turn into an efficient modern training equipment for managers, decision makers and operators (Bruzzone et al. 2010; Massei et al. 2011).
ALACRES is lead by Genoa University and it involves currently Cagliari and Pisa University, Italian Coast Guard, Chamber of Commerce of Var and of Bastia Haute Corse, Cagliari Fire Fighting Department and Liguria Environmental Agency
Indeed this consortium is sponsored by EU funds for regional development in order to develop a solution that could have a great impact in this sector. In facts, the Simulation makes possible to reproduce complex crisis evolution and impact on structures, systems, people and goods considering both the physical aspects and the domino effect. Furthermore, it is possible to test the effectiveness of new technological and infrastructural solutions to reduce vulnerability, mitigate damage and prevent emergencies. The simulation techniques adopt the new MS2G paradigm (Modeling, interoperable Simulation and Serious Games) to combine different models and guarantee a high level of fidelity and at the same time simplicity of use, intuitiveness and immersiveness of these simulations, that can even be distributed. In this way it becomes possible to recreate the emergency scenario using immersive virtual reality technologies, thus allowing the involved operators to take actions and simulate their work performance within scenarios that possibly reproduce, from the visual point of view and sound, the real emergency conditions and that guarantee to be involved in the crisis. ALACRES2 expects to involve both the technical partners to build the environments in virtual reality and to set up the laboratory tools, and the operational partners, in charge for the development of the emergency procedures and for the tests.

CONCLUSIONS

The objective of ALACRES2 is a permanent laboratory to identify, test and validate procedures for emergency management in the event of crises or significant accidents occurring during loading/unloading of goods and hazardous material in port areas. The project is at early stage and the alternative models to be used, paradigm to be adopted and general architecture are currently identified, while the survey on accidents and critical issues is finalizing scenario definition. Currently, the authors are investigating with the experts these situations for evaluating new behavioral protocols, more effective guidelines, new operating standards, new emergency monitoring procedures, new support technologies for infrastructure and on-board systems.

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