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A SIMULATION APPROACH TO THE ANALYSIS OF INTERMODAL FREIGHT TRANSPORT NETWORKS

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KEYWORDS

Discrete event simulation, methodology, intermodal transport, inland navigation, network analysis

ABSTRACT

In regions with an extensive waterway network intermodal transport including inland navigation is a good alternative for unimodal road transport. A discrete event simulation methodology is proposed to analyze policy measures with the intention of stimulating intermodal barge transport. The intermodal hinterland network of the port of Antwerp serves as the real-world application in this study. Various aspects in the modelling process are discussed and a first potential policy for analysis is proposed.

INTRODUCTION

In this paper a discrete event simulation methodology is developed to capture and analyze the interactions in intermodal freight transport networks. Macharis and Bontekoning (2004) define intermodal transport as the combination of at least two modes of transport in a single transport chain, without a change of container for the goods, with most of the route travelled by rail, inland waterway or ocean-going vessel and with the shortest possible initial and final journeys by road. Intermodal transport may include various transport modes. Our objective is to analyze the performance of intermodal networks including inland navigation and road transport. In regions with an extensive waterway network, such as Western Europe, intermodal transport including inland navigation is a good alternative for unimodal road transport.

Intermodal planning problems are more complex due to the inclusion of multiple transport modes, multiple decision makers and multiple types of load units. Because of this increased complexity and the required level of detail, discrete event simulation is the appropriate tool of analysis. A simulation model will be created to support decisions in intermodal transport at the strategic level. Simulation models have been widely used to optimize the design of intermodal terminals. For example, Rizzoli et al. (2002) present a simulation tool for the combined rail/road transport in intermodal terminals. Parola and Sciomachen (2005) describe a strategic discrete event simulation model to analyze the impact of a possible future growth in sea traffic on land infrastructure in the north-western Italian port system. We develop a simulation model that covers the hinterland waterway network of a major port in Western-Europe in order to analyze effects of future policy measures for intermodal container transport. A first policy related to the consolidation network is presented in this paper. Various studies discuss consolidation strategies for intermodal transport by rail, see for example Janic et al. (1999) and Newman and Yano (2000). Konings (2005) presents and evaluates a consolidation strategy for intermodal transport by barge, based on a marginal cost model. In our simulation model the operations of the inland navigation network are modelled in detail. This enables us to examine ex-ante what the effects of a certain consolidation strategy will be and to take into account interaction effects in container flows. In the future, the model will also be used to analyze other policies related to intermodal barge transport. This paper presents current research which is still in progress. The simulation model will be part of a larger decision support system for intermodal transport policy making which is not yet discussed here.

MODELLING METHODOLOGY

In this section the methodology to model the hinterland waterway network is described. First, the main characteristics of the intermodal network under investigation are given. Next, the conceptualization of the network is developed. The inputs and outputs of the simulation model are discussed. In the final subsection special attention is given to the functioning of the locks.

Intermodal Transport Network

The intermodal hinterland network of the port of Antwerp serves as the real-world application in our study. Three regions of origin can be identified in the network. The first group of container terminals is situated along the Albert Canal towards the eastern part of Belgium. A second region of origin is located in the central part of the country, connected to the port of Antwerp by the Brussels - Scheldt Sea Canal. The third group of intermodal container flows originates in the basin of the Upper Scheldt and the river Leie. All intermodal container terminals organize shuttle services either to the port of Antwerp or to the ports of Rotterdam and Amsterdam. Two clusters of sea terminals can be identified in the port area of Antwerp. Until recently the main center of activity was situated on the right river bank. With the construction of a new dock (Deurganckdok) in the port of Antwerp, a second cluster of sea terminals emerged on the left river bank. Barges sail through the Scheldt-Rhine connection to Rotterdam and Amsterdam. A last destination is the port of Zeebrugge, which can be reached via Antwerp and short sea shipping on the river Scheldt. Table 1 summarizes all origins and destinations of shuttle services. Shuttle services transport containers from inland terminals to sea terminals in the port area and carry containers from sea terminals to inland destinations in a round trip.

Table 1: Origins and Destinations

Origins	**Destinations**
Albert Canal	Antwerp: right river bank
Brussels-Scheldt Sea Canal	Antwerp: left river bank
Upper Scheldt and Leie	Rotterdam
	Amsterdam
	Zeebrugge

Conceptual Model

Three major components can be identified in the intermodal hinterland network, as depicted in figure 1. The first component in the intermodal freight transport network is the inland waterway network. The inland waterway network is made up of terminals, waterway connections and container flows. Entities are defined as barges which originate from the different inland terminals and carry containers in round trips to the various ports. A second component is the port area of Antwerp. Barges may visit sea terminals at the left river bank and right river bank in the same round trip, go to Rotterdam or Amsterdam via the Scheldt-Rhine connection or sail to Zeebrugge via the Scheldt estuary. On the right and left river bank, barges queue for handling at the sea terminals. Barges moor as soon as enough quay length is available. The handling time at the sea terminal depends on the number of containers that need to be unloaded from or loaded into the inland vessel. In the inland waterway network as well as in the port area multiple locks are present. Therefore, the lock planning constitutes a third major component, which will be discussed hereafter.

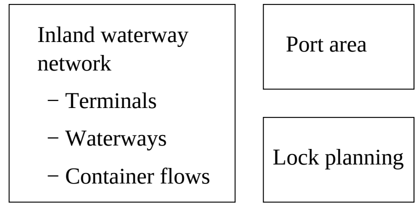

Figure 1: Components

The objective of the model is to simulate possible policy measures for intermodal barge transport. Consequences and implications can be estimated before implementation of the policy measure. Therefore, various conceptual models may be necessary to analyze the implications of proposed policies. The conceptual model of the current container flow is depicted in figure 2. At present all barges enter the port area and visit one or multiple sea terminals.

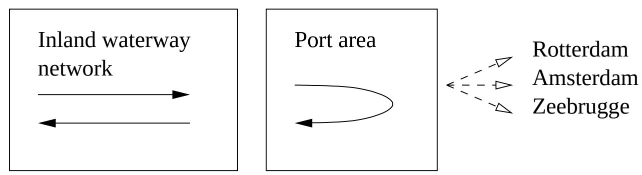

Figure 2: Conceptual Model Current Situation

Assumptions

A number of assumptions are made to translate the actual intermodal network into a discrete event simulation model. The emphasis lays on inland waterway transport. Rail connections in the hinterland network are not taken into account. The model further assumes a homogeneous container type and equal handling time for each container. All main waterway connections between inland terminals and the port area are incorporated in the simulation model. Small waterways without inland terminals are not included in the simulation model of the current situation. Sailing times are assumed to be stochastic and follow a probability distribution. The average sailing time varies with the type of barge. A probability distribution is also used to model the stochastic lockage time.

Data Requirements

All intermodal terminals in the inland waterway network are asked for information to identify the container flows. Real data on shuttle services is used as an input for the simulation model, constructed in the simulation software Arena. For each shuttle service the following information is required: which type of barge is used, which destinations are visited and what is the average number of import and export containers for each destination. Container transport interacts with other freight flows. Therefore, the flow of non-containerized goods on the inland waterway network is introduced as an input in the simulation model. These flows affect the waiting times at locks. Information is also necessary on the network connections. The waterway administrators provided information on the number of locks on each waterway, distances between locks, average lockage times, number of lock chambers and size of the chambers. In the port area of Antwerp three clusters of locks connect the inner port area with the sea side. Data is required on the choice of locks when sailing in the port area. The average quay length available for handling inland navigation at sea terminals gives an indication of the service capacity in the port area of Antwerp. The port authority is asked for the average mooring time and time for loading and unloading in order to model the service times of inland container barges in the port area. Finally, an enquiry is made into the turnaround times of vessels and average waiting times at locks in order to verify and validate the model.

Outputs

Table 2 gives an overview of performance measures which are generated by the simulation model. The turnaround time of shuttles is defined as the total time necessary for a barge to sail from an inland container terminal to the port area, visit all sea terminals and return to the inland terminal. The turnaround time depends on the waiting times at locks and in the port area. The outputs measured at locks are the percentage of barges that have to wait, the number of barges that have to queue and the waiting time of barges in the queue. In the port area the waiting time before handling is measured, as well as the number of vessels queueing for service. A final group of performance measures concerns the capacity utilization. In the port area this is expressed as the average percentage of quay length occupied. In the hinterland network the average and maximum number of barges on each network connection is recorded.

Locks

The operations of locks strongly affect waiting times of barges for lockage. A number of decision rules are defined to make the operations of the locks in the simulation model reasonably realistic. A first decision rule relates to the size of a barge. Barges are assigned to a lock chamber only if its size is within the allowed dimensions. Secondly, barges are assigned to the smallest lock chamber that is open. This decision rule focuses on a rapid lockage process of barges. Smaller lock chambers have a shorter lockage time. On the other hand, a more intensive use of larger lock chambers may reduce waiting times because more barges can be serviced simultaneously. A third decision rule is applied when no lock chamber is open in the sailing direction of the barge. In this situation the barge is assigned to the lock chamber which is the first available. A final decision rule concerns the closing of lock chambers. A lock chamber is closed when there is not enough remaining space for the next barge in queue or when no additional barges arrive within a predefined number of time units. From interviews with waterway administrators it appears that the operations of locks are entrusted to a lockkeeper, without fixed rules. Future research could introduce more complex decision rules in the simulation model.

Table 2: Performance Measures

Shuttles	turnaround time
Locks	total number waiting (%) number waiting in queue waiting time in queue
Port area	waiting time in queue number waiting in queue
Capacity utilization	quay length network connections

ANALYSIS OF CONTAINER FLOWS

The simulation model will be used to analyze policy measures that impact container flows in the intermodal hinterland network and the port area of Antwerp. It will further allow to detect future bottlenecks in the infrastructure of the network. To this end various scenarios of increasing transport volumes can be modelled.

One potential policy might be the introduction of an intermodal barge hub in the port of Antwerp, from which load is distributed to the different sea terminals, as proposed by Konings (2005). The author proposes to split existing barge services into a trunk-line operation in the hinterland and collection/distribution operations in the seaport. This leads to the conceptual model depicted in figure 3. By doing so inland barges do not have to call at multiple sea terminals. They only visit the intermodal barge hub. This leads to a reduction in turnaround time of vessels serving the hinterland. In the collection/distribution network containers with the same origin or destination can be bundled. This enables a more efficient and prompt handling of barges at sea terminals. The simulation model will allow to demonstrate to what extent the waiting times in the port area and the turnaround time of inland barges can be reduced.

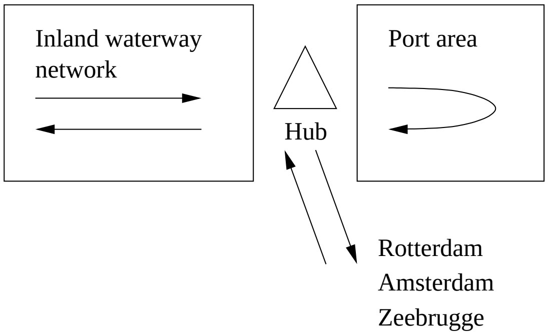

Figure 3: Conceptual Model Future Situation

CONCLUSIONS AND FUTURE WORK

The modelling process is presented of a discrete event simulation model for an intermodal freight transport network. The model will be used to make a quantitative ex-ante analysis of policy measures to stimulate intermodal barge transport. In this study the main focus is on the inland waterway network. Potential improvements include the introduction of more complex decision rules for the operations of locks. A submodel could also be introduced to integrate the intermodal terminal planning into the simulation model.

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BIOGRAPHY

AN CARIS graduated as Master of Business Economics with a major in Operations Management and Logistics at the Limburg University Centre (LUC), Belgium, in 2003. After one year of practical experience in inventory management at Reynaers Aluminium, she started as a teaching assistant in econometrics and operations research at the Hasselt University (UHasselt), Belgium. In addition she is preparing a Ph.D. in Applied Economic Sciences. She is a member of the research group Data Analysis and Modelling and the Transportation Research Institute (IMOB) of the Hasselt University. She takes a research interest in modelling intermodal freight transport networks with a focus on inland navigation.

GERRIT K. JANSSENS received degrees of M.Sc. in Engineering with Economy from the University of Antwerp (RUCA), Belgium, M.Sc. in Computer Science from the University of Ghent (RUG), Belgium, and Ph.D. from the Free University of Brussels (VUB), Belgium. After some years of work at General Motors Continental, he joined the University of Antwerp until the year 2000. Currently he is Professor of Operations Management and Logistics at Hasselt University within the Faculty of Business Administration. He holds the CPIM certificate of the American Production and Inventory Control Society (APICS). During the last fifteen years he has repeatedly been visiting faculty member of universities in Thailand, Vietnam, Philippines, Cambodia and Zimbabwe. His research interests include the development and application of operations research models in production and distribution logistics.

CATHY MACHARIS received her Master of Business Economics and Ph.D. degrees from the Solvay Business School, Free University of Brussels (VUB), Belgium. Currently she is professor at the Free University of Brussels (VUB), Faculty of Economics, Social and Political Sciences and Solvay Business School. She teaches courses in operations and logistics management, transport and business economics. Her research focuses on establishing linkages between advanced operations research methodologies and practical logistics challenges faced by senior management in firms and public agencies. She has been involved in several national and European research projects dealing with topics such as location selection, intermodal transport optimization, road safety enhancement through telematics applications, public transport and inland navigation.