The Synchromodal Coordinator: An optimization and simulation gaming approach to examine port hinterland transport profitability

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Abstract

1. Introduction

Due to its ability to haul large quantities of goods, rail is a cost-effective and environment friendly freight transport modality when used efficiently. It is considered one of the most sustainable ways to transport cargo from port container terminals to the hinterland. Regardless the development of rail infrastructure around the main ports in the Netherlands, many stakeholders are discouraged to choose rail due to uncertain train schedules and the dispersed nature of freight flows across the port terminals. Therefore an immense need arises to investigate the challenges and solutions towards improving the usage of rail for hinterland connections from Dutch ports and specifically for the Port of Rotterdam (Kourounioti et al., 2017).

Freight bundling is gaining traction as a solution to increase the service levels and the efficiency of rail for freight transport across Europe. Furthermore, new transport concepts such as synchromodality, the "vision of a network of well organized and interconnected transport modes, which together cater for the aggregate transport demand and can dynamically adapt to the individual and instantaneous needs of transport users"(Tavasszy, et al,, 2018) requires the tcollaboration of actors to ensure an efficient system. The complex nature of the freight transport system with conflicting and complicated interactions between numerous economic and political actors hinters the efficient freight bungling and the orchestration of transport modes and services (Kourounioti et al., 2018).

We use the Port of Rotterdam (PoR) as a case study. The container terminals in PoR are dispersed making bundling rail freight bundling a complex procedure that requires the collaboration of numerous stakeholders; rail, terminal operators and logistic service providers. 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, increased dwell times of trains in the terminals and delays in the network. The Rotterdam Port Authority initiated the development of the Rail Cargo Challenge Rotterdam (RCCR) game to gather insights into the behaviour of the main stakeholders and their decision making process concerning rail utilization.

In this paper we use the RCCR game, we simulate the behaviour of the actors inside the game and then we develop an optimisation model of the system. Through this hybrid approach we examine the potential benefits for the PoR hinterland container transport from the existence of a Synchromodal Coordinator who has an overview of the system and can optimise freight bundling and rail services.

2. Methodological Framework

Our research approach, shown in Figure 1, comprises of four main steps. Firstly, after intensive consultation with the PoR stakeholders, we identified the game requirements. The second step was the design of the RCCR game, aiming at increasing the stakeholder awareness on the challenges and opportunities for efficient rail transport. The third step was the creation of a simulation metamodel that mirrors the game play and the decisions of the players related to rail bundling. The final part of our research approach is the development of an optimisation model. The optimisation model, represents the role of a Synchromodal Coordinator who controls the rail operators and the shippers and is able to consolidate freight and plan the rail services. The quantitative data and the observations on the behaviour of the individuals during the game sessions were inserted in the simulation model[1]. The simulation model calculates the performance of the players.

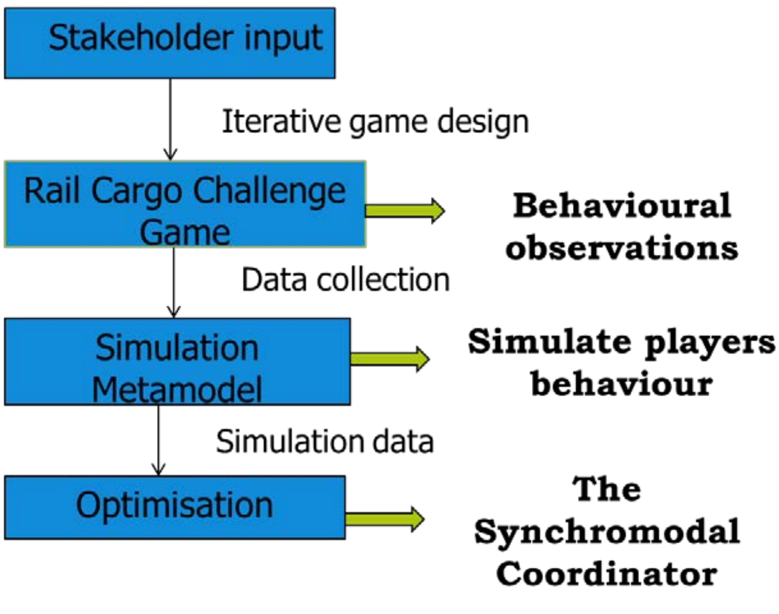

FIGURE 1 Research Methodology

System's performance when using a "Synchromodal" Coordinator is calculated by using Integer Programming optimization combined with the predefined strategy shown in Figure 2. The

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[1] For more information on the game and the simulation model please refer to: *Kourounioti, I., Shalini, K., Lukosch, H., Tavasszy, L., van Veen, L., van Nuland, B. & Smit, T "Exploring Freight Bundling for Rail Transport: A Modeling and Simulation Gaming Validation Study", paper presented at IEEE MT-ITS, Naples, June, 2017.*

optimization model allocates the containers to the train operators in a way that maximizes the profit of the system. We inset in the optimization model the same information and order c is given the same information and the same order cards as the simulation model. In this way, we can compare the results of the two models. The optimization model formulation is presented below.

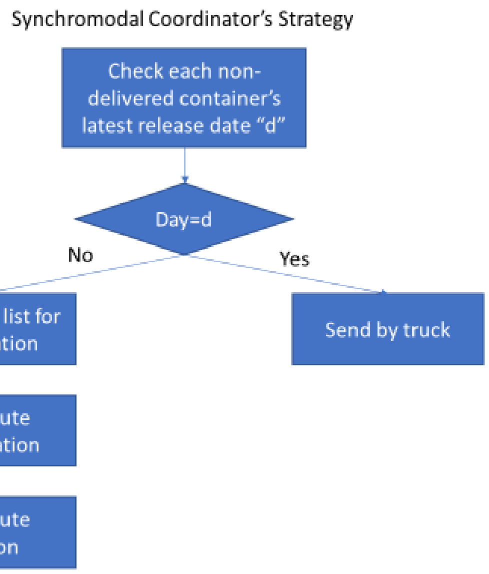

FIGURE 2. Decision process of the Synchromodal Coordinator

2.1 Mathematical model

The optimization approach of the Synchromodal Coordinator is an adaptation of the arc-based Service network design or "Capacitated Multicommodity Network Design" (CMND) as described in (Andersen et al., 2007; Crainic, 2000). Firstly, since trains have fixed costs we consider a profit maximization formula instead of a cost minimization. Secondly, due to the fixed costs per trains we describe train services with design nodes ($xter_i^t$, $xdest_j^t$) instead of design arcs. The nodes represent the terminals/destination that each train can visit. At last, the flow arcs (tr_{ij}^{tp}) are binary variables as each commodity p∈P represents only one container; thus, flow is either zero or one.

The Integer programming optimization model that is used by the coordinator is as follows.

TABLE 1 Explanation of sets, variables and parameters.

Sets:	
T	set of trains that are operating (t∈T).
P	Set of containers (IDs) (p∈P).
O	Set of origin terminals (i∈O).
D	Set of destination (j∈D).
Parameters:	

$dest_j^p$	Binary parameter: 1 if container p∈P has j∈D as destination, 0 otherwise.
$term_i^p$	Binary parameter: 1 if container p∈P has i∈O as destination, 0 otherwise.
$train\_term_t$	Non-negative integer: maximum number of terminals that train t∈T can service
Variables:	
tr_{ij}^{tp}	Binary variable: 1 if train t∈T transports container p∈P from origin terminal i∈O to destination j∈D, 0 otherwise.
$xter_i^t$	Binary variable: 1 if train t∈T service terminal i∈O, 0 otherwise.
$xdest_j^t$	Binary variable: 1 if train t∈T has as destination j∈D, 0 otherwise.

Objective Function

$$max \sum_{t\in T}\sum_{p\in P}\sum_{i\in O}\sum_{j\in D} tr_{ij}^{tp} - \sum_{t\in T} 20 \quad (1)$$

Subject to:

$$\sum_{t\in T}\sum_{i\in O}\sum_{j\in D} tr_{ij}^{tp} \le 1, \quad \forall\, p \in P \quad (2)$$

$$\sum_{p\in P}\sum_{i\in O}\sum_{j\in D} tr_{ij}^{tp} \le 10, \quad \forall\, t \in T \quad (3)$$

$$tr_{ij}^{tp} \le dest_j^p, \quad \forall t \in T, p \in P, i \in O\; j \in D \quad (4)$$

$$tr_{ij}^{tp} \le term_i^p, \quad \forall t \in T, p \in P, i \in O\; j \in D \quad (5)$$

$$tr_{ij}^{tp} \le xter_i^t, \quad \forall t \in T, p \in P, i \in O\; j \in D \quad (6)$$

$$tr_{ij}^{tp} \le xdest_j^t, \quad \forall t \in T, p \in P, i \in O\; j \in D \quad (7)$$

$$\sum_{i\in O} xter_i^t \le train\_term_t, \quad \forall t \in T \quad (8)$$

$$\sum_{j\in D} xdest_j^t \le 1, \quad \forall t \in T \quad (9)$$

$$tr_{ij}^{tp}, xter_i^t, xdest_j^t \in \{0,1\}, \quad \forall t \in T, p \in P, i \in O\; j \in D \quad (10)$$

Objective function (1), maximizes the profit regarding the train use. Each container transported by train has a profit of 4 coins and the cost for using each train is fixed to 20 coins, independently of the number of transported containers.

- Constraint (2) ensures that each container is only transported by one train to the respective origin-destination.
- Constraint (3) is the container capacity constraint for each train.
- Constraint (4) ensures that the container can go only to the destination that is assigned to.
- Constraint (5) ensures that the container can only be picked up by the terminal that is assigned.
- Constraint (6)-(7) ensures that the containers can only be transported if each train is servicing the respective terminals/destinations.
- Constraint (8) limits the terminals that each train can service. Different number for each train, depending on the conditions in each round.
- Constraint (9) restricts the train to have at most one destination.
- (10) is a constraint that sets the type of variables to binary.

Finally, the total profit of the system is calculated when the truck penalty (1 coin per truck) is abstracted from the objective function.

3. **Data**

The data used in this study are collected from gaming sessions with real players. The aim of the RCCR game is at every round to transport the cargo, represented by cargo cards, on time to its final destination. Two competing rail operators transport containers by charging a price to shippers. The 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 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.

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. Then 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[2].

4. Results

In this section we present and compare the results of both the simulation and the optimisation models. Each simulated game has a duration of five rounds and is repeated for 100 iterations. The figures show the total result (five rounds) of each game for every iteration. Note that each iteration is independent from the others and the performance points on the diagrams are connected only for visualization reasons.

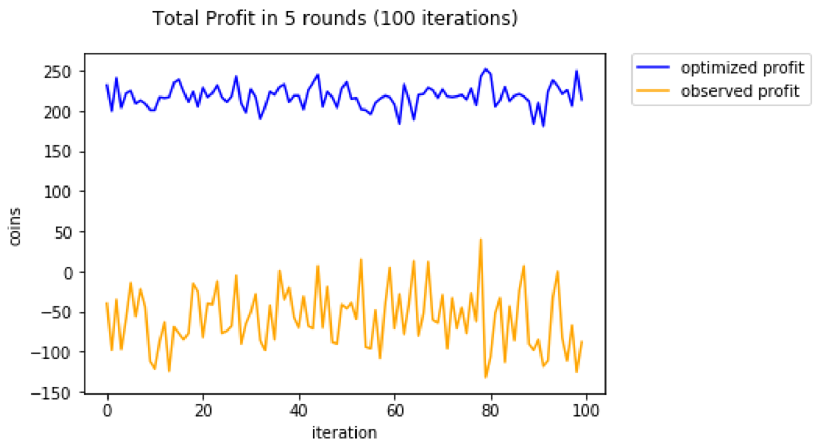

FIGURE 3 Total Profit in 5 rounds

As can be seen on figure 3, the Synchromodal Coordinator deliver higher profits compared to the players when they play independently. In addition the optimisation of the Synchromodal Coordinator outperforms the simulated reality in all the cases. Another important point to notice is the deviation between the iterations. The coordinator solution presents less deviation compared to the players, which makes the system more "stable". Furthermore, during gameplay rai operators often operate on loss, while the profits when using coordinator has no negative prices (losses) which means that the welfare of the system constantly increases.

[2] For more information on the game and the simulation model please refer to: *Kourounioti, I., Shalini, K., Lukosch, H., Tavasszy, L., van Veen, L., van Nuland, B. & Smit, T "Exploring Freight Bundling for Rail Transport: A Modeling and Simulation Gaming Validation Study", paper presented at IEEE MT-ITS, Naples, June, 2017.*

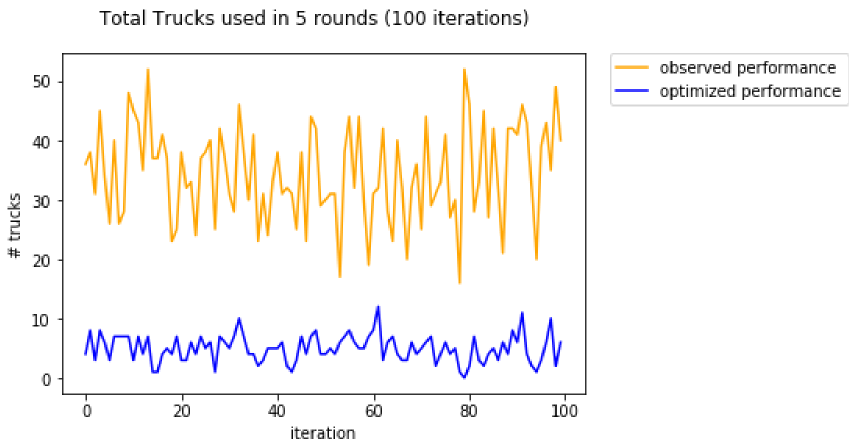

FIGURE 4 Total trucks used in 5 rounds

Apart from profitability the scope of the game is to promote sustainability by transporting more cargo by rail than by trucks. In figure 4 the Synchromodal Coordinator manages to decrease the number of containers transported by trucks. Trucks are only used when the latest release date of a container is reached and there is no train service or remaining capacity to the specific terminal to destination. The total number of transported containers is shown in figure 5 and proves that when the Synchromodal Coordinator optimizes the systems more containers are being transported.

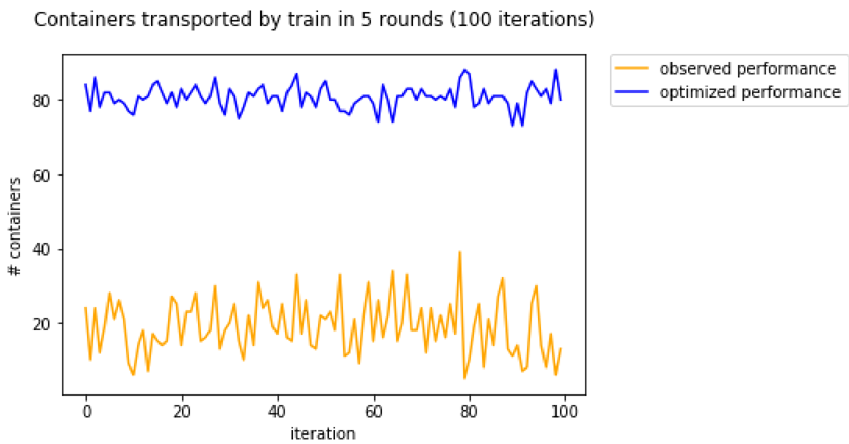

FIGURE 5 Total containers transported in 5 rounds

Overall, the Synchromodal Coordinator manages to keep the port rail transport system operating in high levels of sustainability and profitability.

5. Implications of the 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. The Rail Cargo Challenge Rotterdam game aims to raise the awareness of the stakeholders on the importance of collaboration to bundle freight and increase the system efficiency. It should be highlighted here that the aim of the game is not to simulate the PoR environment but the decisions of the stakeholders and their effects on the final profit and efficiency. The innovation of this research lies in the combination of the game play simulation with an optimization model. The two models are used to compare the stakeholders actual behavior simulate in the game play with the optimized systems. Game playing results show that the inability of stakeholders to cooperate results in lower profits and lower reputation rates. These observations are 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. Decisions that are made based on individual's benefits can lead to short-term profits. However, long-term, when the welfare of the system decreases the profits for each individual also decrease. On the other hand the development of an optimized system with the existence of a Snchromodal Coordinator can lead to a more stable system more sustainable with more profits. The game and the optimisation results prove that the optimal allocation and planning can be done by a coordinator who is accepted and followed by all involved actors. In this way the benefits are maximized both for the system and the individual actors. Ensuring system optimality, however, does not mean fewer profits for the actors involved. The more efficient the system the more new clients/ shipments it can attract and more profits can be made by the actors.

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