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[1]An Caris, [1]Gerrit K. Janssens, [1]Katrien Ramaekers and [2]Cathy Macharis
[1]Transportation Research Institute, Hasselt University – campus Diepenbeek, Wetenschapspark – Building 5, 3590 Diepenbeek, Belgium
[2]Department MOSI – Transport and Logistics, Vrije Universiteit Brussel – Management school Solvay, Pleinlaan 2, 1050 Brussel, Belgium

Abstract: In this paper a discrete event simulation model for intermodal barge transport (SIMBA) is presented. The intermodal context in Belgium is described. The simulation model covers the hinterland waterway network of a major port in Western-Europe. The simulation modeling approach is elaborated. The SIMBA model is part of a larger decision support system for intermodal transport policy making (DSSITP). The simulation model is applied to analyze potential impacts of adding a new intermodal barge terminal to a hinterland network.
Keywords: Discrete event simulation, intermodal freight transport, ex-ante analysis, decision support system, policy making

INTRODUCTION

Emerging freight transport trends, such as a geographical expansion of distribution networks and continuing growth rates in freight transport, demonstrate the importance and necessity of intermodal freight transport systems. European, national and regional governments intend to stimulate a modal shift towards more environment-friendly transport modes, such as rail and barge transport. Intermodal transport has grown into a dynamic transportation research field. Many new intermodal research projects have emerged. Intermodal transport integrates at least two modes of transport in a single transport chain, without a change of container for the goods, with most of the route traveled by rail, inland waterway or ocean-going vessel and with the shortest possible initial and final journeys by road (Macharis and Bontekoning[1]). An overview of planning issues in intermodal transport is given by Caris, Macharis and Janssens[2].

This paper describes a discrete event Simulation Model for InterModal BArge transport (SIMBA), which is developed as part of a Decision Support System for supporting Intermodal Transport Policy making in Belgium (DSSITP). Intermodal planning problems are 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. The SIMBA simulation model is 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, Fornara, and Gambardella[3] present a simulation tool for the combined rail/road transport in intermodal terminals. Parola and Sciomachen[4] 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.

The SIMBA simulation model covers the hinterland waterway network of a major port in Western-Europe. In the following section, the intermodal context in Belgium is presented. Next, the discrete event simulation model is discussed. The SIMBA model is part of a larger decision support system for intermodal transport policy making. The DSSITP framework is briefly introduced. In the final section the SIMBA model is demonstrated by analyzing the impact of an additional barge terminal in the hinterland waterway network.

INTERMODAL CONTEXT IN BELGIUM

In the intermodal context in Belgium, the importance of inland navigation is increasing. A key element in the competitiveness of seaports consists of their hinterland access. Ports have become a part of intermodal networks and competition takes place amongst transport chains instead of between ports. The intermodal hinterland network of the port of Antwerp serves as the

Corresponding Author: Gerrit K. Janssens, Transportation Research Institute, Hasselt University – campus Diepenbeek, Wetenschapspark – Building 5, 3590 Diepenbeek, Belgium, E-mail: gerrit.janssens@uhasselt.be

real-world application in our study. In the port of Antwerp a modal shift towards inland navigation is observed in recent years. The share of barge container transport in the modal split of the port of Antwerp amounted to 32% in 2004. As transport volumes are expected to further increase, inland navigation is often seen as a promising solution to ensure an effective hinterland access. The quality of the hinterland access of a port depends on multiple actors in the transport flow, such as truck companies, terminal operators, barge operators, freight forwarders, carriers and port authorities. De Langen and Chouly[5] think of the improvement of hinterland access as a collective action problem, which requires coordination between actors. Inter-organizational coalitions are necessary to invest in hinterland transport services.

SIMULATION MODEL FOR INTERMODAL BARGE TRANSPORT

This section gives an overview of the methodology of the SIMBA model. The simulation model covers the hinterland waterway network of a major port in Western-Europe. First, the intermodal transport network is presented. Next, the conceptual model of the current network is discussed. A number of assumptions are made to implement the conceptual model into a computer simulation model. Finally, an overview is given of the inputs and outputs of the discrete event simulation model.

Intermodal Transport Network

In Belgium three regions of origin can be identified in the hinterland network of the port of Antwerp. 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 navigation on the river Scheldt. 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.

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 on 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, lock planning constitutes a third major component.

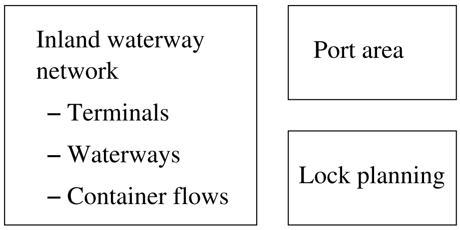

Fig. 1: Components

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 group of decision rules relates to the assignment of barges to lock chambers. 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. 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 second group of decision rules is introduced to determine when a lock chamber is closed. 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.

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.

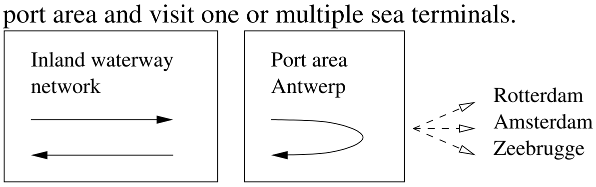

Fig. 2: Conceptual model of the current situation

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. A probability distribution is also used to model the stochastic lockage times and handling times in the port area.

Inputs

The intermodal terminals in the inland waterway network were requested for information to identify the container flows. Real data on shuttle services is used as 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 input in the simulation model. These flows affect the waiting times at locks. The waterway administrators provided information on the network connections. 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. 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 1 gives an overview of performance measures 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. 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 set 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.

Table 1: 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

EVALUATION OF POLICY MEASURES

The SIMBA model is part of a decision support system for evaluating policy measures intended to stimulate intermodal transport. The DSSITP framework is depicted in figure 3 [6]. Due to the combination of three models, the analysis of policy measures is performed on multiple levels of aggregation over multiple transport modes. Each model has its specific purpose and outputs. The multimodal freight model NODUS is situated on the highest level of aggregation and constitutes the first step in the analysis of a potential policy measure. NODUS implements the virtual networks methodology as defined by Jourquin and Beuthe[7]. The NODUS model provides traffic prognoses and optimal locations which serve as inputs for the LAMBIT model and SIMBA model. The

NODUS model produces aggregated outputs of the various transport modes, such as their accessibility, environmental impact, share in modal split and total costs of an intermodal service. The LAMBIT model is scaled on the Belgian intermodal network. The model analyzes the potential market area of a new terminal and assesses the impacts on existing terminals. It further produces cost indicators and potential modal shifts. The SIMBA model is situated on the lowest level of aggregation and produces detailed output related to the reliability, speed and capacity utilization of the waterway network. The operations of the inland navigation network are modeled in detail. This enables an ex-ante examination of potential policy measures to stimulate intermodal transport by barge. With the SIMBA model, the impact of volume increases in the network or the introduction of new intermodal barge terminals can be simulated. Also alternative consolidation strategies may be compared.

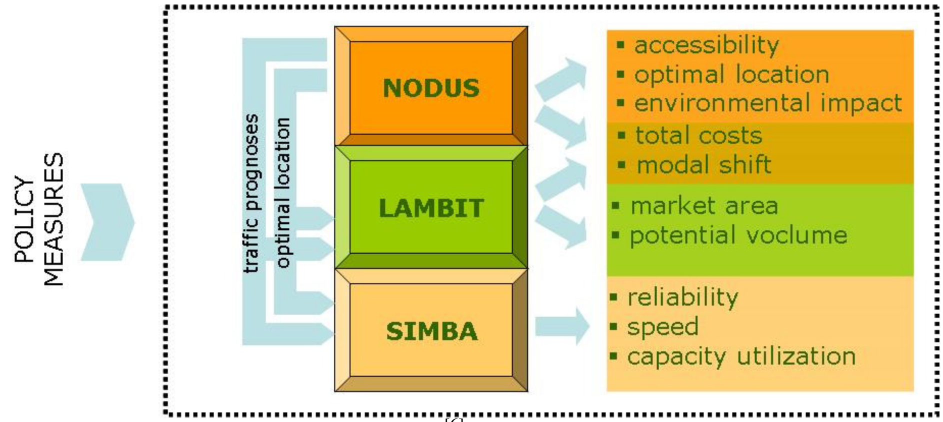

Fig. 3: DSSITP assessment framework [6]

Three categories of policy measures may be identified. The first group of policy measures affects intermodal transport costs. Both federal and regional governments in Belgium establish subsidy schemes to promote the growth of intermodal transport. Second, transport policies may affect investments costs necessary to provide intermodal transport infrastructure. Infrastructure related policy measures include the construction of new terminals and intermodal network extensions. A third group of policy measures is intended to improve intermodal transport services. An example of service related policy measures is given by Caris, Macharis and Janssens[8] who study the effect of alternative consolidation strategies in intermodal barge transport.

In this paper the SIMBA model is applied to analyze the impact of a new intermodal barge terminal on the waterway network. The impact on network characteristics such as average and maximum waiting times at locks and in the port area is measured. Potential bottlenecks and necessary capacity investments may also be deducted. As depicted in figure 3, the location and volume of a new intermodal barge terminal is received from the NODUS model. The market area may also be analyzed with LAMBIT. A new location is identified in the southern part of the country, at Roucourt on the Nimy-Blaton-Péronnes canal. A potential volume of 7,000 containers per year with the port of Antwerp as origin or destination is assumed. Vessels will sail via the Upper Scheldt to the port area in Antwerp. The Nimy-Blaton-Péronnes canal is navigable for vessels up to 1350 tons. As the terminal currently does not exist, assumptions have to be made regarding the service schedule offered to customers. Vessels of size 32 TEU and 66 TEU sail in a roundtrip to the port area. Three departures are equally distributed in a weekly schedule. Vessels may visit both clusters of sea terminals on the right and left river bank in a single roundtrip. As the new terminal is situated in the southern part of Belgium, it takes almost a day to sail from the hinterland to the port of Antwerp. Barges depart in the morning of day 1 in Roucourt and arrive at sea terminals in the morning of day 2. No changes are made to the schedules of the existing inland terminals. A separate random-number stream is dedicated to each source of randomness in the model in order to synchronize the current and new situation as much as possible.

Performance measures relevant for the comparison of the current and new situation are discussed next. Ten simulation runs of 672 hours are performed. Table 2 gives the average turnaround times of all inland terminals, expressed in hours in the current and future situation. Inland vessels may only sail to Antwerp (Antw) or they can make a combined trip to Antwerp and Rotterdam (Rdam) or Amsterdam (Adam). The standard deviation is mentioned between brackets below the average turnaround time. From table 2 may be concluded that the introduction of a new terminal has no influence on the turnaround times of existing terminals. Shuttle services offered by the terminal in Roucourt incur a turnaround time of 63.31 hours.

Table 2: Average turnaround times current situation and after introduction new terminal

Shuttle services	Current Avg	New terminal Avg
Gosselin Deurne - Apen	15.10 (0.32)	15.20 (0.41)
Gosselin Deurne - Rdam	21.21 (0.09)	21.26 (0.07)
Gosselin Deurne - Apen + Rdam	22.44 (0.46)	21.64 (0.88)
WCT Meerhout - Apen	29.09 (0.46)	28.84 (0.41)
WCT Meerhout - Rdam / Adam	38.20 (1.07)	38.30 (0.46)
WCT Meerhout - Apen + Rdam / Adam	41.59 (0.42)	41.75 (0.56)
Haven van Genk - Apen	38.70 (0.53)	38.84 (0.66)
Haven van Genk - Rdam	45.07 (0.46)	45.03 (0.54)
Haven van Genk - Apen + Rdam	50.30 (0.95)	49.87 (1.05)
Renory Luik - Apen	46.47 (0.31)	46.28 (0.38)
IPG Gent - Apen	20.24 (0.53)	20.55 (0.69)
IPG Gent - Rdam	35.43 (0.49)	35.28 (0.32)
RTW Wielsbeke - Apen	38.63 (0.51)	38.77 (0.36)
RTW Wielsbeke - Rdam	49.29 (0.91)	49.04 (1.10)
AVCT Avelgem - Apen	41.98 (2.13)	42.09 (1.99)
AVCT Avelgem - Rdam	57.53 (0.90)	58.21 (1.16)
AVCT Avelgem - Apen + Rdam	62.82 (0.48)	62.57 (0.41)
TCT Willebroek - Apen	14.74 (0.19)	14.79 (0.13)
TCT Willebroek - Apen+Rdam	35.47 (0.36)	35.36 (0.36)
Cargovil Grimbergen - Apen	20.91 (0.17)	21.07 (0.38)
Cargovil Grimbergen - Rdam	38.17 (0.38)	38.24 (0.11)
BTI Brussel - Apen	21.74 (0.29)	21.76 (0.29)
BTI Brussel - Rdam	40.61 (0.83)	40.84 (0.99)
BTI Brussel - Apen + Rdam	40.63 (0.36)	40.78 (0.45)
Batop Herent - Apen	21.98 (0.27)	21.80 (0.14)
Roucourt - Apen	/ /	63.31 (0.70)

Table 3 summarizes performance measures in the port area. The average and maximum waiting time before handling, expressed in hours, are given for the sea terminals on the right and left river bank. Next, the average and maximum utilization of the quays on the right and left river bank and at the hub are measured.

Table 3: Performance measures in port area

	Current		New terminal	
	Avg	**Stdev**	**Avg**	**Stdev**
Avg Waiting time port area				
RO	0.06	0.02	0.08	0.02
LO	0.05	0.02	0.05	0.02
Max Waiting time port area				
RO	4.37		7.72	
LO	3.98		3.97	
Avg Capacity utilisation				
RO	0.1666	0.0017	0.1715	0.0015
LO	0.1742	0.0017	0.1786	0.0019
Max Capacity utilisation				
RO	0.9834		0.9834	
LO	0.9850		0.9850	

Following Law[9], paired-*t* confidence intervals are constructed to compare the results. Table 4 presents the 95% confidence intervals for which the difference between the introduction of a new terminal in Roucourt and the current situation is significant. The average handling time in both clusters of sea terminals on the left and right river bank increases slightly due to the introduction of a new terminal in the waterway network. An increase of 0.5% is only a minor effect. No large impact was to be expected in light of the small market area of the new inland terminal. However, the analysis clearly demonstrates the possibilities of the SIMBA model and the DSSITP framework. The framework is able to quantify ex-ante the impact of future policy measures.

Table 4: Comparison current and new situation

Avg Capacity utilisation	95% Confidence interval
Quay RO	0.0005; 0.0094
Quay LO	0.0002; 0.0084

CONCLUSIONS

A discrete event simulation model is set up to analyze potential impacts of policy measures intended to stimulate intermodal barge transport. The operations in the hinterland network of the port of Antwerp are modeled in detail to assess the impact on the network infrastructure and operational characteristics. The model is applied to estimate the influence of a new intermodal barge terminal in Roucourt. The shuttle services offered by the new terminal cause a slight increase in average handling time in both clusters of sea terminals on the left and right river bank. Impacts are only minor or non-existent due to the fact that this new terminal is not able to attract large volumes. The analysis clearly shows the possibilities of the simulation model and the DSSITP framework.

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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 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.

Katrien Ramaekers graduated as Master of Business Economics at the Limburg University Centre in 2002. In October 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 and for decision support with limited information in supply and demand. Currently, she is a post-doctoral researcher at Hasselt University and is working on the modelling of freight transport. She is a member of the research group Data Analysis and Modelling and the Transportation Research Institute of Hasselt University.

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.