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# Exploring Challenges and Solutions for Container Transportation Using Rail

## *A Modelling and Simulation Gaming Study*


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***Abstract***— **Rail is a cost-effective and environment friendly freight transport modality when used efficiently. Stakeholders around Dutch ports are discouraged to choose rail due to uncertain train schedules and the dispersed nature of freight flows across terminals in the port. To understand the challenges and opportunities of freight transport using rail, we used a combined approach of modelling and simulation gaming as participative research method. In addition to a simulation game, we developed a metamodel to simulate all possible choices of the players in the game. We designed and executed simulation gaming sessions with professionals and students. Within these sessions, we collected data in the form of surveys and in-game observations on the behaviour of the players. We compared and contrasted the results of the metamodel with those of the gaming sessions. The main contribution of the research is the provision of a deep insight into the challenges and opportunities offered by efficient transportation of containers using rail. The combined approach allows us to assess the effectiveness of various incentives to consolidate freight, promote intermodal transportation and to encourage the development of efficient services for rail freight transport.**



***Keywords—serious game, simulation model, container terminal, rail bundling , rail cargo challenge.***


## I. INTRODUCTION

The Port of Rotterdam is one of the major container terminals in Europe with an annual throughput of 127.1 million TEUs in 2016 [1]. One of the key success factors for a port is the development of efficient hinterland connections for the transportation of goods and to offer services that are cost-effective, reliable and have a short transit time [2]. In today's globalized supply chain, port competition has moved from competition between ports to competition between transport chains [3]. Previous research has showed that container flows can easily switch between ports, especially in western Europe [4]. Therefore ports increasingly need to enhance the quality of hinterland transport services [4]. Towards the achievement of more sustainable freight transport rail and barge are considered as more sustainable and cost-effective modes compared to trucking [2]. Table 1 shows the modal-split of container transportation in Rotterdam. Although the percentage of containers transported by rail has slightly improved in the first half of 2015, it remains a long way behind its major competitor, Port of Hamburg. Therefore an immense need arises to investigate the challenges and solutions towards improving the usage of rail for hinterland connections from Rotterdam.

**TABLE 1. MODAL SPLIT OF MARITIME CONTAINERS IN ROTTERDAM (source: [1])**

| % | 2015 | 2014 | 2013 | 2012 | 2011 |
|---|---|---|---|---|---|
| Rail | 12.2 | 10.9 | 10.7 | 10.7 | 11.4 |
| Road | 46.2 | 53.4 | 54.6 | 54 | 55.2 |
| Barge | 41.6 | 35.7 | 34.8 | 35.3 | 33.4 |

With this paper we present our innovative research approach that combines simulation modelling and gaming to investigate the challenges and opportunities related to efficient utilization of rail for hinterland container transport.

Our research approach, shown in Figure 1, comprises of four main steps. Firstly, after intensive discussions with stakeholders and literature review we gathered information on the current situation and identified the challenges related to rail transport. The second step is the design of a simulation game known as 'Rail Cargo Challenge' (RCC), aiming at increasing the stakeholder awareness on challenges and opportunities for efficient rail transport. We developed a simulation game as in games participants take up a specific role and react in different situations within a safe and controlled simulated environment [3]. Specifically, the definition of a simulation game is given by [3] as 'a conscious endeavour to reproduce the central characteristics of a system in order to understand, experiment with and/or predict the behaviour of that system'. The development of the RCC game represents a deliverable of a Dutch research project with a focus on the situation at the Port of Rotterdam. The game is used to gather insights into the behaviour of the main stakeholders and their decision making for rail utilization. The third step is the creation of a simulation metamodel that mirrors the game play and the decisions related to rail bundling. The final part of our research approach is to create



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an optimization model based on the data generated by the simulation metamodel. The results of the optimization model are expected to provide us with valuable insights on plausible strategies and policy interventions aiming at an improvement of the efficiency of the rail utilization from the Port of Rotterdam to the Hinterland. The model results are then compared to the game play results. The quantitative data and the observations on the behaviour of the individuals during the game sessions are inserted in the simulation model. The metamodel is used to calculate the effect of these decisions on the profit of operators.

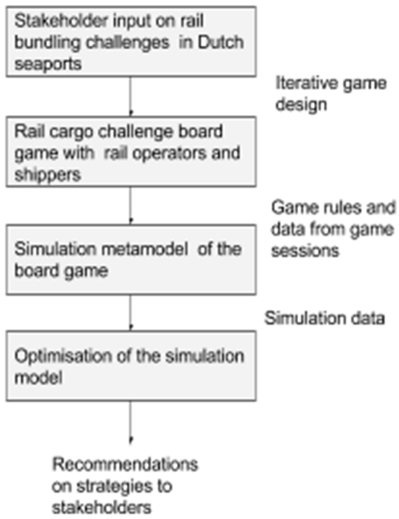


**FIGURE 1. RESEARCH METHODOLOGY**

This paper is structured as follows: In Section II we present the background and description of the RCC game, in Section III we describe the simulation model development based on the RCC game. In Section IV the results of the model are presented and discussed in Section V.

## II. RAIL CARGO CHALLENGE GAME: BACKGROUND AND DESCRIPTION

We gathered insights into the various challenges regarding rail utilization from discussions with officials of the Rotterdam Port Authority and rail operators involved in container transportation from the terminals in the port. We also cross-referenced our discussion with relevant studies from literature.

The container activities in the port of Rotterdam are clustered in three areas--- Eem/Waalhaven, Botlek and Maasvlakte [7]. More than 70% of the containers are handled in the newest part of the port known as Maasvlakte [7] shown in Figure 2. The light blue spots on the Maasvlakte represent container terminals and dark blue spots represent container depots. We can observe that while the terminals in the Maasvlakte have deep-sea vessel access, they are quite dispersed. This puts a new challenge in the efficient rail bundling of flows. The dispersed nature of terminals in the Maasvlakte makes it even more difficult for the rail services to reach, load and unload goods from all the terminals. Bundling freight from the different terminals to one rail service is a complex procedure that requires the collaboration of numerous stakeholders; rail and terminal operators and logistic service providers [6]. The current common practice is for every logistic provider to use a different rail service resulting in a high number of trains to be served by the terminal operators. Currently, more than 8 rail operators offer their services in Rotterdam. High number of trains is translated into an increase in the dwell time of every train and in frequent delays.


**FIGURE 2. TERMINAL DISTRIBUTION IN MAASVLAKTE**

This has a ripple effect on the rail pick-ups at other terminals and often results in a train being able to serve fewer terminals than expected. The inability of a train to reach all programmed destinations, apart from delays and disruptions in terminal operations, creates an increase in the amount of containers trucked. Delays and last minute changes are also a source of client dissatisfaction.

In an effort to engage stakeholders and to raise their awareness on the challenges and benefits of efficient container transportation using rail, we developed a board game - the Rail Cargo Challenge Rotterdam (Image 1) as part of a national research project, partially commissioned by of the Port Authority of Rotterdam. The key objective of the Rail Cargo Challenge (RCC) is to assess attitudes and behaviour of stakeholders regarding efficient utilization of rail services in the port of Rotterdam. The effects of their decisions are not only reflected on their individual profits but also on the overall efficiency and reputation of the port in terms of sustainability and cost-effectiveness.

The RCC is multiplayer tabletop board game, set in the ambience of a seaport corridor connecting Rotterdam with several destinations in Europe. There are four roles in the game. Two competing rail operators transport containers by charging a price to shippers. Two shippers in the game must ship freight from the various container terminals in the port. In the first round of the game, there are three terminals - A, B and C, and three shippers. Each shipper has order cards that denote the number of containers that need to be transported, the terminal in which they are stored, their destination and the time limit for transporting them. The rail operators have to



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**IMAGE 1. THE RAIL-CARGO GAME**

pick up freight from different terminals in the port at a pre-defined or a negotiated price. However, rail operators have limitations in picking up containers from different terminals. By throwing a dice, the number of terminals, which can be visited, is determined. All rail operators and shippers start with a money capital of 50 tokens each. The rail operators can arrange trains, with each train having a capacity of 10 containers and a price of 10 tokens. The shippers are allowed to make arrangements with the rail operators to pick up their containers from a certain terminal at a specific price. If they can ship their containers successfully through rail, they receive 4 tokens per shipment. If they fail to reach an agreement they have to send their containers through trucks with an extra charge. The rail operators will benefit most if they can manage to run their trains with full capacity and make sure they can pick up all the shipments from the terminals as agreed with the shippers. If the dice is at their favour, and are able to transport all containers as planned on time they receive 4 tokens per shipment. If they fail to do so, they are responsible to ship the cargo using trucks that will cost them additional tokens. Additionally, the competitiveness of the port will drastically reduce if many containers are shipped using trucks instead of rail. In the subsequent rounds, two new terminals open up in the port that makes the starting position of the containers even more scattered across the port, while the rail services and frequency remain the same. The challenge of the game is to efficiently transport the dispersed freight through rail.

At the end of the play session the participants reflect on the challenges and opportunities of container transport through rail and on solutions to increase the efficiency and increase rail modal split. A typical game session lasts more than 2.5 hrs. We organized 5 gaming sessions with 40 professionals from the Dutch logistics, supply chain and transportation domain. We collected the data from these sessions based on the in-game negotiations and discussions, costs and prices offered and accepted by the participants, pre- and post-game surveys and game observations. Given the length, limited scalability,, and stochastic nature of the game play, the data from the gaming sessions was not sufficient to validate the player decisions and their consequences at real world applications. Therefore we developed a metamodel of the game play to simulate multiple game play sessions and to generate data on the effects of player decisions on individual profit and overall efficiency of the port.

## III. SIMULATION METAMODEL DEVELOPMENT

The model developed is the first attempt to simulate the various decisions of rail operators and their impact on the rail network efficiency. We used the Python programming language to create the metamodel of the simulation game using the numpy package.

Firstly, the model randomly generates the orders from the shippers (simulating the pick of cards in the game). Every order card, generated at the beginning of every round, consists of the destination, the number of containers that must be shipped, the terminal and the intended delivery day. The price offered by shippers for a container to be transported by rail is mirrored as a Beta distribution with α=2, β=5. We assume that this price tends to be lower than the average price so we skewed the distribution towards lower price offers using the above α and β values.

Based on the shipper's offer the rail operator either accepts or rejects to transport the containers in his/her train based on the probability function shown in (1).

$$P(x) = \begin{cases} 0 \; if \; x \leq LT \\ \left(\frac{|x - LT|}{HT - LT}\right)^{\alpha} if \; LT < x < HT \\ 1 \; if \; x \geq HT \end{cases} \quad (1)$$

, where x is the price offered by the shippers.

We also set threshold values for the acceptance by the rail operator. LT is the lower threshold value and HT is the higher threshold value. The rail operator will only accept offers within this threshold. $\alpha$ is the acceptance coefficient, that determines the shape of the probability function for the acceptance or rejection s. This means that if $\alpha \rightarrow 0$, the rail operator accepts all offers greater than the LT. If $\alpha \rightarrow \infty$ then the rail operator rejects all offers lower than HT.

This process is applied for both operators. The first operator that accepts the offer starts collecting the containers from the terminal. The collection sequence of the containers consists of the steps below:

1. First criterion: the destination with most containers to deliver is chosen.
2. The terminals are ordered based on the number of containers to be delivered at the chosen destination
3. The probability to be able to visit a specific number of terminals is simulated as a uniform distribution that simulates the throw of the dice in the game.
4. At the end of each round, the containers that need to be shipped that day and operators did not manage to transport them are trucked.

The whole process is repeated until the required number of rounds is reached. The parameters that can be changed in the simulation model, based on the game observations, are the average price of the Beta distribution that determines the shipper price offers and the threshold price values that determine the probability of price acceptance by the rail operators. The size of the wagons, the number of



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terminals, the number of containers generated in each route and the number of rounds of the game play are all parameters that can be changed.

After developing the simulation model we inserted the values observed in the gaming sessions and obtained the results presented in the following section. Part of our future research is to develop an optimisation model that provides the optimal solution for the rail bundling problem.

## IV. RESULTS

From the game sessions with Dutch logistics professionals we observed that most of the times shippers offered 2 coins, and increased their bid until the rail operator accepted. In general the average price offered by the shippers was 3 tokens. Sometimes the shipper refused to pay more than 2 tokens and chose to truck the container. We used these values as parameters in the Beta distribution that determines the shipper's offer. After 1000 runs, this resulted in a price offer distribution shown in Figure 3.

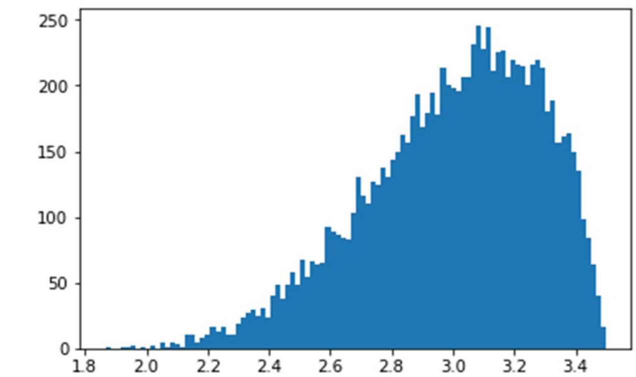

**FIGURE 3 BETA DISTRIBUTION OF THE PRICE OFFER OF SHIPPER, α=2 , β=5, avg. price=3**

We observed that the majority of the price offers was less than the average value, which was also observed in the game. From the post-game survey, players who assumed the role of rail operators stated that they were willing to accept offers as low as 2 and as high as 5 from the shippers. We also inserted these values in the equation (1). We ran the game play metamodel 1000 times to observe the profits of individual rail operators using the above price offer distribution of shippers and acceptance function of the rail operators.

From Figure 4 we can see that both operators make more losses than profits. The differences in the profit distribution can be attributed to the extent to which the rail operators accepted the shipper price offer, and to the number of disruptions. This was also observed in the game play. Among the most important reasons was that after the price negotiations, rail operators would fail to accept prices offered by the shippers, they would lobby, and frequently they would underestimate the delays. The game itself was not designed to find the optimum but to highlight the challenges of rail bundling and to show the participants exactly this: If they do not decide to collaborate, bundle freight and fill in the rail services, they would all suffer loses. This means the rail operators would operate trains at a loss if they weren't able to fill their trains. The terminal operators, apart from the negative effects of disruptions in terminal operations due to train delays, would have to deal with high dwell time of containers within the terminal. Shippers on the other hand would have to transport their containers using trucks, which may directly affect their profits and competitiveness. This result highlights that inability to cooperate and service all shippers negatively affects the terminal reputation.

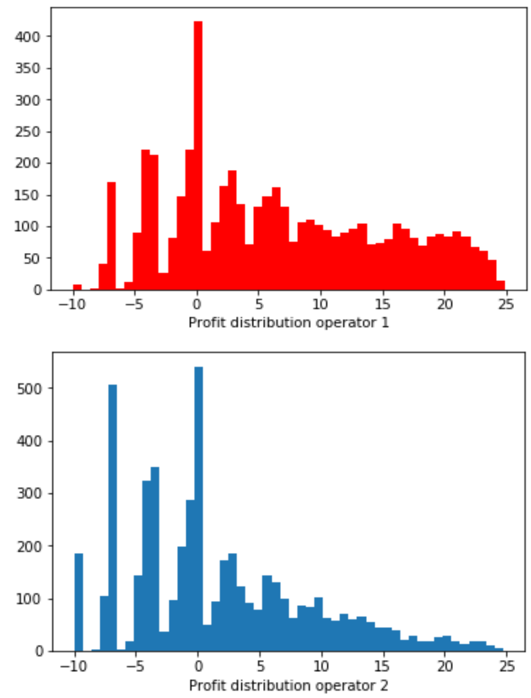


**FIGURE 4 PROFIT DISTRIBUTION FOR OPERATORS 1 AND 2**

The simulation of the game play (N=1000) based on the prices above gave the price range and profit ranges per train presented in Figure 5. As expected, the higher the number of containers on a train was, the higher the profit per train became. Since shippers were not willing to offer higher prices the maximum profit for a full train is 25. We can also observe that for less than half full trains the operator will possibly run the service and have a loss.



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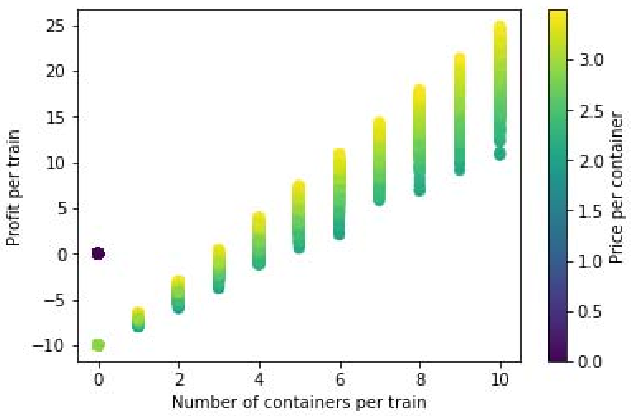


**FIGURE 5. PRICE AND PROFIT RANGES PER TRAIN**

We will discuss the implications of the results and conclude the paper in the following section.

## V. DISCUSSION AND FUTURE RESEARCH

Efficient utilization of rail to transport containers from the port of Rotterdam can improve the efficiency and quality of its services to hinterland destinations. This increases the reputation of the port in terms of sustainability and cost effectiveness, thus making it more competitive. As mentioned in the introduction the Rail Cargo Challenge Rotterdam represents a complex problem that needs to be addressed in order to meet up with the 18% increase in rail transport that was set as a prerequisite for the construction of the Maasvlakte area. In order to better understand the behaviour of stakeholders and help them design policies that promote rail bundling, we propose a combined approach of simulation modelling and serious gaming as participative research method. The development of the RCC game permits stakeholders to understand how their decisions influence the efficient transport of freight between the port terminals. The introduction of the reputation mechanism serves as a demonstration that failure to deliver goods has a negative effect to all the stakeholders.

Game playing results show that the inability of stakeholders to cooperate results in lower profits and lower reputation rates. These observations were also supported by the results of the simulation model. The low profit of the rail operators can be attributed to real life challenges of the rail bundling such as bad connectivity between the terminals and increased delays.

Furthermore, the biggest issue rail operators face in the Port of Rotterdam is the uncertainty on the number of terminals that they can serve. Train operators in the game were optimistic that they could call in three terminals, which was not always possible resulting in more containers being trucked and an increase of transportation costs and $CO_2$ emissions.

After the game sessions, the stakeholders were asked to identify the key challenges of rail bundling in the current situation around the Port of Rotterdam. Information and data sharing as well as legal issues were identified among the key challenges [7]. Our game does not address these issues but sets the ground for the development of common understanding on the merits and problems of freight bundling.

While board games are excellent instruments to facilitate stakeholder engagement, the main limitation lies in their lack of scalability for effective data collection. Additionally it is not easy to incorporate changes into a board game. Although a larger number of players participates in one game session, we can only gather one data point per session. Often such game sessions don't run into completion due to the brief availability of professionals. In addition, a lot of the data are qualitative and they are derived from closely observing the behaviour and the interactions of the players during the game play rounds. The simulation model can be used to quantify the effect of these decisions on the performance of the simulated system. The combination of these two methods is a unique tool that instantly shows how each decision can affect the results of the model.

The innovation of this research lies in the combination of a simulation game developed to assess and solve a particular problem together with the development of a simulation metamodel. The model does not simulate the actual situation, but the game play and tries to quantify the effect of the players' decisions on the profit and the efficient transportation of the goods in the game. It should be highlighted here that the aim of the paper is not to reproduce the process itself but the decisions of the stakeholders and their effects on the final profit and efficiency.

The next step of our research is the development of an optimisation of the profit function. The optimisation algorithm will calculate the maximum profit of the players and then compare it with their final profit in the game. It is expected that this comparison will provide stakeholders with an insight of the increase in their profit they choose to cooperate and bundle rail freight.

Future work involves the addition of the decision models of all te related stakeholders such as shippers and terminal operators. We also need to perform a sensitivity analysis on the effects of the various parameters of the metamodel on the profit and efficiency. The ensuing results are expected to provide us with deep insights into strategies and policy interventions for efficient rail utilization for container transportation in Rotterdam.


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