Modelling and optimising the inland waterway network in Belgium

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Abstract

In this paper the main idea of my PhD research is described. We aim to analyze the operational performance of intermodal networks including inland navigation. The intermodal hinterland network of the port of Antwerp serves as the real-world application in our study. Characteristics of the inland waterway network in Belgium are discussed. From this description our research objectives are further formulated. The research methodology comprises three phases. The first phase of the research aims at gaining an insight into modelling techniques in the field of operations research applicable to intermodal transport. The second phase consists of designing a discrete event simulation model of traffic in the port of Antwerp and its hinterland terminals in Belgium. This model will be used to analyze the consequences of various policies intended to improve the efficiency of barge transport. In a third phase we intend to investigate whether a central planning of containers on barge leads to efficiency improvements in the intermodal network. An overview of existing planning models for intermodal networks is given in order to position our research in scientific literature. Finally, expected results are formulated.

1. Introduction

In recent years intermodal transport has received an increased attention due to problems of road congestion, environmental concerns and traffic safety. A growing recognition of the strategic importance of speed and agility in the supply chain is forcing firms to reconsider traditional logistic services. As a consequence, research interest in intermodal freight transportation problems is growing. 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 types of transport modes. Many research efforts have been focused on intermodal rail transport. An overview of intermodal rail-truck freight transport literature can be found in Bontekoning, Macharis and Trip (2004). Conversely, only few papers have appeared on intermodal freight transport including inland navigation. This is the focus of our research.

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. In the port of Antwerp a modal shift towards inland navigation is observed in recent years. The share of barge transport in the modal split of the port of Antwerp amounted to 32% in 2004. As transport volumes are expected to 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. Figure 1 shows the resulting intermodal transport chain. De Langen and Chouly (2004) think of the improvement of hinterland access as a collective action problem, which requires coordination between actors. Inter-organisational coalitions are necessary to invest in hinterland transport services.

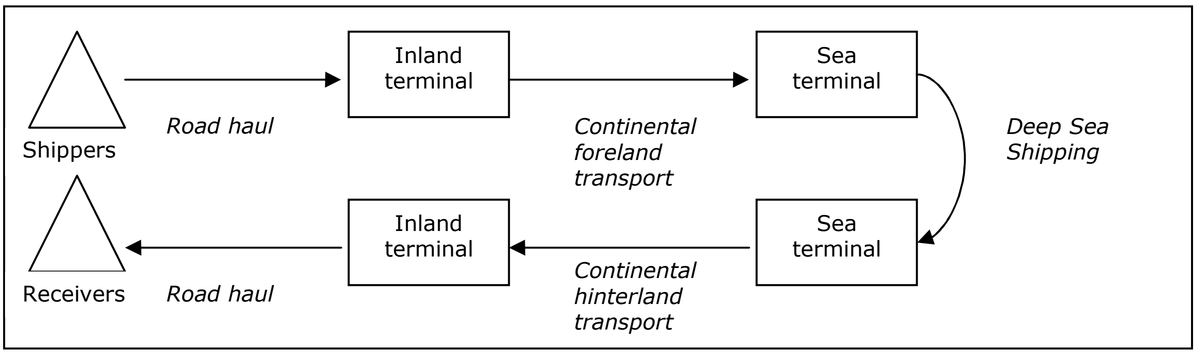

Figure 1: Intermodal transport chain

We aim to analyze the operational performance of intermodal networks including inland navigation. The intermodal hinterland network of the port of Antwerp serves as the real-world application in our study. The paper is organized as follows. Section 2 describes the characteristics of the real-world application. This description is based on interviews with various practical experts and relevant literature. In Section 3 the object of our research is further specified. Section 4 presents the research methodology. Section 5 gives an overview of existing planning models for intermodal networks. Finally, expected results are indicated in section 6 .

2. Characteristics of hinterland services of the port of Antwerp

The share of inland navigation in the modal split of the port of Antwerp was 32% for container traffic in 2004 (Macharis, Verbeke: 2004). This relatively high market share is due to the availability of an extensive waterway network in the hinterland of the port of Antwerp. The network also gives access to other European countries in which barge transport plays an important role. Three main market segments for barge container transport to and from Antwerp can be distinguished. First, feeder transport of containers between Antwerp and Rotterdam comprises the largest part of the intermodal transport by barge. About 1,000,000 TEU (Twenty-foot-Equivalent-Unit) was transported by barge between both ports in 2004. Second, the Rhine river trade stands for 700,000 TEU transported to and from inland destinations along the Rhine in 2004. A third market segment consists of the transport of containers to and from inland container terminals in Belgium. In 2004 about 275,000 containers were transported in domestic trade. Figure 2 shows the major market segments of transported TEU by barge in Flanders in 2004. Barge operators carried in total 2,500,000 TEU in Flanders. The major part (2,330,000 TEU) has either its origin or its destination in the port of Antwerp. The remainder mainly concerns transport of containers between Flemish inland terminals and Rotterdam. Less then 2% of the amount of TEU transported in Flanders has neither Antwerp nor Rotterdam as origin or destination.

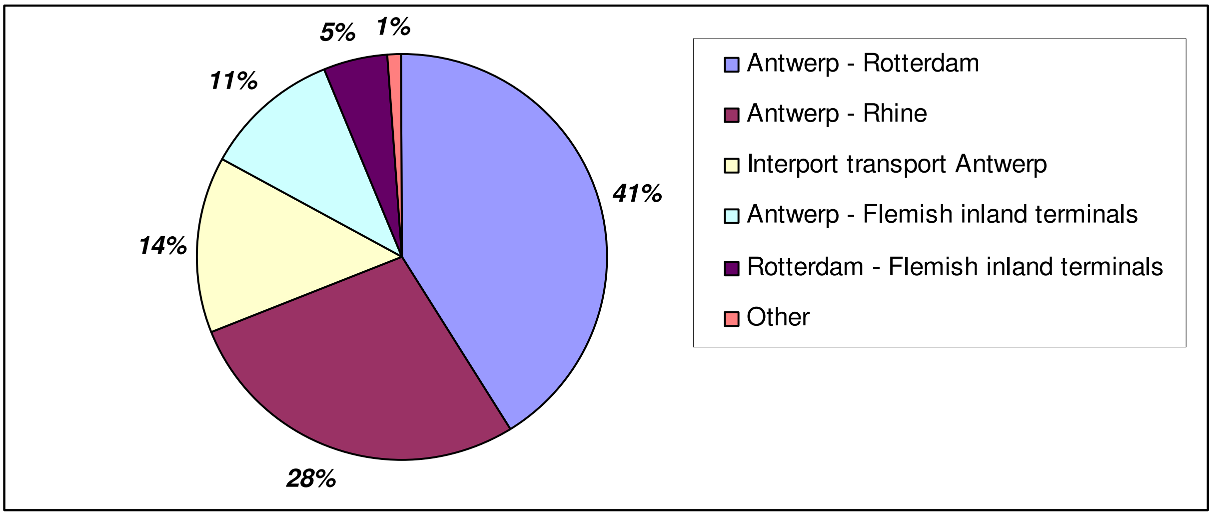

Figure 2: Market segments of inland navigation in Flanders (Promotie Binnenvaart Vlaanderen)

Other arguments in favour of inland navigation are its environmental friendly character and low transport costs. A disadvantage is the handling cost of the two extra movements necessary to load and unload containers on barge. Handling costs at a sea terminal are higher for inland navigation compared to road transport. Also a higher initial investment in handling material is needed. Containers are placed on trucks by means of a straddle carrier. A gantry crane is mostly used to put containers on barge. On the other hand, capital costs per container move are lower for a crane than for a straddle carrier. The number of moves which can be executed in a shift by a gantry crane are about the triple of the number executed by a straddle carrier. (Promotie Binnenvaart Vlaanderen)

2.1 Inland waterway network structure

The structure of the inland waterway network consists of three main axes, parallel to the three main motorways to Antwerp. The first axis is made up of the Albert canal which is an alternative for the motorway E313. Second the Upper-Sea Scheldt connects Ghent to Antwerp, as also does the motorway E17. A third axis is formed by the Sea canal Brussels - Scheldt which parallels the motorway E19. Figure 3 depicts the structure of the waterway network in Belgium.
Because of the considerable growth in inland navigation a recent study has been made of the capacity of waterways in Flanders under the authority of the Administration of Waterways and Marine (AWZ: 2003). Two scenarios are developed to forecast demand. A trend scenario predicts growth rates for each waterway based on the development of transhipment in sea ports and the development of inland barge transport. Historical elasticities are applied to derive the relative growth of inland navigation from the maritime transhipment in sea ports. A second scenario takes into account an additional growth due to future policies and campaigns to stimulate inland navigation. In addition, three elements augment inland transport by barge and are included in the demand forecasts: the construction of a new dock (Deurganckdok) in the port of Antwerp, a government program to stimulate the construction of quaysides and an improved connection between the rivers Scheldt and Seine. Next, accessibility of waterways and capacity of locks and bridges are analyzed. Nineteen measures necessary to make the predicted growth in inland navigation feasible are indicated. For example the bridges across the Albert canal need to be raised to at least 9.10 meters, coordination between various locks in the port area of Antwerp needs to be analyzed and a better distribution of arrivals at the lock of Evergem, near Ghent, needs to be realised.

2.2 Inland container terminals

Figure 3 shows all locations of barge container terminals in Belgium. Macharis and Verbeke (2004) give a description of existing inland container terminals and future initiatives. A recent government program subsidizes private companies to construct quaysides in order to stimulate transport of containers by barge. Terminal operators fear that this might lead to a proliferation of container terminals. However, the current number of private initiatives is limited and private companies usually book their containers on existing barge services instead of chartering a ship on their own.

Inland terminals apply a new logistic concept in order to attract customers. As well as offering transport of containers, the terminals also function as container depot. Containers are picked up or delivered at a customer location in a time window specified by the customer. Inland container terminals conclude contracts with shipping companies to function as depot for empty containers. Consequently empty containers do not have to be supplied to inland terminals or returned to sea terminals. By shipping only loaded containers as much as possible, total costs of barge transport can be reduced significantly. The problem of returning or receiving empty containers is referred to in literature as 'empty balancing'. It should be interpreted in the international context of sea shipping companies. These companies prefer to work with their own containers, displaying their name in large characters for commercial reasons.

Figure 3: Seaports and inland waterway terminals in Belgium (http://www.containerafvaarten.be)

2.3 Network configuration

In Belgium inland terminals are connected by shuttle services on a regular basis to the ports of Antwerp or Rotterdam. Barges visit only one or a limited number of terminals in the hinterland. As a consequence multiple terminals in the port area may have to be visited. This may also result in a low number of containers loaded or unloaded during a single terminal call. In the port of Antwerp two terminal clusters can be identified. Up to now handling of containers was mainly concentrated on the right river bank of the Scheldt. The construction of the Deurganckdok creates a new container terminal cluster on the left river bank. Barges will have to pass through a lock to go from one terminal cluster to the other.

In recent years waiting times of barges for container handling in the port of Antwerp have been increasing. Barges have to call at multiple terminals when visiting the port of Antwerp. Calling at several terminals may be a time-consuming process. The queue of barges waiting to be handled is substantial at peak periods. First, this is partly due to a limited capacity of labour forces, quaysides or cranes at sea terminals. However, the capacity of quaysides and cranes has significantly expanded through the construction of the Deurganckdok. Second, the layout of sea terminals is aimed at handling seagoing vessels. Inland barges are handled with the same infrastructure and equipment. Sea terminals give priority to handling seagoing vessels. The cost of a delay for sea-going vessels is much higher than for inland vessels. The priority of seagoing vessels may further increase waiting time of inland vessels. Moreover a delay at one terminal may result in missing the agreed time window for handling at a next terminal. Third, sea terminals only have a contractual commitment with sea shipping companies. No legal tie exists between barge operators and sea terminal operators. This places barge operators in a very weak negotiation position concerning service levels, modes of operation and handling charges. Due to the expected ongoing increase in container throughput in the port of Antwerp, the problem of congestion and waiting times for barges may become worse. Therefore container barge services need to be reorganised in order to stay competitive as transport mode. In the port of Rotterdam barge operators face the same problems, as described by Konings (2005).

A distinction has to be made between three ways of organising intermodal transport of goods. Carrier haulage involves the organisation of the entire door-to-door transport service by the sea shipping company. The carrier also organises hinterland-transport of containers. Merchant haulage stands for the organisation of the entire transport by the shipper or a forwarding agent. Recently a new system, Terminal Operated Haulage, has emerged. Sea terminal operators organise the entire transport service in order to obtain timely information on the final destination of a container. In this way they are able to sort containers by mode while unloading a sea ship. Terminal operators are convincing carriers to 'outsource' their haulage activities to them. This evolution may constitute a threat to the forwarding agents.

Inland container barges may operate more effectively through the cooperation between terminals in order to bundle containers with the same destination terminal. Less sea terminals will have to be visited and more handling operations are executed at a single terminal. A possible proliferation of inland terminals strengthens the need of cooperation between terminals in order to supply sufficient load to one sea terminal. The inland container terminal Water Container Terminal (WCT) in Meerhout already bundles its own load. The operator has negotiated fixed time slots at sea terminals. As a result waiting times in the port area are notably reduced. A requirement for an inland terminal to be able to bundle its own load is the availability of enough containers to consolidate. Inland terminals with smaller market segments can still consolidate their load by cooperating with other terminals on the same waterway axis. Smaller inland terminals may be unresponsive towards cooperation because of fear of domination by larger terminals. A stronger partner may direct the cooperation and plan barges in his advantage. Sea terminals can give incentives to barge operators to bundle load. Priority in handling or reduction in handling costs may be given to barges that require more container movements in one terminal call.

Waiting times in the port area may also be reduced by a central planning of barge handlings. The handling of barges at sea terminals of the operator Hessenoordnatie (HNN) is already planned as a whole. A barge operator can submit a request for handling two days in advance and receives a berth window one day before arrival at the sea terminal. However, time windows at other sea terminals are not taken into account. A central planning of barge handlings at all sea terminals may reduce waiting times and lead to a better routing of barges in the port area. This central planning can be disturbed by a slow passage through locks. Waterway administrators have to ensure a smooth passage through locks so that inland barges can maintain their schedule. However, when container barges are favoured at locks, problems may arise with transports of other goods by barge. A careful planning at critical locks so as to spread arrivals of barges may be necessary.

In order to meet the capacity requirements for handling inland navigation in the port of Antwerp in recent years dedicated nightshifts were introduced. For this aim a Mobility Fund was organised by the port authority, the Flemish government and terminal operators. Barges are handled during the night by a dedicated labour force and a dedicated crane at dedicated quaysides. This kind of subsidy was allowed by the European Union because of construction works on the ring road of Antwerp. The use of dedicated capacity resulted in a more effective handling of barges. The organisation for promotion of inland navigation (Promotie Binnenvaart Vlaanderen) proposes to continue with a similar handling system for barges after the road works have been completed.

Multiple parties are involved in the problem of waiting times of barges in the port of Antwerp. A better exchange of information between all parties involved could lead to a higher efficiency in container barge transport. Cooperation and joint efforts are necessary to improve the operations of inland navigation. Intermodal transport by barge can be seen as multi-actor chain management. Various organisations are involved, each controlling a part of the transport chain. This type of decentralised control does not prompt to taking private initiatives. The complete transportation chain should be regarded as one service and each party in this chain should strive for the same goal, delivering a transport service of high quality to customers.

3. Research objectives

Our objective is to analyse the operational performance of intermodal networks including inland navigation. The intermodal transport chain contains several actors who are responsible only for one part of the chain and who operate independently. An increased level of coordination is necessary to improve the intermodal transport flow. In our analysis we aim to demonstrate the advantages of cooperation between actors (such as different intermodal terminals) and optimise the network of operators as a whole. To guide our research the following questions need to be answered.

3.1 Which bundling concepts need to be investigated?

Which bundling concepts can contribute to the improvement of operations of intermodal barge transport in Belgium? Kreutzberger (2005) argues that the design of a service network depends on the interaction between the following four design variables: network volume, transportation vehicle scale, frequency of service and network concentration (or the number of begin- and end-terminals in the network). Network volumes sometimes may be insufficient to run a direct service from origin to destination on the desired frequency level. In this instance scale advantages can only be achieved by reducing frequency of service, increasing concentration of the network or introducing complex bundling. The author discusses alternative bundling networks in intermodal rail transport. Figure 4 depicts two main complex bundling network types, a hub-and spoke (HS) network and a trunk-collection-and-distribution (TCD) network.

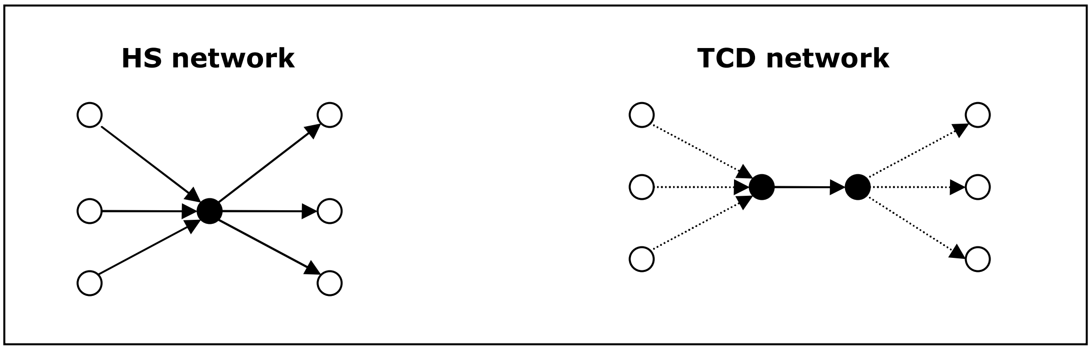

Figure 4: Two complex bundling network types (Kreutzberger: 2005)

In Belgium inland barge terminal operators transport load of various customers to multiple sea terminals in the port of Antwerp. Scale advantages may be achieved by bundling load of different inland terminals destined to the same sea terminal. Containers of inland terminals along the same waterway may be first collected and then transported in a trunk line to the same sea terminal. Another form of consolidation can be realised by providing a hub in the port of Antwerp, from which load is distributed to the different sea terminals. This idea is further elaborated in the following section.

3.2 What are the effects of an intermodal barge hub in the port of Antwerp?

Konings (2005) proposes to split existing barge services into a trunk-line operation in the hinterland and collection/distribution operations in the seaport. By doing so the turnaround time of vessels serving the hinterland can be reduced. This may lead to a higher productivity because of an increased frequency of service or an increased number of containers transported. 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. These revised services are feasible if the feeder costs can be sufficiently compensated by savings in hinterland transport. The author defines three basic models for organising the collection/distribution operations. First, in a 'Container Exchange Point' service model all barges call at one terminal. Here containers are transhipped to other vessels operating in the port. The potential improvement in turnaround time of vessels in hinterland traffic and the economies of scale and scope in the feeder service are maximal. A disadvantage is that every container requires an additional handling operation, which leads to high transhipment costs. A nearby inland terminal can be considered as a potential location for this Container Exchange Point. Second, a 'Barge Service Centre' service model assumes that hinterland vessels call at a limited number of sea terminals for which they have a large number of containers. Small container batches for other terminals are brought to a Barge Service

Centre, which bundles these smaller collection/distribution flows. In this model the savings in turnaround time will be smaller, but also the operational costs of collection/distribution transport are lower. Third, in a 'multi hub' service model hinterland barges call directly at terminals for which the call size is sufficiently large, but collection/distribution of small container batches takes place locally. This decentralized process offers less opportunities for economies of scale and scope in collection/distribution transport, but transport distances are smaller and the model is more flexible to use. The three models are compared on the basis of a marginal cost model, in which the author makes assumptions about potential costs and benefits. He further identifies opportunities and threats for implementing a split of the container barge service. An important barrier for implementation might be that barge operators may have doubts about the possibilities to capitalize the time savings in the port.

3.3 Will a central planning of containers on barge lead to efficiency improvements in the intermodal network?

A central planning of containers on barge may give an idea of the potential benefits of increased cooperation between intermodal terminals. A barge can pickup containers with the same destination at various terminals. The consolidation of containers for the same sea terminal may reduce waiting times in the port area and enables intermodal operators to offer a higher frequency of departures to customers.

Newman and Yano (2000) compare a variety of decentralized planning approaches with a centralized approach for scheduling trains in an intermodal network. The authors simultaneously determine an explicit direct and indirect train schedule and corresponding container routing decisions. The problem is formulated as an integer program and decomposed into a number of sub-problems. Their decentralized scheduling approaches lead to near-optimal solutions within significantly less computational time than the centralized approach. An investigation can be made into whether the same conclusion holds for intermodal transport by barge.

3.4 What are the consequences of increasing transport volumes on the hinterland network of the port of Antwerp?

The port authority of Antwerp aims to increase the share of inland navigation in the modal split for container transport from 32% to 40% in 2030. This implies that barge transport has to achieve an additional growth on top of the expected growth in shipping volumes in Antwerp. We want to examine the effects of these increasing transport volumes on the operations of inland navigation.

4. Research methodology

The *first* phase of the research aims at gaining an insight into modelling techniques in operations research applicable to intermodal transport. To this end a general literature study on the state of the art intermodal transport research is performed. An overview of planning models for intermodal transport is given in section 5.

Formulations of network planning problems can be classified into two groups: network simulation models and network optimization models. According to Crainic and Laporte (1997), the main limitation of simulation is its inability to generate new operating strategies that would incorporate a network-wide analysis of their impact and the evaluation of a number of apparently conflicting objectives. Network optimization models, on the other hand, are less detailed but offer the advantage of fast generation, evaluation and selection of integrated, network-wide operating strategies with respect to some objective function. Many planning problems in intermodal transport are complex and therefore difficult to solve. Interesting perspectives are offered by metaheuristics in addressing complex planning problems. Law and Kelton (2000) argue that in some studies both simulation and analytic models might be useful. In particular, simulation can be used to check the validity of assumptions needed in an analytic model. On the other hand, an analytic model can suggest reasonable alternatives to investigate in a simulation study. We intend to apply both simulation and optimization models.

The *second* phase consists of designing a discrete event simulation model of traffic in the port of Antwerp and its hinterland terminals in Belgium. This model will be used to analyze the consequences of various policies intended to improve the efficiency of barge transport. A potential policy is the introduction of an intermodal barge hub in the port of Antwerp, as described in section 3.2. We aim to investigate whether this policy is operationally effective and yields the expected time savings in the port area. Next, the simulation model may be used to identify bottlenecks in the network. Required capacity expansions may be deducted. Further, we want to examine the effect of increasing transport volumes in the port of Antwerp on the intermodal network. To this end various scenarios of transport demand are evaluated with the model.

In a *third* phase we investigate whether a central planning of containers on barge leads to efficiency improvements in the intermodal network. A centralized planning mechanism of containers on barges may give an idea of the potential benefits of an increased cooperation between intermodal terminals. A barge can pickup containers with a common destination at various terminals. The consolidation of containers for the same sea terminal may reduce waiting times in the port area and enables intermodal operators to offer a higher frequency of departures to customers. A combined simulation-optimization approach may be suitable as a solution method. A metaheuristic can be applied to generate solutions for the planning problem. A simulation model, as in the second phase, can serve as an 'objective function evaluator' to the metaheuristic to evaluate these planning solutions. Van Dijk et al. (2005) argue that a combined approach of simulation and operations research techniques can be beneficial. Simulation is generally used and known for evaluation purposes of process performance. Its application for optimization often remains limited to a simple comparison of scenarios or what-if analyses. However, simulation can be used in a more sophisticated way in combination with OR-techniques for optimization purposes.

5. Planning models for intermodal networks

In this section a literature review of existing models for intermodal freight transportation is given. The models described may deal with different modes of transport and different products, but the objective is to investigate whether any of these approaches can be applied to our research problem. Following Crainic and Laporte (1997), the planning models discussed in this section are categorized according to the three classical decision-making levels: strategic, tactical and operational.

5.1 Strategic models

Strategic planning typically involves large capital investments over long time horizons. Decisions at this planning level affect the design of the physical infrastructure network. In intermodal transport, location models help to determine the optimal location of a new intermodal terminal. Network design models are concerned with the configuration of the infrastructure network. Regional multimodal planning models consider the entire transportation system in a certain region, the products that use it, as well as the interaction between passenger travel and freight flows. The impact of infrastructure modifications, evolution of demand or government and industry policies is verified. (Crainic, Laporte: 1997)

Guélat, Florian and Crainic (1990) developed a model for predicting multicommodity freight flows over a multimodal network. The model supports strategic decision making at national or regional level. Origins and destinations correspond to relatively large geographical areas. Individual shippers and carriers are not identified explicitly, instead the model is intended for scenario comparisons when major investments are considered. The authors develop a network model that considers congestion effects. Demand for transportation services and mode choice are exogenous. A link of the multimodal network is defined by its origin and destination nodes and a single transportation mode. Parallel links are introduced between two adjacent nodes if more than one mode is available to transport goods between them. The flows of product *p* on the multimode network are the decision variables in the model. The total generalized cost of flows for all products over the multimode network is to be minimized over the set of flows which satisfy the transport demands, conservation of the flow and nonnegativity constraints. The model is also sufficiently flexible to represent the transport infrastructure of one carrier only.

5.2 Tactical models

Tactical planning aims to ensure an efficient and rational allocation and utilization of existing resources to improve the performance of the whole system. A key tactical problem in intermodal transport is the service network design problem. The service network design problem concerns the selection of routes on which services will be offered and the determination of the characteristics of each service, particularly their frequency. For each origin-destination pair a routing has to be specified. A decision needs to be made about the type of consolidation network. Empty balancing looks for an optimal repositioning of empty vehicles to meet forecast needs of the next planning period. Crew and motive power scheduling regards the allocation and repositioning of resources required by the selected transportation plan.

Crainic (2000) introduces a new classification of service network design problems, which emphasizes the functionality of the formulation rather than the transportation mode to which it is applied. The author distinguishes between *frequency* and *dynamic* service network design models. Frequency service network design models address strategic/tactical planning issues. These models concern questions such as: What type of service to offer? How often over the planning horizon to offer it? What traffic itineraries to operate? What are the appropriate terminal workloads and policies? Frequency service network design problems may be further classified according to the role service levels play in the formulation. Service frequencies can either be modelled as explicit integer decision variables or as output variables derived from traffic flows subject to lower bound constraints that represent minimum service levels. Dynamic service network design models have a more operational focus. These models are concerned with the planning of schedules and support decisions related to 'if' and 'when' services depart.

In general the frequency service network design model with service frequencies as decision variables is represented as a path-based formulation. The service network S specifies the transportation services that could be offered to satisfy the demand. A service $s \in S$ is defined by its route r_s through the physical network and an number of service characteristics, such as a terminal set comprising the origin, destination and intermediary terminals, mode of transport, speed, priority and capacity of the service. P represents the set of products to be transported through the network. L^p is the set of paths for product p. The vectors $\boldsymbol{y}$ and $\boldsymbol{h}$ contain the decision variables y_s and h_L^p respectively. The service frequencies y_s define the level of service offered, expressed as the number of times each service is run during the planning period. The variables h_L^p indicate the volume of product p moved by using its itinerary l. An itinerary l for product p specifies the physical route and the service path used to move the corresponding demand. Each product has a positive demand w^p. The model states that total generalized system costs have to be minimized, while satisfying the demand for transportation and the service standards:

Minimize

$$\sum_{s \in S} \psi_s(\boldsymbol{y}) + \sum_{p \in P} \sum_{l \in L^p} \Phi_l^p(\boldsymbol{y}, \boldsymbol{h}) + \Theta(\boldsymbol{y}, \boldsymbol{h}) \qquad (1)$$

subject to

$$\sum_{l \in L^p} h_l^p = w^p, \qquad p \in P \qquad (2)$$

$$y_s \geq 0 \text{ and integer}, \qquad s \in S \qquad (3)$$

$$h_l^p \geq 0, \qquad l \in L, p \in P \qquad (4)$$

In the objective function the following components can be identified:

$\psi_s(y)$: total cost of operating service *s*

$\Phi_l^p(y,h)$: total cost of moving freight of product *p* by using its itinerary *l*

$\Theta(y,h)$: penalty terms capturing relations and restrictions, e.g. limited service capacity

The first term in the objective function represents total fixed costs of offering the selected services. The second term describes total variable costs of using the network. The model states that total generalized system costs have to be minimized, while satisfying demand for transportation and service standards. Service quality can be measured as the delay incurred by transportation vehicles due to congestion and operational policies in terminals and in transit. The cost functions in the objective consist of two components, an operating cost and a delay cost. Most network design formulations are NP-hard and therefore difficult to solve. Crainic (2000) emphasizes the interesting perspectives offered by metaheuristics in addressing complex service network design problems.

A tactical model for identifying the best service network design is discussed by Warsing, Souza and Greis (2001). The authors study a network containing international air cargo operations and pre- and end-haulage by air, road or rail to and from global air cargo hubs. The benefits of a network of dedicated multimodal cargo facilities (DMCF) are examined. A DMCF is defined as a single facility at which a set of firms can locate production, assembly or warehousing operations in direct proximity to multimodal cargo handling and transfer facilities. The operational costs of a DMCF are compared with those of traditional passenger based airports. The authors investigate the effects of congestion at these transfer points in the network on the overall cost of operating the system. The problem is developed from the viewpoint of the shipper and consists of delivering products to customers at least cost, providing rapid delivery service using a limited number of delivery vehicles that are subject to queueing delays at their points of departure and arrival. Warsing et al. (2001) first describe a discrete optimization model of the problem, which is formulated as a large-scale, non-linear program. The waiting times at the transfer points in the network are calculated using a queueing approach. A multi-class *GI/G/c* queue is applied, in which 'customers' represent aircrafts to be loaded or unloaded, customer classes are aircraft types and servers are gates at the cargo facility. The non-linear model is very difficult to solve due to a large number of variables. The authors suggest an iterative procedure to solve the problem approximately. A numerical example demonstrates that significant cost savings can result from using dedicated multimodal cargo facilities.

Lin and Cheng (2004) study a network design problem of a door-to-door express service. An air-ground intermodal carrier provides a delivery service in a hierarchical hub-and-spoke network. The network consists of multiple clusters. Local cluster centres are connected to their own hub through a secondary route. Each hub is connected to other hubs through a primary route. Large trucks or aircrafts are used on primary routes, smaller trucks or aircrafts on secondary routes. The problem is to determine fleet size, routes and schedules for both primary and secondary trucks or aircrafts simultaneously, with the objective to minimize the sum of fixed and operating costs while meeting the desired service level. The authors formulate the problem as an integer program in a routespace directed network. The binary program is solved through an implicit enumeration algorithm that contains an embedded least time path sub-problem.

Choong, Cole and Kutanoglu (2002) present a model for empty container management in intermodal transportation networks. The authors analyse the effect of planning horizon length on mode selection. Their hypothesis is that a longer planning horizon should lead to higher utilization of slower modes of transportation. Empty containers can be transported by barge at a very low cost. Within barge capacity limits, empty containers can be piggy-backed onto existing barge tows of loaded containers. However, a trade-off has to be made between the low transportation cost and the relatively slow speed of barge transport. The problem is formulated as an integer programming model that minimizes total cost of empty container management. The integer programming model is applied to a case study of the Mississippi River basin. The authors conclude that a longer planning horizon, used on a rolling basis, can give better empty container distribution plans for the earlier periods. A longer horizon encourages the use of slower cheaper transportation modes, such as barge transport, but the advantages might be small for a system that has a sufficient number of container pools. The impact of choosing a planning horizon that is too short depends on three conditions: the concentration of activities in the network, transit time of container movements and end-of-horizon effects. If the periods immediately following the short planning horizon are very active, a longer planning horizon might give a better solution. Also a system that has long transit times may need a longer planning horizon. A small end-of-horizon effect may reduce the significance of lengthening the planning horizon. The authors do not integrate loaded and empty container flow decisions in a single model.

5.3 Operational models

In operational planning the time factor plays an important role. The dynamic aspect of operations is further compounded by the stochasticity inherent in the system. Real-life operational management is characterized by uncertainty. Important operational decisions include the scheduling of services, empty vehicle distribution and repositioning, crew scheduling and allocation of resources. The main issues are similar to those at the tactical decision level. However, while tactical planning is concerned with 'where' and 'how' issues (selecting services of given types and traffic routes between spatial locations), operational planning is interested in 'when' issues (when to start a given service, when the vehicle arrives at destination or at an intermediary terminal, etc.).(Crainic, Laporte: 1997)

Powel and Carvalho (1998) developed a Logistic Queueing Network (LQN) methodology for solving dynamic fleet management problems. The authors consider the problem of managing a homogenous fleet of vehicles over time to serve a set of loads, with a known origin and destination and a specified time window. However, their formulation can be extended to include several equipment types or loads that use a sequence of links through intermediate terminals from origin to destination. The solution method starts with a linear programming formulation and is reformulated as a dynamic program. The general solution approach is based on a linear approximation of the dynamic programming formulation. A series of forward (to allocate vehicles) and backward (to evaluate vehicle values at nodes) passes are made until convergence is ensured. Powel and Carvalho (1998) state that their LQN algorithm achieves solutions that are generally within three percent of the optimal solution of the linear programming relaxation.

Ziliaskopoulos and Wardell (2000) discuss a shortest path algorithm for intermodal transportation networks. The authors introduce the concept of time dependency of optimal paths in their routing model. The time horizon is divided into discrete intervals. Also delays at switching points, fixed time schedules of transport modes and movement delays or movement prohibitions are taken into account. The algorithm computes optimal routes from all origins, departure times and modes to a destination node and final transport mode, accounting for the time-dependent nature of the arc travel times and delays occurred when switching transport mode, without explicitly expanding the network. The computational complexity of the algorithm is independent of the number of modes. An almost linear computational time with the number of nodes in the network and the number of time intervals is observed.

Erera, Morales and Savelsberg (2005) define an integrated model for routing and repositioning tank containers in an intermodal network. Traditionally the operational management of tank containers is decomposed into customer order planning decisions and repositioning decisions. The authors demonstrate that planning loaded and empty movements simultaneously can lead to significant cost benefits. The problem is formulated as a deterministic network flow model over a time-expanded network. A computational study verifies that integrated container management can substantially reduce empty repositioning costs. Moreover, the integrated model is able to produce a feasible schedule in an environment with less containers available. The model is able to fully exploit any routing flexibility offered by the service time windows for each customer order. This indicates that it may be beneficial for container operators to try to collaborate with their customers to obtain timely and accurate information about bookings. The results also indicate that it is worthwhile to make repositioning decisions on a daily, rather than weekly, basis. Imposing a lower bound on the repositioning quantity has relatively little impact on total costs.

Jansen et al. (2004) develop an operational planning system for a real-life application of Danzas Euronet. The authors also take repositioning aspects into account but planning and repositioning problems are not solved simultaneously. This is due to the large size of the practical case. The problem is decomposed into a number of sub-problems and solved in an iterative algorithmic approach, with the objective of minimizing total cost of transportation. First, modality choice is made and transport of orders by train is planned in a pre-processing step and is performed only once. Second, planning of orders by road and generation and planning of empty container orders is done in a sequence of iterations. Each iteration consists of a repositioning, order combination, order planning and planning improvement step. The planning algorithm is also used to simulate the cost and planning effects of network synergies, customer offerings and changes in constraints.

5.4 Conclusion

The second phase of our research as described in section 4 is situated at a strategic decision level. So far we have no knowledge of existing analyses of network wide simulations including barge transport. The third phase of our research is concerned with tactical planning decisions. The central planning problem of containers on barge can be represented as a frequency service network design problem.

6. Expected results

Our analysis should provide a deeper insight into the efficient and effective organisation of intermodal freight transport networks including inland navigation. We wish to contribute to developing a theoretical approach and conceptualisation of intermodal barge transport networks. More precisely, we expect to answer the following research questions :

- Which modelling techniques can be used for intermodal networks including inland navigation?
- Which bundling concepts could lead to efficiency improvements in intermodal transport by barge?
- What are the effects of an intermodal barge hub in the port area?
- What are the potential benefits of more cooperation between intermodal barge terminals?
- What is the impact of an increasing transport volume on the intermodal network?

Finally, we hope our research will stimulate the use of operations research techniques in intermodal transport.

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