ANALYSING THE EFFICIENCY OF AN INTERMODAL TERMINAL USING SIMULATION

K.. Ramaekers, A. Caris, L. Gorissen

Hasselt University, Transportation Research Institute (IMOB)
Universiteit Hasselt, campus Diepenbeek
Wetenschapspark – Building 5, 3590 Diepenbeek

katrien.ramaekers@uhasselt.be, an.caris@uhasselt.be

ABSTRACT

For intermodal transport to be competitive with road haulage, it is of importance that the transferring of transport units happens efficiently. Therefore, in this paper, the working of an intermodal terminal is analysed using a simulation model. The focus is on a rail-road freight transport terminal. To analyse the impact of several input factors on the efficiency of the terminal, an experimental design is set up. The results of the simulation study show that the number of containers and the number of handling equipment are the most important variables. The arrival pattern of trucks has almost no influence on the output measures.

Keywords: simulation, experimental design, rail-road terminal

1. INTRODUCTION

Intermodal freight transport has received increased attention due to problems of road congestion, environmental concerns and traffic safety. Intermodal transportation means that the primary transport is performed by alternative transport modes like rail, barge or sea, while the secondary pre- and post-transport goes by road and is as short as possible (Macharis and Verbeke 1999). Transferring the transport units between the different transport modes is inevitable in intermodal transport. This transferring takes place in terminals. The terminals provide the space, the equipment and the operational environment for transferring intermodal transport units between the different transport modes. For intermodal transport to be competitive with road haulage, it is of importance that the transferring of transport units happens efficiently. Therefore, in this paper, the working of an intermodal terminal is analysed using a simulation model. The focus is on a rail-road freight transport terminal.

The paper is organized as follows. In section 2, a literature review on factors influencing the efficiency of a container terminal is given. In section 3, the simulation study is described. Finally, section 4 formulates conclusions and possible directions for future research.

2. LITERATURE REVIEW

Based on literature, the decisions that influence the efficiency of a container terminal can be divided in three categories, depending on the time horizon: strategic decisions, tactical decisions and operational decisions (Caris et al., 2008).

2.1. Strategic decisions

Long term, strategic planning involves the highest level of management and requires large capital investments over long time horizons. Decisions at this planning level affect the design of the physical infrastructure network. At the strategic level, the location of the terminal, the service area of the terminal, the potential volume of the terminal and the design of the terminal are important factors that influence the efficiency of the terminal. Table 1 gives an overview of these strategic factors and the relevant references. In the remainder of this section, the references that are most relevant for our research, are discussed.

A terminal is ideally located in an area where a lot of production and consumption of goods takes place. Other factors determining the location of a terminal are the location of distribution centers, antagonistic terminals and the access to the main rail and road networks (Ballis and Golias, 2002). Methods for determining the location of a terminal are often based on economic factors, environmental factors or quality aspects (Bergqvist and Tornberg (2008).

The service area of a terminal is the area in which intermodal transport is competitive with road transport (Limbourg and Jourquin, 2010). It is important to know the service area of a terminal in order to determine the potential volume of a terminal.

Once the potential volume of a terminal is known, the layout of the terminal can be determined. Bottani and Rizzi (2007) propose a model to predict the potential volume based on the distance between origin and destination, the time from origin to terminal or from terminal to destination, and the suitability to transport the goods in containers.

Finally, the design of a terminal is an important factor influencing the efficiency of the terminal. Ballis and Golias (2002) indicate the utilization of the tracks, the length of the tracks and the access to the terminal as important factors determining the design of a terminal.

Table 1: Literature review: strategic planning

Strategic Planning		
Factors	Terminal location	Arnold et al., 2004; Benson et al., 1994; Bergqvist & Tomberg, 2008; Limbourg & Jourquin, 2009; Ballis & Golias, 2002
	Service area	Limbourg & Jourquin, 2010; Niérat, 1997
	Potential volume	Bottanis & Rizzi, 2007
	Design	Ballis & Golias, 2002

2.2. Tactical decisions

Medium term, tactical planning aims to ensure, over a medium-term horizon, an efficient and rational allocation of existing resources in order to improve the performance of the whole system. Important factors at the tactical level are the number and type of handling equipment, gantry crane operation modes, train loading/unloading operations and the stacking of containers. Table 2 gives an overview of these tactical factors and the relevant references. In the remainder of this section, the references that are most relevant for our research, are discussed.

A variety of handling equipment exists in the intermodal transport market. Reachstackers and gantry cranes seem to dominate among conventional equipment. Simulation results show that a limited number of fast ‘servers’ gives better service times than a larger number of slow ‘servers (Ballis and Golias, 2002).

Marin Martinez et al. (2004) present a simulation model and modeling approach to the transfer of cargo between trains at rail terminals. Four operation modes for the crane to transfer containers between two trains are proposed: parallel, zigzag, parallel (II) and unloaded train. Based on the results of their simulation study, it can be concluded that the parallel operation mode performs worst in all situations, and the unloaded-train operation performs the best.

Train loading/unloading operations play an important role in determining terminal performance (Ballis and Golias, 2002). Figure 1 shows typical train loading/unloading operations. Four phases can be distinguished and are indicated on the horizontal axis. In the first phase, usually following arrival of the train, direct transshipments from wagon to truck are carried out. After some time, truck arrival rate falls and the handling equipment is using the idle times to transship load units to the storage area. The third phase is pure wagon to store transshipment because no trucks are available in the terminal. In the fourth phase, the trucks that arrive are loaded indirectly from store.

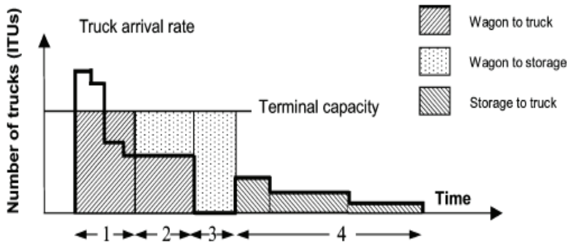

Figure 1: Typical four crane phases of crane work.

The stacking of containers reduces storage requirements and mean travel distance but it increases handling activities (Ballis and Golias, 2002).

Table 2: Literature review: tactical planning

Tactical planning		
Factors	Handling equipment	Ballis & Golias, 2002; Kozan, 2006; Vis, 2006
	Gantry crane operation modes	Marín-Martínez et al., 2004
	Loading/unloading operations	Ballis & Golias, 2002
	Stacking of containers	Ballis & Golias, 2002

2.3. Operational decisions

Short term, operational planning is performed by local management in a highly dynamic environment where the time factor plays an important role. At the operational level, important factors influencing the efficiency of the terminal are the crane area and the load plan of the trains (allocation of containers to wagons). Table 3 gives an overview of these operational factors and the relevant literature. In the remainder of this section, the references that are most relevant for our research, are discussed.

Cranes are often a bottleneck in the handling of containers. Therefore, the determination of a crane area is an important operational factor for the efficiency of an intermodal rail terminal. This crane area can be static (every crane has its own area) (Boysen and Fliedner, 2010) or dynamic (no fixed borders) (Alicke, 2002).

The purpose of a load plan is to transship the containers in such a way that the number of handlings or the time is minimized. The throughputtime of a container is optimized when containers can be loaded from train to truck (or from truck to train). Double handling should be avoided as much as possible (Corry and Kozan, 2006).

Table 3: Literature review: operational planning

Operational planning		
Factors	Crane area	Alicke, 2002; Boysen & Fliedner, 2010; Linn & Zhang, 2003
	Load plan of trains	Bostel & Dejax, 1998; Corry & Kozan, 2006

3. SIMULATION STUDY

3.1. Introduction

A simulation model representing a rail-road freight transport terminal is built in Arena. The simulation model is based on data obtained from the terminal Mainhub in Antwerp and data obtained from literature. Three entity types are considered in the model: containers (both import and export containers), wagons and trucks.

Importcontainers arrive in the terminal by train. The train takes place on the unloading track and the train in unloaded. A gantry crane is used to unload the containers from the train. First, the containers are stored in the storage zone next to the tracks. When a reach stacker is available, the container is moved to a different storage zone. Here the container will be stored until a truck arrives.

For export containers, which reach the terminal by truck, the steps are similar to the import container, but in the reverse order.

When a truck arrives at the terminal, first a distinction is made between a truck that comes to pick up a container and a truck that delivers a container. If a truck comes to pick up a containers, the truck is loaded using a reach stacker. If the truck comes to deliver a container, the truck waits next to the loading track until an empty wagon is available. Then the container is loaded on the train using a gantry crane.

A simulation of 24 hours is run. 10 replications are made for each configuration of the simulation model.

3.2. Design of experiments

To analyse the impact of several input factors on the efficiency of the terminal, an experimental design is set up. Four input factors are considered: the number of containers, the number of handling equipment (reachstackers and cranes) and the arrival pattern of trucks.

For each of the input factors, two levels are considered. The number of containers handled (factor 1) equals 300 containers a day for the lower level and 750 containers a day for the upper level. These levels are based on Ballis and Golias (2004).

Since reachstackers and gantry cranes are the handling equipment that is mostly used in rail terminals, the number of these two types of handling equipment are used as input factors in the experimental design. Based on data of the Belgian terminals, the two levels for the number of cranes (factor 3) are set to 1 and 2. Small terminals in Belgian have maximum one crane, while big terminals in Belgian have 2 of 3 cranes. The mean number of reach stackers in a Belgian terminal is around 3. Therefore, the two levels for the number of reach stackers (factor 2) are set to 2 and 4.

Two types of arrival patterns for the trucks (factor 4) are considered: all trucks arrive in a small timespan or the trucks arrive spread over a large timespan.

Concerning the output measures of the system, it is important to have a look at both the efficiency of the system and the profitability of the system. As output measures the utilization of handling equipment, the throughput time of containers and the profit of the system are calculated.

A full factorial design is used, table 4 gives an overview of the 16 experimental points.

Table 4: Experimental design

	Containers	Reach-stackers	Cranes	Arrival pattern
1	300	2	1	Close
2	300	2	1	Spread
3	300	2	2	Close
4	300	2	2	Spread
5	300	4	1	Close
6	300	4	1	Spread
7	300	4	2	Close
8	300	4	2	Spread
9	750	2	1	Close
10	750	2	1	Spread
11	750	2	2	Close
12	750	2	2	Spread
13	750	4	1	Close
14	750	4	1	Spread
15	750	4	2	Close
16	750	4	2	spread

3.3. Main simulation results and discussion

The results of the simulation study are shown in Table 5. For each of the output measures, confidence intervals for the main and interaction effects are given.

Significant effects are indicated in italic. Eight of the eleven significant effects are main effects.

The results indicate that the number of containers, the number of reachstackers and the number of cranes are significant variables. The arrival pattern of trucks has no significant influence on the output measures.

The utilization of the reachstackers is significantly influenced by the number of containers handled and the number of reachstackers. The higher the number of containers handled in the terminal, the higher the utilization of the reachstackers. The higher the number of reachstackers in the terminal, the lower the utilization of the reachstackers.

The utilization of the cranes is significantly influenced by the number of containers handled and the number of cranes in the terminal. The higher the number of containers handled, the higher the utilization of the cranes. The higher the number of cranes the terminal, the lower the utilization of the cranes.

The troughputtime of an exportcontainer depends on the number of cranes in the terminal. When the number of cranes is higher, the throughputtime of the container is lower.

The troughputtime of an importcontainer depends on the number of reachstackers in the terminal. When the number of reachstackers is higher, the throughputtime of the importcontainer is lower.

The profit of the container terminal is significantly influenced by the number of containers handled and the number of reachstackers. The more containers are handled in the terminal, the higher the profit of the terminal. The more reachstackers the terminal uses, the lower the profit of the terminal. One would expect here that the number of cranes also has an influence on the profitability of the terminal. However, although this effect is asymmetric, no significant effect is found.

Based on the results, it can be stated that both the number of containers handled as the number of handling equipment has an influence on the output measures. When both the throughput time and the utilization of the equipment are high, new equipment can be necessary. When the terminal is handling mostly import containers, a reach stacker is the best option. When export containers are mostly handled by the terminal, a crane is the best option.

4. CONCLUSIONS AND FUTURE RESEARCH

For intermodal transport to be competitive with road haulage, it is of importance that the transferring of transport units happens efficiently. Therefore, in this paper, the working of an intermodal terminal is analysed using a simulation model. The focus is on a rail-road freight transport terminal.

Based on literature, the decisions that influence the efficiency of a container terminal are described. At the

Table 5: Main and interaction effects for the output measures (1)

Effect	Utilization reachstackers	Utilization cranes
1	*[0,16;0,24]*	*[0,18;0,25]*
2	*[-0,19;-0,13]*	[-0,006;0,01]
3	[-0,05;0,05]	*[-0,21;-0,13]*
4	[-0,05;0,03]	[-0,03;0,02]
1-2	*[-0,10;-0,04]*	[-0,01;0,009]
1-3	[-0,04;0,04]	*[-0,12;-0,03]*
1-4	[-0,07;0,04]	[-0,05;0,03]
2-3	[-0,04;0,04]	[-0,03;0,04]
2-4	[-0,04;0,06]	[-0,03;0,03]
3-4	[-0,05;0,05]	[-0,02;0,03]
1-2-3	[-0,03;0,03]	[-0,02;0,03]
1-2-4	[-0,06;0,08]	*[-0,10;-0,03]*
1-3-4	[-0,04;0,05]	[-0,04;0,05]
2-3-4	[-0,04;0,07]	[-0,03;0,04]
1-2-3-4	[-0,04;0,05]	[-0,03;0,04]

Table 6: Main and interaction effects for the output measures (2)

Effect	Throughput-time export container	Throughput-time import container
1	[-0,81;0,25]	[-0,44;1,80]
2	[-0,65;0,53]	*[-1,17;-0,04]*
3	*[-1,88;-0,68]*	[-1,44;0,33]
4	[-0,59;0,71]	[-0,84;0,91]
1-2	[-0,60;0,53]	[-0,99;0,03]
1-3	*[-2,01;-0,17]*	[-1,18;0,14]
1-4	[-0,74;0,40]	[-1,01;0,66]
2-3	[-0,63;0,83]	[-1,02;0,68]
2-4	[-0,43;0,68]	[-0,62;1,18]
3-4	[-0,59;0,99]	[-0,71;0,88]
1-2-3	[-0,40;0,49]	[-0,69;0,30]
1-2-4	*[0,49;1,68]*	[-0,84;1,17]
1-3-4	[-1,32;1,13]	[-0,75;0,73]
2-3-4	[-0,57;0,54]	[-0,64;0,85]
1-2-3-4	[-0,21;0,64]	[-0,75;0,86]

Table 7: Main and interaction effects for the output measures (3)

Effect	Profit
1	*[1.920.153,74;2.381.120,47]*
2	*[-395.669,28;-132.454,14]*
3	[-785.502,12;185.869,46]
4	[-273.580,85;123.522,64]
1-2	[-151.061;89.402]
1-3	[-395.601;349.174,2]
1-4	[-362.876;259.788,7]
2-3	[-307.231;330.472]
2-4	[-246.128;239.357]
3-4	[-300.170;250.257,7]
1-2-3	[-319.277;315.376,6]
1-2-4	[-314.108;237.050]
1-3-4	[-300.028;303.073,3]
2-3-4	[-250.496;397.690,4]
1-2-3-4	[-247.621;295.394,1]

strategic level, the location of the terminal, the service area of the terminal, the potential volume of the terminal and the design of the terminal are important factors that influence the efficiency of the terminal. Important factors at the tactical level are the number and type of handling equipment, gantry crane operation modes ,train loading/unloading operations and the stacking of containers. At the operational level, important factors influencing the efficiency of the terminal are the crane area and the load plan of the trains (allocation of containers to wagons).

A simulation model representing a rail-road freight transport terminal is built in Arena. To analyse the impact of several input factors on the efficiency of the terminal, an experimental design is set up. Four input factors are considered: the number of containers, the number of handling equipment (reachstackers and cranes) and the arrival pattern of trucks (all trucks arrive in a small timespan or the trucks arrive spread over a large timespan). As output measures the utilization of the handling equipment, the throughput time of the containers and the total costs of the system are calculated.

The results of the simulation study show that the number of containers and the number of handling equipment are the most important variables. The arrival pattern of trucks has almost no influence on the output measures. When both the throughput time and the utilization of the equipment are high, new equipment can be necessary. When the terminal is handling mostly import containers, a reach stacker is the best option. When export containers are mostly handled by the terminal, a crane is the best option.

The simulation model in this paper is mainly based on the literature review. However, in future research, the model could be refined based on the practical, real-life working of a rail-road container terminal. Based on this practical information, other input factors and/or output measures can also be added to the experimental design and advice could be given to improve the working of the terminal.

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AUTHORS BIOGRAPHY

Katrien Ramaekers graduated as Master of Business Economics at the Limburg University Centre in 2002. In 2007, she obtained her Ph.D. in Applied Economic Sciences at Hasselt University. Her Ph.D. research is on the integration of simulation and optimisation, especially as a support for complex logistics decision-making. Currently, she is a post-doctoral researcher at Hasselt University and is working on the integration of simulation and optimization and on the modeling of freight transport.

An Caris is a postdoctoral researcher supported by the Research Foundation Flanders (FWO) at Hasselt University, Belgium. She received a Master degree in Business Economics with a major in Operations Management and Logistics at the Limburg University Centre (LUC), Belgium, in 2003. In 2010 she defended her Ph.D. in Applied Economic Sciences at Hasselt University, Belgium. She takes a research interest in modelling intermodal freight transport networks, vehicle routing problems and metaheuristics.

Leen Gorissen graduated as Master of Business Economics at Hasselt University in 2011. The topic of her masterthesis was the simulation of an intermodal rail-road terminal.