A SIMULATION METHODOLOGY FOR THE ANALYSIS OF BUNDLING NETWORKS IN INTERMODAL BARGE TRANSPORT

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ABSTRACT

This paper presents the modelling methodology of a discrete event simulation model for intermodal barge transport. An intermodal freight transport network is modelled with the objective to understand the system and analyse various network configurations. Intermodal transport networks exhibit an increased complexity due to the inclusion of multiple transport modes, multiple decision makers and multiple types of loading units. Because of this increased complexity and the required level of detail, discrete event simulation is the appropriate tool of analysis. The conceptual and computerized modelling process is described and an application involving the simulation of alternative bundling networks is presented.

INTRODUCTION

In this paper a discrete event simulation model is presented to support decisions in intermodal barge transport. The objective of the simulation model is to assess the impact of policy measures on performance measures such as turnaround time of vessels, waiting time of barges in the port area and handling time of inland barges at sea terminals. According to Law (2007), simulation is a technique to imitate the operations of a real-world facility or process. The facility or process of interest is called a *system* and a set of assumptions about how it works is made in order to study it scientifically. An intermodal freight transport network is modelled with the objective to understand the system and analyse various network configurations. Intermodal transport networks exhibit an increased complexity due to the inclusion of multiple transport modes, multiple decision makers and multiple types of loading units (Caris et al. (2008)). The complexity of the intermodal transport system makes it impossible to describe all interactions by a mathematical model. Because of this increased complexity and the required level of detail, discrete event simulation is the appropriate tool of analysis. The intermodal hinterland network of the port of Antwerp serves as the real-world application in this study. This paper continues the work of Caris et al. (2009) by applying the proposed modelling methodology to the analysis of bundling networks. In the following section the simulation model is presented. Next, an application is demonstrated by simulating two alternative consolidation networks for intermodal barge transport. Finally, conclusions and directions for future research are given.

SIMBA MODEL

The discrete event Simulation model for InterModal BArge transport (SIMBA) described in this section is incorporated in a Decision Support System for Intermodal Transport Policy making (DSSITP), presented in Macharis et al. (2008). The DSSITP assessment framework uses three different models that are capable of assessing policies intended to enhance the growth of intermodal inland waterway and rail transport. The impact of policy measures is measured on all related transport modes and at multiple aggregation levels. Three core models, LAMBIT, SIMBA and NODUS make up the decision support system for intermodal transport policy making. For a detailed description of the LAMBIT and NODUS models, the reader is referred to the respective chapters in Macharis et al. (2008). The objective of the SIMBA model is to simulate possible policy measures for intermodal barge transport, but it can also be applied to analyse planning decisions of private stakeholders. Consequences and implications for the network performance measures can be estimated before implementation of a policy measure. The first subsection gives an overview of the current network configuration. Next, the conceptual model of the hinterland waterway network is presented. In the last subsection various aspects in the computerized modelling process are discussed.

Intermodal transport network

Figure 1 represents the port area of Antwerp. Three clusters of sea terminals can be identified. Until recently the main center of activity was situated on the right river bank. Sea terminals on the right river bank are either situated behind the locks (cluster 1) or in front of the locks at the river Scheldt (cluster 2). The two clusters are separated by three lock systems, indicated in figure 1 by three white blocks. Barges have to pass one of the three available lock systems to sail between cluster 1 and cluster 2. With the construction of a new dock (Deurganckdok) in the port of Antwerp, a third cluster of sea terminals emerged on the left river bank. Inland barges spend time in the port area, calling at multiple sea terminals and passing through the time-consuming locks.

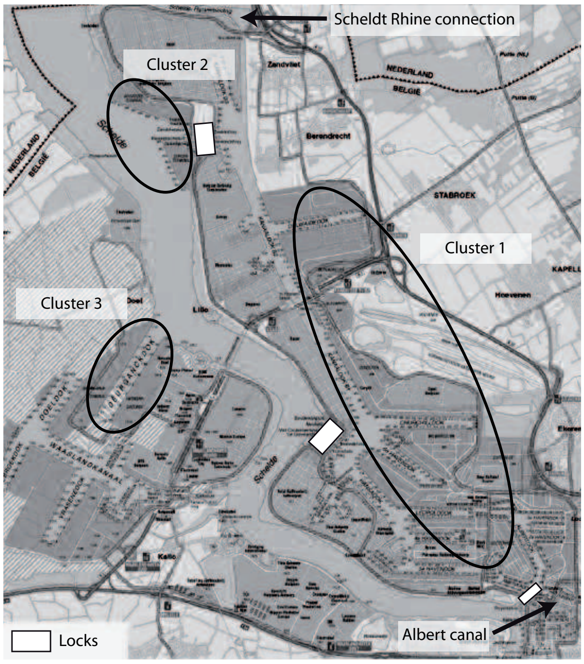

Figure 1: Port area of Antwerp (Adapted from Port of Antwerp)

In the analysis of alternative bundling networks, clusters are defined as all sea terminals at the same side of the three lock systems. Cluster 2 and cluster 3 are both situated on the left of the locks, directly accessible from the sea side through the river Scheldt. Therefore, these clusters are jointly referred to as 'left river bank'. Cluster 1 will be referred to as 'right river bank'. Inland vessels have to pass through a lock in the port area to sail from cluster 1 behind the locks on the right river bank to the sea terminals at the river Scheldt or on the left river bank in the Deurganckdok. Inland barges coming from the Albert canal have direct access to sea terminals on the right river bank in cluster 1 without having to pass through a lock system. Barges may also sail through the Scheldt-Rhine connection to Rotterdam and Amsterdam.

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. A structural overview of the current network figuration, as assumed in the further analysis, is presented in figure 2. All inland terminals along each waterway axis that are included in the simulation model are mentioned. Three regions of origin can be identified in the Belgian hinterland network of the port of Antwerp: the basin of the Upper Scheldt and the river Leie, the Brussels - Scheldt Sea Canal and the Albert Canal.

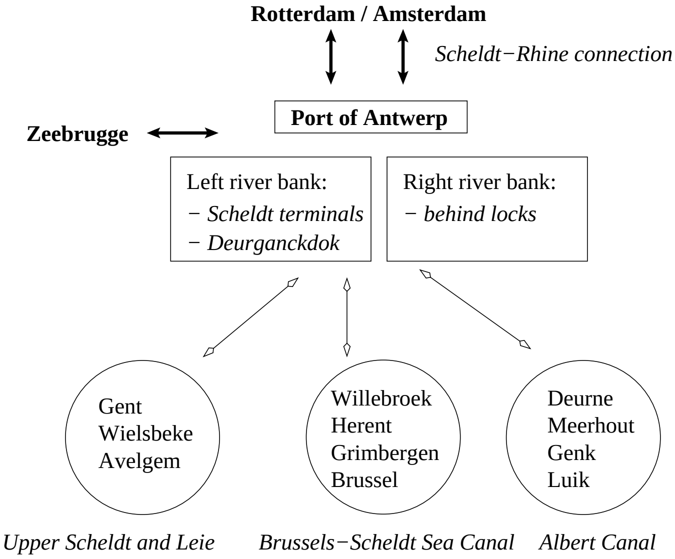

Figure 2: Current network configuration

Conceptual modelling

Three interrelated components can be identified in the intermodal hinterland network, as depicted in figure 3. 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. Barges originate from the different inland terminals and carry containers in round trips to the various ports. Barges are of multiple sizes and carry a variable number of containers, based on real data input from inland container terminals. All barges enter the port area and visit one or multiple sea terminals. This may result in a low number of containers loaded or unloaded during a terminal call. 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. When sailing from one cluster of sea terminals to the other, barges have to pass through one of the lock systems in the port area. Other port destinations are the port of Rotterdam or Amsterdam via the Scheldt-Rhine connection or the port of Zeebrugge via the Scheldt estuary. On the right and left river bank, barges queue for handling at the sea terminals. Service capacity at sea terminals is limited by the quay length for handling vessels. Maritime as well as inland vessels moor for loading or unloading containers at sea terminals. However, priority is given to seaborne vessels. Inland 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.

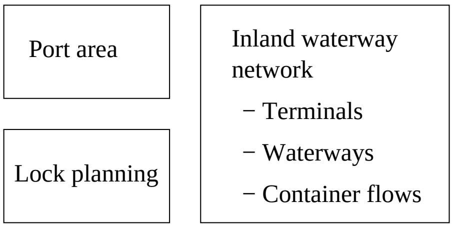

Figure 3: Components

Computerized modelling in Arena

This section describes how the conceptual model is translated into a computerized model in the simulation software Arena. The first subsection presents the general simulation approach. Next, assumptions underlying the simulation model are summarized. The following two subsections give an overview of inputs and outputs of the SIMBA model. Finally, the modelling of lockage operations and the calibration of the SIMBA model are discussed.

Discrete event simulation

In a discrete event system, one or more phenomena of interest change value or *state* at discrete points in time. These points in time are moments at which an *event* occurs. An event is defined as an instantaneous occurrence that may change the state of the system (Fishman (2001); Law (2007)). The players or *entities* in our discrete event simulation model are barges which sail through the waterway network. The simulation model is constructed in Arena, a simulation software based on queuing theory. Entities are defined as barges which originate from each inland terminal. Barges queue for handling at locks along waterway connections. Locks may be considered as a first group of service facilities in the network. Opening hours of locks are introduced in the simulation software as schedules for the availability of resources. Barges are collected in batches to go through the lockage process. After lock passage, batches are split into the original entities. When arriving in the port area, barges queue for handling at the quays of sea terminals. A second group of service facilities are thus the quays in the port area. The concept of shared queues is applied to model queueing at sea terminals throughout the model logic. Figure 4 depicts the flow of entities through the simulation model.

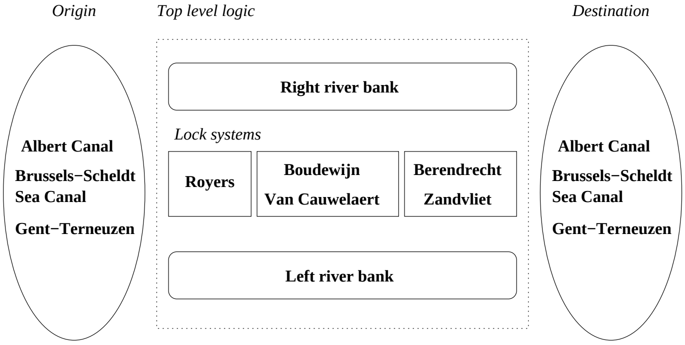

Figure 4: Flow of entities through the simulation model

The top level logic represents the port area. The model logic describes the two clusters of sea terminals on the right and left river bank, separated by three lock systems. Locks are constructed in separate submodels. Submodels are also applied for the three regions of origin in the hinterland network, namely the Albert Canal, the Brussels-Scheldt Sea Canal and the canal Gent-Terneuzen. Barges originating in the western part of the hinterland may sail through the canal Gent-Terneuzen and the Scheldt estuary to the port of Antwerp. After visiting all required terminals in the port area, barges return to their inland terminal and leave the simulation system. Stations and Route modules are introduced to keep the simulation model manageable. Examples of state variables in this discrete event system are the status of the servers (idle or busy), the number of barges waiting in a queue for handling at a lock or the time of arrival of a barge waiting in a queue for handling at a sea terminal. Events are for example the completion of service of a barge at a lock or the arrival of a barge at a sea terminal.

Assumptions

A number of assumptions are made to translate the conceptual model of the 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. 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. Pre- and end-haulage by road is also not incorporated.

In the first group of service facilities, the stochastic lockage times are represented by a triangular distribution. Sailing times on the network connections are assumed to be stochastic and also follow a triangular distribution. The arrival process of barges is based on real data input collected from the inland terminals, the waterway operators and the port authority.

The second group of service facilities consists of the quays at sea terminals. A fixed quay length is assumed for handling inland barges at each sea terminal. In reality the layout of sea terminals is aimed at handling seagoing vessels. In the port of Antwerp no dedicated quay sides are provided for inland navigation. Inland barges are handled with the same infrastructure and equipment and priority is given to handling seagoing vessels. However, no data is available on the arrival pattern and length of maritime vessels at the sea terminals. Therefore maritime vessels are not introduced into the simulation when modelling the handling at sea terminals. Instead, a given percentage of total available quay length is assigned to serving inland barges. In order to take the variability in available quay length into account, the handling of barges is modelled as a stochastic process. The handling of inland barges consists of mooring and loading or unloading containers. Both elements are modelled stochastically. The model further assumes a homogeneous container type. The same probability distribution is used for modelling the handling time of each container.

The variance-reduction technique of common random numbers is applied to synchronize various scenarios. A separate random number stream is assigned to each source of randomness. The basic idea is to compare alternative bundling networks under similar experimental conditions so that observed differences are due to differences in the system configuration rather than to fluctuations of the experimental conditions (Law (2007)). A stream of random numbers is dedicated to the lockage times, sailing times, handling times at terminals and choice of lock in the port area.

Data Requirements

All intermodal terminals in the inland waterway network are asked for information to identify current container flows in the network. Real data on shuttle services is used as an input for the simulation model. 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. Table 1 lists the attributes of each barge entering the network. In the second column an example is given. The simulation is run over 28 days or 672 hours. In this example a barge arrives in the simulation system at 16.43 hours, meaning it departs from the inland terminal Genk and sails to the port area of Antwerp. The barge has a width of 11.5 metres and a length of a hundred metres, leading to a surface area of 1150 m^2. In the port area first the cluster of sea terminals on the right river bank is visited. 57 containers need handling (loading or unloading) at two sea terminals. Next, the barge moors at four sea terminals on the left river bank and requires handling of 85 containers.

Attribute	Example
Departure time	16.43
Origin	Genk
Destination1	Antwerp: right river bank
Destination2	Antwerp: left river bank
Surface area	1150 m^2
Width	11.5 m
Length	100 m
Nb terminals right river bank	2
Nb handlings right river bank	57
Nb terminals left river bank	4
Nb handlings left river bank	85

Table 1: Entity attributes

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 provided the average mooring time and time for loading and unloading in order to model service times of inland container barges in the port area. Service times in the port area include the time for mooring at each sea terminal plus the handling time of all import and export containers.

Performance measures

The simulation model allows to quantify a number of network properties resulting from the interaction of freight flows. Table 2 gives an overview of performance measures which are generated by the SIMBA 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. Other performance measures can be added to the simulation model when necessary for future analyses.

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

Table 2: Performance measures

Lockage process

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, as depicted in figure 5. Barges are assigned to a lock chamber only if its size is within the allowed dimensions. The second decision rule assigns barges to the lock chamber with the smallest number of barges in queue. Thirdly, when no barges are waiting or an equal number of barges are queueing in front of each lock chamber, 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 served simultaneously. A final decision rule is applied when in the latter case 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 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. For example, Ting and Schonfeld (1996) propose heuristic methods for the sequencing of vessels through locks, including locks with two dissimilar chambers. Theunissen and Janssens (2005) formulate a heuristic algorithm for the placement of inland vessels in a lock, with the aim to place as many vessels as possible from the arrival queue.

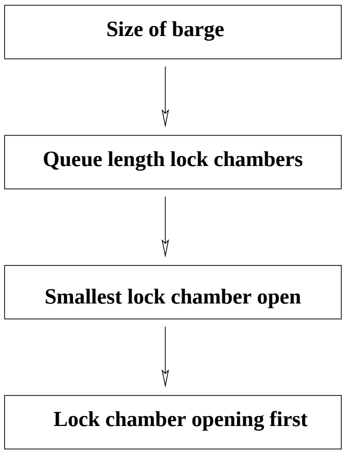

Figure 5: Decision rules for the assignment of barges to lock chambers

Calibration

Parameter settings for the description of locks are based on data input from the waterway operators. As an example, the parameter settings of the locks along the Albert Canal are described. Six lock systems are constructed on the Albert Canal, each consisting of two lock chambers for vessels up to 2000 tonnes and a third, larger lock chamber for push-towing. The standard service time for the first two lock chambers equals 45 minutes and for the third lock chamber 50 minutes. The standard service time is defined by the waterway operator as the maximum time in normal circumstances between arrival at 500 metres distance from the lock system and opening of the lock chamber to leave the lock system. This includes waiting until the lock chamber opens, sailing into the lock chamber and lockage time, but excludes sailing out of the lock chamber. From the data on lock passages provided by the waterway operator, an estimation could be made of the lockage times. For the two smaller lock chambers a triangular distribution is chosen with a mode of 16 minutes and a minimum and maximum of 12 to 20 minutes. The lockage time of the larger lock chamber is modelled with a triangular distribution with a mode of 18 minutes and a minimum and maximum of 16 to 20 minutes. The distance between locks is used together with an average speed of 10 km per hour to determine the average sailing time between locks.

The parameter setting in the port area is based on data provided by the port authority. The mooring and unmooring of barges takes 10 to 14 minutes, with a mode of 12 minutes. The loading or unloading of a single container when the inland barge has moored, is assumed to take 2.5 minutes and varies between 2 to 3 minutes. The choice of locks is modelled with a discrete distribution for each combination of origin and destination in the port area. The same parameter settings for sailing times, lockage times and service times in the port area are made in all simulation scenarios in the following section.

During the DSSITP project, progress was regularly reported to a follow-up committee. This committee consisted of various stakeholders from the freight transport field, including waterway operators, railway operators, the Belgian railway infrastructure manager, terminal operators, the road haulage federation and the port authority. These follow-up committee meetings enabled a first verification of the model. Next, an enquiry is made into the turnaround times of vessels in order to verify the model. Table 3 summarizes transit times expressed in hours for sailing one way to the ports of Antwerp, Rotterdam and Amsterdam, as reported by the inland terminals. Some terminals mention a time interval, for example sailing from the terminal in Meerhout to the port of Antwerp may take six to eight hours. The data is based on the experience and general knowledge of inland terminal operators. Table 4 reports on the average transit times expressed in hours in the simulation model from the inland terminals to the entry point in the port area without lock passage. The transit times to the ports of Rotterdam and Amsterdam represent an inland barge sailing directly from the inland terminal to this port. As sailing times and lockage times are stochastic processes, individual transit times of vessels may deviate from the reported averages. Differences between the reported transit times of terminal operators and transit times in the simulation model may depend on the final point assumed in the port area. Furthemore, terminal operators may assume a combination of port visits. When looking at table 3, differences are also observed between estimates of various terminals. However, table 4 shows that transit times in the simulation model represent the estimates of the terminal operators.

Terminal	Antwerp	Rotterdam	Amsterdam
Deurne	3	12	
Meerhout	6-8	14-16	16-20
Genk	10-12	19-22	
Luik	14		
Gent	5-6	13	
Wielsbeke	12	18	
Avelgem	15	18	
Willebroek	4	14	
Grimbergen	5	15	
Brussel	5-6	19-20	
Herent	6		

Table 3: One way transit times (hours) - terminal operators

Finally, results of various simulation scenarios, reported in the following section, were presented and discussed with the port authority of Antwerp.

Terminal	Antwerp	Rotterdam	Amsterdam
Deurne	1.7	10.3	
Meerhout	6.6	15.2	19.2
Genk	11.9	20.5	
Luik	15.9		
Gent	6.0	14.4	
Wielsbeke	11.8	20.2	
Avelgem	15.9	21.5	
Willebroek	3.2	11.9	
Grimbergen	6.5	15.2	
Brussel	7.5	16.2	
Herent	7.3		

Table 4: One way transit times (hours) - SIMBA

ANALYSIS OF BUNDLING NETWORKS

In this section the SIMBA model is applied to investigate bundling concepts which may contribute to the improvement of intermodal barge operations. When looking at opportunities for consolidation in intermodal barge transport, two options can be discriminated. Freight may be bundled in the port area or in the hinterland of a sea port. A comparison is made between the current situation (**Current**) and these two bundling ideas by means of the SIMBA model.

First, consolidation of freight flows may be realised by providing a hub in the port area, from which cargo is distributed to the different sea terminals. Konings (2007) proposes to uncouple the collection and distribution services in the port area from the trunk haul services to the hinterland. By doing so inland barges do not have to call at multiple sea terminals. They only visit a hub in the port area. 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. In Caris et al. (2010b) the SIMBA model is applied to analyze four implementation scenarios of this bundling concept in the port of Antwerp. The most interesting scenario involves the provision of two hubs in the port area, one in each cluster of sea terminals at one side of the three lock systems. Inland barges only visit a single hub for which they do not have to pass through a lock system. The collection/distribution network is organized jointly for the two hubs. This hub scenario in the port area (**Port**) is the first bundling network reported in subsequent tables.

Second, economies of scale may be achieved by bundling load of different inland terminals destined to the same sea terminal. Inland terminals may cooperate with the objective to create denser freight flows. In Caris et al. (2010a) cooperation between intermodal barge terminals in a hinterland network is analyzed from a network design perspective. The hinterland network is studied as a whole to see whether or not inland terminals in the network should cooperate in a corridor network. The methodology is applied to the hinterland network of inland barge terminals in Belgium. Next, selected cooperation schemes in the hinterland (**Hinter**) constitute the second bundling network simulated with the SIMBA model in tables 5 to 7. Table 5 gives the turnaround times of inland vessels, expressed in hours.

Table 5: Average turnaround times of inland terminals (in hours)

Avg turnaround time	**Current**	**Port**	**Hinter**
Deurne - Antw	15.20	9.16	33.07
	(0.47)	(0.14)	(0.33)
Deurne - Antw/Rdam	22.08	22.73	22.01
	(0.89)	(0.51)	(0.15)
Meerhout - Antw	29.24	25.64	35.06
	(0.47)	(0.39)	(0.54)
Meerhout - Antw/Rdam/Adam	41.70	38.84	42.44
	(0.38)	(0.59)	(0.48)
Genk - Antw	38.97	35.85	53.36
	(0.62)	(0.67)	(0.30)
Genk - Antw/Rdam	49.89	47.28	50.26
	(0.87)	(0.29)	(0.71)
Luik - Antw	46.46	41.90	59.68
	(0.34)	(0.23)	(0.40)
Gent - Antw	20.62	14.73	33.39
	(0.49)	(0.20)	(0.56)
Wielsbeke - Antw	38.62	28.77	40.22
	(0.42)	(0.24)	(0.37)
Avelgem - Antw	41.19	35.30	40.93
	(0.88)	(0.51)	(1.16)
Avelgem - Antw/Rdam	62.69	62.79	62.52
	(0.48)	(0.31)	(0.17)
Willebroek - Antw	14.79	11.45	23.06
	(0.17)	(0.07)	(0.16)
Willebroek - Antw/Rdam	35.59	35.81	35.37
	(0.39)	(0.25)	(0.22)
Grimbergen - Antw	20.93	16.55	32.59
	(0.21)	(0.08)	(0.28)
Brussel - Antw	21.91	19.03	33.59
	(0.34)	(0.17)	(0.28)
Brussel - Antw/Rdam	40.94	41.30	40.69
	(0.29)	(0.38)	(0.40)
Herent - Antw	21.91	18.75	21.85
	(0.19)	(0.08)	(0.20)

Inland vessels may only sail to Antwerp (Antw) or they can make a combined trip to Antwerp and Rotterdam (Rdam) or Amsterdam (Adam). Standard deviations are mentioned in brackets below the average turnaround times. In the hub scenario in the port area turnaround times of all inland terminals are significantly reduced. This reduction is explained by the fact that inland vessels only call at one hub and do not pass through any lock system in the port area. Results show that terminals involved in a corridor network in the hinterland have to take a longer turnaround time into account. The impact on turnaround times is larger as more terminals are involved.

Table 6 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 and at the two hubs in the port area. Secondly, the average and maximum utilization of the quays on the right and left river bank and at the hubs are measured.

Table 6: Performance measures in the port area: current situation and intermodal barge hub right river bank

Port area	**Current**	**Port**	**Hinter**
Avg waiting time (in hours)			
Right river bank	0.0629	0.0000	0.0159
	(0.0306)	(0.0000)	(0.0117)
Left river bank	0.0557	0.0000	0.0255
	(0.0115)	(0.0000)	(0.0166)
Hub right	/	0.1352	/
		(0.0372)	
Hub left	/	0.0572	/
		(0.0088)	
Max waiting time (in hours)			
Right river bank	7.6128	0.0000	2.2597
Left river bank	4.3095	0.0000	5.1275
Hub right	/	8.1493	/
Hub left	/	2.7953	/
Avg capacity utilization			
Quay right river bank	0.1666	0.1583	0.1852
	(0.0017)	(0.0015)	(0.0019)
Quay left river bank	0.1741	0.1691	0.1997
	(0.0017)	(0.0018)	(0.0021)
Quay hub right	/	0.2050	/
		(0.0026)	
Quay hub left	/	0.1579	/
		(0.0011)	
Max capacity utilization			
Quay right river bank	0.9834	0.8696	0.9834
Quay left river bank	0.9850	0.5985	0.9850
Quay hub right	/	0.9660	/
Quay hub left	/	0.9100	/

Table 6 reveals that at peak moments the maximum capacity utilization in the hub scenario in the port area decreases by 38.65% on the left river bank and by 11.38% on the right river bank. Less quay length is necessary

to handle inland containers at peak hours. In the hinterland scenario less efficiency gains are recorded at sea terminals as in the hub scenario in the port area. At a hub in the port area freight is bundled of all terminals in the hinterland network, whereas in a hinterland cooperation network freight is only bundled of two to three terminals.
In table 6 the maximum waiting time over the ten simulation runs is mentioned. More details on the maximum waiting time before handling in the port area in each of the ten simulation runs may be found in table 7. Cooperation between terminals in the hinterland offers an opportunity to reduce maximum waiting times of inland barges at sea terminals.

Run	**Current**		**Port**		**Hinter**	
	Right	Left	Hub right	Hub left	Right	Left
1	3.60	3.33	3.18	2.80	1.15	1.76
2	7.61	4.07	2.31	2.52	0.57	3.49
3	2.71	4.31	2.48	1.93	2.21	1.02
4	3.72	3.81	2.86	1.94	1.21	0.54
5	3.88	3.12	3.52	2.62	0.00	1.43
6	4.74	4.15	3.60	1.54	2.06	1.13
7	2.88	3.34	8.15	1.75	2.26	5.13
8	3.50	1.30	4.00	1.89	0.54	0.46
9	3.48	3.31	3.43	1.77	1.48	1.37
10	2.09	4.17	6.32	2.05	0.90	1.53

Table 7: Maximum waiting times in port area

CONCLUSIONS AND FUTURE RESEARCH

In this paper the modelling process is presented of a discrete event simulation model for an intermodal barge transport network. The model is constructed to make a quantitative ex-ante analysis of policy measures to stimulate intermodal barge transport and is part of a larger decision support system for intermodal barge transport. The simulation model is applied to analyse opportunities of bundling freight flows in the port area and along the same river axis in the hinterland. In this study the main focus is on the inland waterway network. Potential extensions to the simulation model include the introduction of rail connections and the addition of a submodel to integrate intermodal terminal planning. The SIMBA model is also suited for other analyses, such as assessing the network wide impact of more complex decision rules for the operations of locks, the introduction of new intermodal barge terminals in the network or analyzing the consequences of growth scenarios on the network capacity.

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