Network dynamics in container transport by barge

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ABSTRACT

In a time span of twenty years, container transport by barge has acquired a significant share in the hinterland modal split for containers of the load centres Rotterdam and Antwerp. In other European load centres, barge container transport as yet plays a modest role, but the interest in the barge option is growing. The growth in container volumes by barge and the increase of the number of seaports and inland terminals involved go hand in hand with fundamental spatial developments in the European inland terminal network.

This paper addresses the organisational changes in the European barging industry that have taken place in the last twenty years and its impact on the spatial dynamics in the European container barge network. The paper analyses structural changes in liner service schedules by barge and the changing functional interdependencies between inland terminals in the network and organizational changes in the industry.

The paper will conclude by discussing future perspectives for the spatial development of the barging network.

KEY WORDS: container, bundling, network, inland navigation, Europe

RÉSUMÉ

DYNAMIQUES DE RÉSEAUX DANS LE TRANSPORT CONTENEURISÉ PAR BARGES

Depuis les vingt dernières années, le transport conteneurisé par barges a connu une augmentation de part modale significative, des centres logistiques de Rotterdam et Anvers vers leurs arrières-pays. Malgré un intérêt croissant, la part du transport conteneurisé par barge demeure modeste dans les autres centres logistiques européens. L'augmentation du volume conteneurisé transporté par barges, ainsi que le nombre croissant de ports et terminaux intérieurs vont de pair avec les transformations spatiales fondamentales du réseau portuaire intérieur européen.

Cet article aborde les changements organisationnels qui ont cours depuis les vingt dernières années dans l'industrie du transport conteneurisé par barges et leurs impacts sur les dynamiques spatiales dans les réseaux maritimes intérieurs européens. L'article analyse les changements structuraux dans les horaires des transporteurs par barges ainsi que les interdépendances fonctionnelles entre les réseaux de terminaux intérieurs européens et les changements organisationnels de l'industrie maritime.

L'article conclut par une discussion sur les perspectives futures du développement spatial du réseau de transport maritime intérieur européen par barges.

MOTS-CLÉS: conteneurs, empaqueter, réseaux, navigation intérieure, Europe

INTRODUCTION

This paper addresses the organisational and spatial dynamics in the European container barge network. The observed spatial developments in the network are the result of a complex interaction between many influencing factors such as the spatial development of adjacent seaport systems, changes in liner service schedule design, the changing functional interdependencies between inland terminals in the network and the organisational changes in the industry.
As little work has been published on the interrelation between organisational and spatial dynamics in inland navigation, the main objective of the paper lies in analysing the functional interdependencies between inland terminals (e.g. inland hub concept versus multiporting) and organizational changes in the industry (e.g. operational agreements among barge operators). Structural changes and interdependencies will be identified on the basis of a historical overview on the development of the European container barge network. Furthermore, potential future development patterns will be identified. As such, this paper aims to contribute to the existing literature on transport system development.

A THEORETICAL NOTE ON INLAND TERMINAL NETWORKS

Container barge networks up to now have always been primarily focused on maritime container flows. As such, the development pattern of the barging network is strongly entwined with the development of the associated seaport system. Hayuth (1981) developed an idealized theoretical model on container port system development consisting of five phases. The model remains vague when it comes to specific features connected with the related hinterland networks. Notteboom (2001) and Slack (1999) argued that inland hub and corridor formation are indispensable for allowing large-scale concentration in a port system and to avoid fierce congestion in the collection and distribution networks and in the load centres. This observation formed the basis for a theoretical model on the spatial development of a port-linked container rail network.
This spatial development model on rail networks developed by Notteboom (2001) cannot be transposed to inland barge systems. Hence, the geographical and operating conditions of rail networks and barging networks differ considerably. First of all, river systems typically have a treelike structure with limited or no lateral connections between the different branches. Under these conditions, a network design based on the hub-and-spoke concept is less obvious compared to rail systems consisting of many lateral connections. Secondly, the deployable vessel capacity is restricted and not homogeneous due to variations in draft limitations and other physical conditions in segments of the river system. Thirdly, wagons of shuttle and block trains can be regrouped quite easily through shunting. As such, the handling of containers in rail networks can be based either on horizontal operations (i.e. shunting of wagons) or on vertical operations (i.e. the loading/unloading of containers). In inland barge networks the regrouping of containers requires vertical container handling operations by crane. Horizontal operations might only occur when an operator uses push barges in view of regrouping large container batches. But even in that case the flexibility of push convoys is rather limited compared to trains.

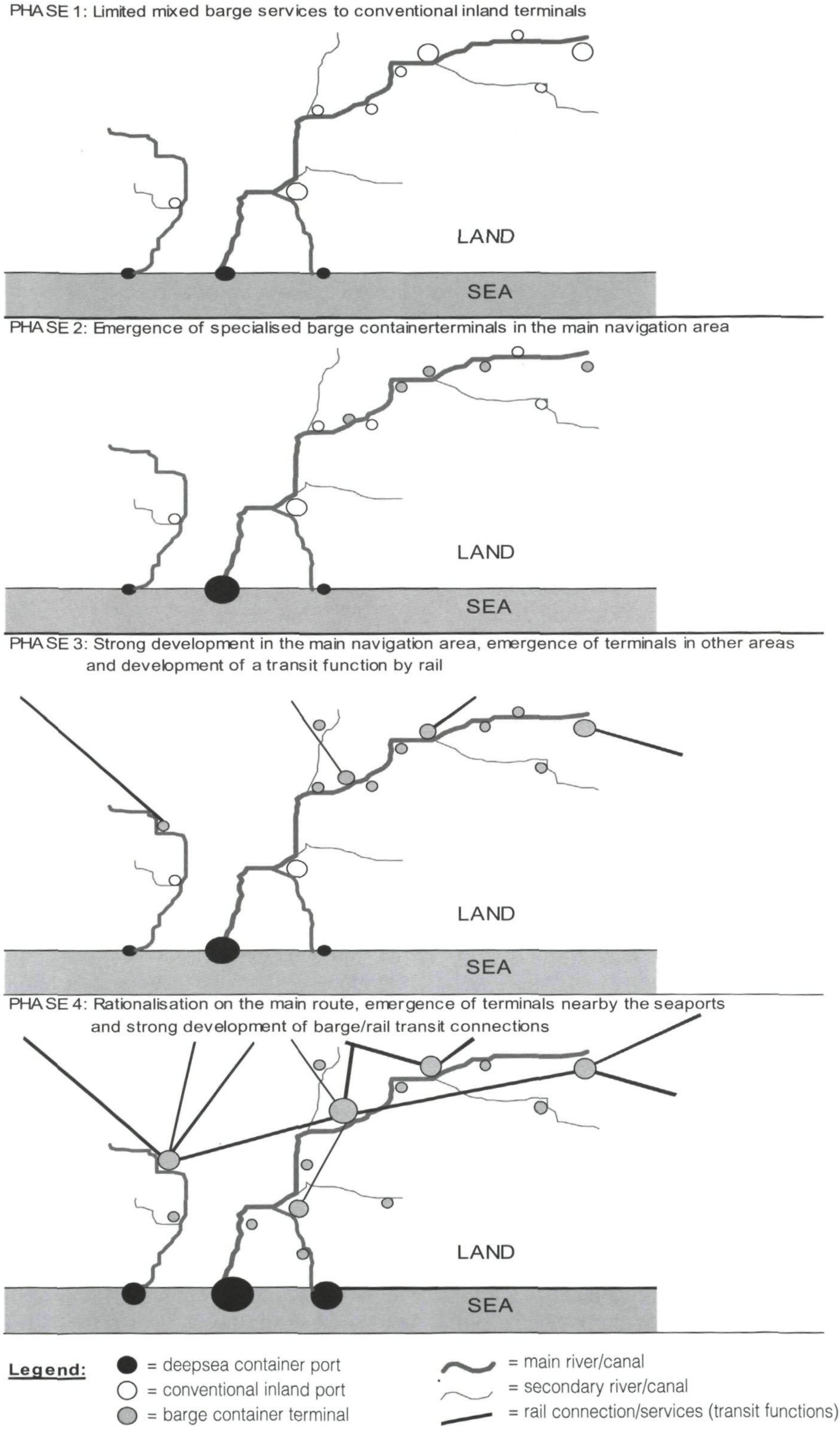

Figure 1. A spatial development model for a hypothetical port-linked container barge network.

The spatial model in figure 1 describes how a hypothetical container barge network could develop over time. The model distinguishes four separate phases, each with specific spatial features. The model basically focuses on the growth, concentration and dispersion of inland container terminals in the network in connection to port system development. In order to highlight the underlying dynamics of the theoretical model the next section deals with the development of the European container barge network.

THE DEVELOPMENT OF THE EUROPEAN CONTAINER BARGE NETWORK

The inland barging network in Europe has its origins in transport between Antwerp, Rotterdam and the Rhine basin, and in the last decade it has also developed greatly along the north-south axis between the Benelux countries and northern France. It is possible to distinguish four phases in the historical growth pattern of the European container barge network, each with distinctive characteristics related to terminal development, barge service design, container volumes and market organisation. These four elements are strongly entwined and together explain the dynamics as presented in the four-phased model.

FIRST PHASE (THE PIONEERING PHASE MID-1968 TILL EARLY 1970s)

Terminals. The first container terminal was set up in Mannheim (middle Rhine) in 1968. This was followed shortly afterwards by specialised terminals in Strasbourg and Basel (upper Rhine).

Services. Small containerised volumes were carried at irregular intervals by conventional barges from Rotterdam to conventional transhipment points on the upper Rhine (Basel and Strasbourg) and middle Rhine (Mannheim and Karlsruhe) (Van Driel, 1993). These services primarily grouped empty containers in the immediate vicinity of the users.

Volumes. Volumes remained low. Total annual transport volume on the Rhine did not exceed 10.000 TEU until 1975. Since the service offered by barge operators did not include transhipment and pre- and endhauls by truck, barge transport long remained unattractive to deepsea carriers and shippers, despite the price advantage per TEU.

Market organisation. The first phase featured only few pioneering barge operators in the market.

SECOND PHASE (MID 1970s TILL MID 1980s)

Terminals. A number of established inland ports along the Rhine set aside part of the existing multifunctional terminals for container transhipment. New terminals were also set up within the perimeter of existing ports, or at new locations along the main navigation route. No less than twenty new Rhine terminals were opened in the period 1980-1987. The initiative for setting up inland waterway terminals now also came from the Rhine carriers, who saw the operation of their own single-user terminals as a way to guarantee success of their liner services. Independent terminal operators tried to get around the system of single-user terminals by setting up common-user terminals. A good example is the opening of ICG (Inland Container terminal Germersheim) in 1984.

Services. Scheduled liner container services by barge developed gradually. For this purpose, operators divided the Rhine into three navigation stretches, namely the Lower Rhine (as far as Cologne/Bonn – only limited number of services at that time), the Middle Rhine (from Bonn up to Karlsruhe) and the Upper Rhine (from

Karlsruhe up to Basel in Switzerland). Once punctuality could be guaranteed by fixed departure schedules for each navigation area, with exceptions only occurring in case of problems with water levels, barge transport quickly gained in competitiveness.

Volumes. The growth in maritime container transport and the limitation in the number of ports of call led to a high concentration of container volumes in just a few maritime load centres. In this period annual transport volume on the Rhine grew from 20,000 TEU (1976) to 210,000 TEU (1985).

Market organisation. The market was dominated by carriers such as CCS (48% of the barge container market in 1985), Rhinecontainer (31%) and Frankenbach (12%). Each carrier operated own liner services.

PHASE THREE (MID 1980s TILL MID 1990s)

Terminals. In phases 1 and 2, the terminal initiatives mainly developed along the upper and middle Rhine. The Rhine carriers and other terminal operators took the view that barge container transport could only be competitive with road transport over distances of at least 500 km, given the comparatively high fixed costs and low variable costs. The development of the basic volume for barge transport only started to bring large-scale initiatives on the lower Rhine from 1985 onwards.

Services. Jointly operated and frequent liner services to each of the three navigation areas on the Rhine (i.e. line-bundling services with typically five inland ports of call per loop), complemented by a limited number of direct point-to-point shuttles.

Volumes. The volumes carried on the Rhine increased from about 200,000 TEU in 1985 to 800,000 TEU in 1995. In Antwerp containerised barge traffic evolved from 128,700 TEU in 1985 to 675,000 TEU in 1995, in Rotterdam from 225,000 TEU to 1,15 million TEU.

Market organisation: In order to raise the level of service and prevent destructive competition, the existing barge carriers started to operate joint liner services on the different navigation areas of the Rhine, backed by operational collaboration agreements. These are characterised by a limited degree of central planning and commitment of barge units, with each of the participating parties maintaining its own commercial identity and freedom. Examples are the «Fahrgemeinschaft Oberrhein» (Upper Rhine transport collective) and the «Fahrgemeinschaft Niederrhein» (Lower Rhine transport collective) (see Van Driel, 1993, Konings, 1999 and Boer, 1999). The partners streamlined their sailing schedules so as to offer a high frequency of departures from the seaports to the lower Rhine.

PHASE FOUR (SINCE MID 1990s)

Terminals. Despite the spatial concentration of freight in terms of carriers, the number of terminals in the Rhine basin is still increasing. This is partly the result of new terminal operators arriving on the market (e.g. ECT in Duisburg since 1999 and the P&O Ports/Logport combination also in Duisburg in 2002). However, it is also due to new terminals appearing along the Rhine and its tributaries, e.g. Aschaffenburg, Hoechst terminal, Krefeld and Mannheim Container Terminal.

A number of inland terminals are increasingly concentrating on complementarity between rail and barge transport. The German inland terminals are seeking to emphasise the trimodal character of the facilities offered, seeking connections to the KLV (Kombinierten Ladungsverkehr) network operated by Deutsche Bahn. Emmerich, Neuss, Mainz, Mannheim, Cologne, Duisburg and Dortmund are some of the inland ports trying to combine their leading role in barge transport with a hub function in international intermodal rail networks. However, in most of them there is still no combined barge/rail transport to speak of: the transit volumes between barge and rail on most of the Rhine terminals are still very low.

The growing realisation of the potential offered by barge container shipping has led to a wave of investment in new terminals over the past few years, in northern France, the Netherlands and Belgium (table 1). A noteworthy feature of this development is that some of the new terminals are located at a short distance from the seaports (even less than 50 km).

Services. After a period of decentralisation in the Rhine basin, the large container carriers are following a strategy aimed at concentrating river freight volumes in just a few freight terminals. This rationalisation in the number of Rhine terminals served (in particular on the lower and middle Rhine) opened up the possibility of larger barges being introduced. Exceptional examples are the sister ships Jowi and Amistade, motorised barges with a slot capacity of 398 TEU used on the CCS services between Antwerp/ Rotterdam and the Rhine. Outside the Rhine basin and the Antwerp-Rotterdam link, smaller barges are used. The next step is to arrive at a network of liner services connecting the various terminals outside the Rhine basin.

Volumes. The Rhine remains by far the most important corridor, notwithstanding rising volumes in the other navigation areas and on the link Antwerp-Rotterdam (figure 2). The middle Rhine still accounts for nearly half of the total container volumes on the Rhine, despite a declining market share (table 2). Rotterdam and Antwerp between them account for around 95% of barge container transport to and from the European port system. The modal split data for 2002 show a market share of barges in land container transport of 31.2% for Antwerp and 43% for Rotterdam – Maasvlakte. The Antwerp case is depicted in figure 3.

In the other container ports of the Hamburg-Le Havre range, barge container transport as yet plays a modest but increasing role. The barge services of GIE Logiseine carried 37,500 TEU between Le Havre, Rouen and Gennevilliers (Paris) in 2002, compared to 19,500 TEU in 1999. Inland navigation had a market share of some 2.5% in the modal split of Le Havre in 2000 (based on TEU-figures), compared to only 1.2% per cent in 1998. Hamburg is slowly developing barge ser-

	Before 1985	1985-1990	1991-1997	1998-2002	N.A.	TOTAL
Upper Rhine	4	2	0	1	1	**8**
Middle Rhine	7	5	2	2	0	**16**
Lower Rhine	3	4	0	3	1	**11**
Northern France & Luxembourg	0	0	4	1	0	**5**
Belgium	0	1	2	9	0	**12**
the Netherlands	0	1	6	19	0	**26**
Total number of terminals	**14**	**13**	**14**	**35**	**2**	**78**

	Start of terminal activities (number of terminals per navigation area)			
	Before 1985	Before 1991	Before 1998	Before 2002
Rhine Basin (D, F and CH)	100%	93%	66%	43%
Other navigation areas	0%	7%	34%	57%
Total number of terminals	**14**	**27**	**41**	**76**

Table 1. The start of operations at new terminals (number of terminals per navigation area).
Remark: barge terminals in seaports and along the Danube river are not included.
Source: author based on individual terminal data

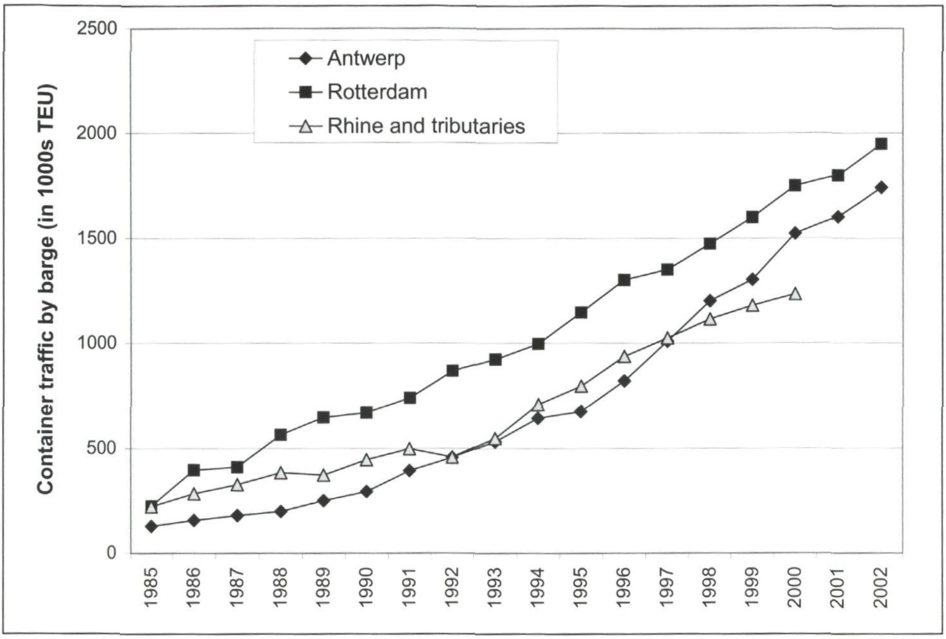

Figure 2. Growth of container traffic by barge in Antwerp, Rotterdam and on the Rhine (in TEU, source: port figures and Central Commission for Navigation on the Rhine).

	Lower Rhine	Middle Rhine	Upper Rhine
1994	28.9%	56.3%	14.8%
1995	29.6%	54.5%	16.0%
1996	26.6%	57.3%	16.1%
1997	28.4%	56.0%	15.7%
1998	31.2%	52.2%	16.6%
1999	32.2%	51.2%	16.6%
2000	32.0%	49.8%	18.2%

Table 2. Relative importance of the navigation areas on the Rhine (based on volumes in TEU).
Source: Central Commission for Navigation on the Rhine

vices on the Elbe, with annual volumes in 2002 exceeding 22,000 TEU compared to only 10,000 TEU in 2000. The Marseilles-Lyon route in southern France for its part accounted for about 22,000 TEU in 2002 compared to only 2,800 TEU in 1999.

Market organisation. Rising volumes put pressure on the existing co-operation agreements on the Rhine as more and more operators are eager to start services independently from their partners. For instance, CCS withdrew from the

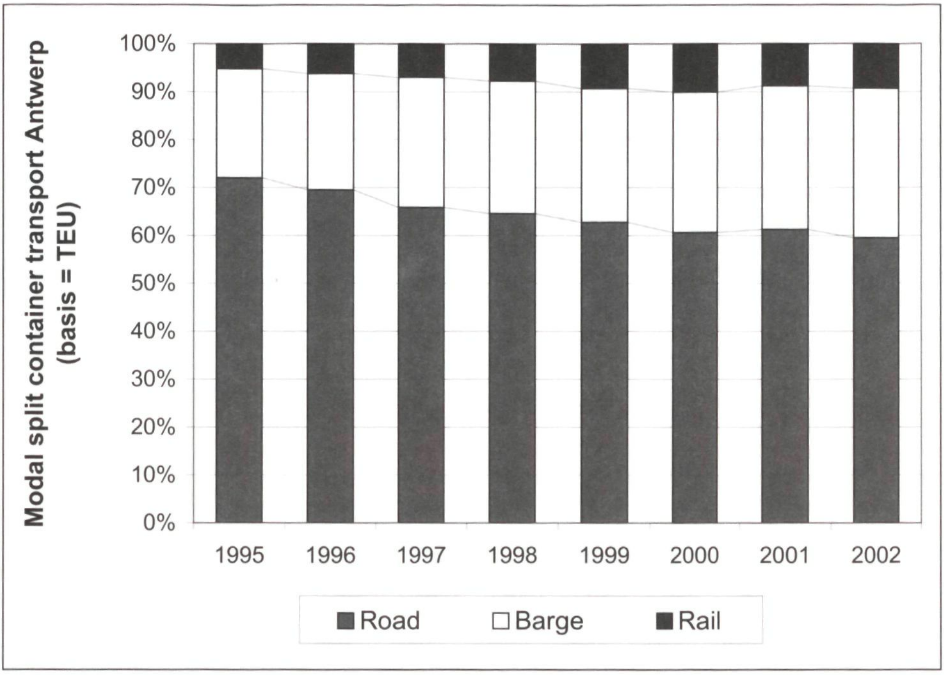

Figure 3. The modal split for container transport in the port of Antwerp (1995-2002, source: based on statistics of the Antwerp Port Authority).

Fahrgemeinschaft Niederrhein collective on 1 January 2000, but the collaboration agreement continued with the three remaining partners, under the name of NFG 2000. Joint ventures, mergers and takeovers form a relatively new aspect, aimed at increasing the geographical scope of the services offered, and at developing the operators' own barge transport networks. In 2000, CCS and SRN Alpina came under the same ownership, as a result of Rhenus (the parent company of CCS - SRN Alpina) acquiring the Swiss holding company Migros.

In addition, the leading barge container carriers are increasingly trying to achieve a functional vertical integration of the container transport chain by extending the logistical services package to include complete door-to-door logistical solutions. Inland terminals often play a key role within the logistical strategy followed. Some two thirds of the barge carriers on the Rhine operate one or more Rhine terminals and/or participate as a shareholder in a terminal. Barge container carriers in fact control about half of the Rhine terminals. A large number of the remaining inland barge terminals are operated by subsidiaries, parent companies or allied companies of container terminal operators based in seaports (Notteboom, 2002). The remaining inland terminals are operated by rail operators (who wish to exploit the complementarities of rail and barge transport by setting up trimodal hubs), independent logistics service providers (who set up terminal activities to assure their own supply of freight), inland port authorities (such as the «Port Autonome de Strasbourg», who sees a barge terminal and the associated logistics activities as a means of regional development and as a way of increasing regional competitiveness) and holding

companies (they acquire stakes in inland terminals in order to diversify their portfolio or package of activities).
A last and fairly new aspect of the vertical integration strategy followed by barge operators is the desire to fully exploit the complementarity with rail transport, by forging closer links with existing rail companies, or if required even acting as rail operator themselves.

SCENARIOS FOR REVISED NETWORK OPERATIONS IN THE RHINE RIVER BASIN

The growing container volumes and the dynamics in market organisation open opportunities for rearranging the barging network. The aim of the barge operator is to offer attractive rates and transit times to shippers, without reducing the level of service. This section discusses scenarios for the further optimisation of network operations in the Rhine river basin.
The present network configurations in the Rhine river basin show more or less identical operations. The vessels sail between the seaports (Rotterdam and Antwerp) and dedicated regions in the hinterland (Lower, Middle and Upper Rhine river basin) on the basis of a line bundling loop system. In the hinterland regions about 4-6 terminals are called, while in the seaports the average number of terminal calls can be as high as ten (see figure 4). To discuss scenarios for revised barge network operations on the Rhine river it is useful to distinguish between operational changes in the seaport and/or the hinterland.

THE REVISION OF NETWORK OPERATIONS: THE SEAPORT SIDE

A key factor determining the performance of container barge transport is the turnaround time of the vessel (Konings, 2003). The typical turnaround time of a vessel operating in the Rhine river basin consists on average of 60% sailing time, about 25% is port duration time and about 15% of time that is reserved to absorb possible delays, mainly those caused at terminals in the seaports (Stichting RIL, 1996). Waiting times at terminals are partly caused by seagoing vessels having the priority over barges when it comes to the allocation of berths. This situation demands for some kind of reorganisation of network operations.
The port of Rotterdam has about 35 con-

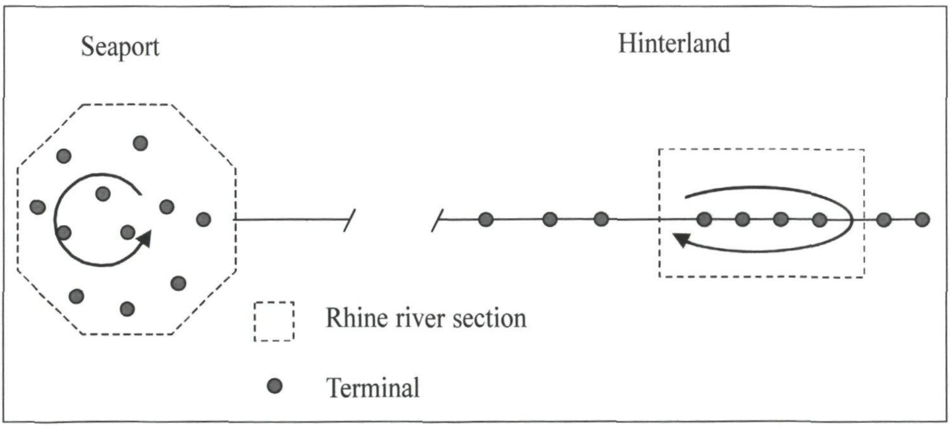

Figure 4. Typical pattern of barge transport operations in Rhine river hinterland transport.

tainer terminals (including empty depots), which are spread over a rather large port area (the distance between Rotterdam Eemhaven and Rotterdam Maasvlakte is 40 km). The port of Antwerp is more compact than Rotterdam, but still the problems are quite severe because of the need to pass the time-consuming locks. From this perspective it is easily understood that the collection and distribution of containers in Rotterdam and Antwerp, which requires calling at many terminals, is a time-consuming process, even leaving the time delays at terminals out of consideration.
Two basic organisational models can be distinguished to reorganise the collection and distribution of containers in the port: completely centralised handling of hinterland vessels and partly centralised handling of hinterland vessels.

Completely centralised handling of hinterland vessels
In the regime of completely centralised handling, all vessels operating in the hinterland traffic call at one container exchange point (figure 5). In this model the potential improvement in turnaround time of vessels in hinterland traffic is maximal, however every container is handled an additional time, additional transport equipment (vessels or barges) is needed to organise the collection-distribution traffic between the exchange point and the terminals in the port and due to the high performance requirements of this exchange point (large capacity and efficient sorting possibilities) large investment costs are involved in setting up such a terminal, either by restructuring an existing terminal or, more likely, developing a complete new one.

The effectiveness of such an organisation model also depends on the location of the exchange point. Moreover, the higher the transport volumes, the better are the conditions to exploit the exchange point and to optimise the feeder transport between the exchange point and the (other) port terminals.

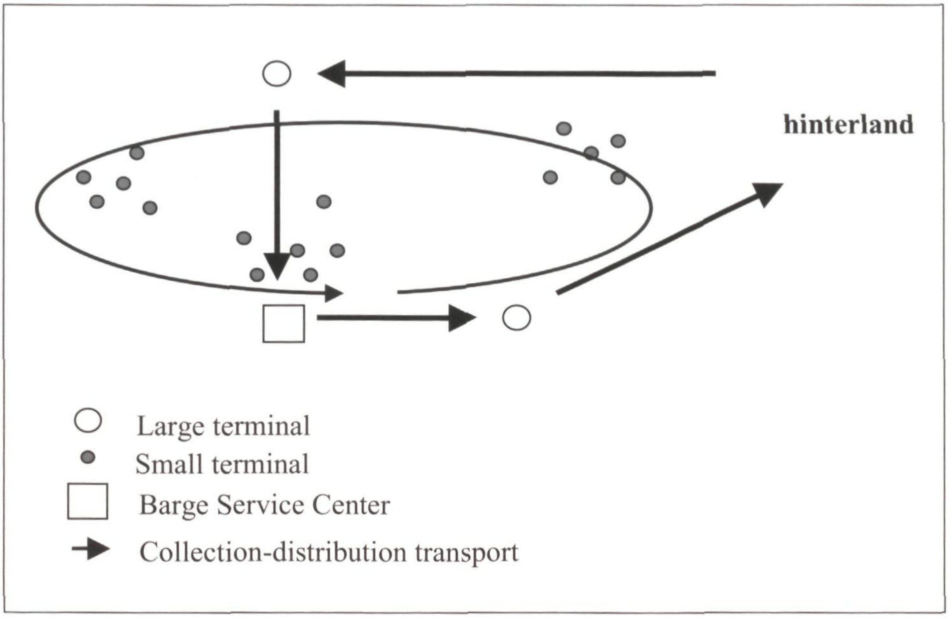

Figure 5. Centralised organisation of collection-distribution transport by barge in the seaport.

Partly centralised handling of hinterland vessels

The model of partly centralised handling assumes that hinterland vessels only call at a limited number of seaport terminals (figure 6). This choice of terminals will be based on call size. Hinterland vessels will only call at the terminals for which a large number of containers is destined. In this model the savings in turnaround time are smaller, but also the operational costs of collection-distribution transport are lower.

The optimal organisation model for the collection-distribution transport in a seaport depends on the additional costs of transhipment and the sailing costs in the port on the one hand and the potential monetary benefits of turnaround time savings of hinterland vessels on the other hand. These benefits should be obtained from increased sales, either from additional roundtrips or from operating larger vessels, which due to time savings in the port, can sail according to the original sailing schedule.

Since the tariffs of container transport are dependent on distance, a reduction in port terminal callsrevision of operations in the port will be most beneficial for vessels servicing the Upper Rhine and least attractive for those servicing the Lower Rhine. Hence, long distance services can more easily afford the additional port costs than short distance services.

THE REVISION OF NETWORK OPERATIONS: THE HINTERLAND SIDE

As mentioned earlier, container barge services on the Rhine river are organised according to the three navigation sections, so as to achieve regular and acceptable turnaround times of vessels. Dependent on transport volumes and the usability of different vessel sizes, a reorganisation of hinterland transport services can be beneficial. This section briefly discusses some basic scenarios for one-stop services and local hub or trunk-feeder services.

One-stop services

This kind of barge service assumes that a vessel only calls at one terminal in the hinterland. The turnaround time of the vessel is in principle small (dependent of the sailing distance) and so is the transit time of containers. Because intermediate hinterland stops are omitted, the reliability of services is high. However, daily services require large transport volumes. The DeCeTe-terminal in Duisburg meets these conditions and barge services to this terminal are therefore already offered as one-stop services.

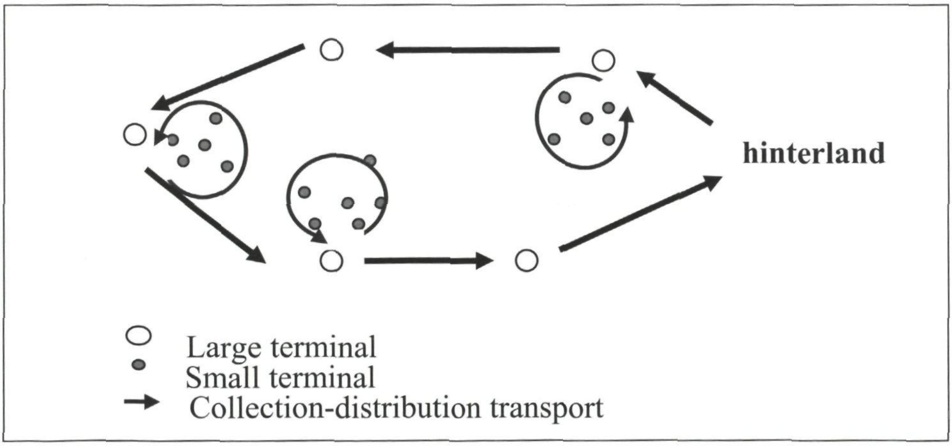

Figure 6. Decentralised organisation of collection-distribution transport by barge in the seaport.

Local hub or trunk-feeder services
Characteristic for these services is the existence of a barge service between the seaport and an inland hub, out of which the cargo is feedered to one or several (smaller) regional terminals. An important driving force for this system can be waterway constraints that prohibit the sailing of large vessels to the regional terminals. At the trunk route lower costs can be achieved due to the additional transport volumes which enable economies of scale[1]. However, evidently these cost advantages also benefit the containers destined for the terminals along the feeder route. These cost savings will to some extent be absorbed by the transhipment from the trunk to feeder route, but the net benefit might be an improvement of the cost performance of barge services to these regional terminals. Currently this concept is being tested in a pilot between Rotterdam/Antwerp – Duisburg DeCeTe (trunk route) and Duisburg - Dortmund (feeder route). This pilot is known as the Rhein-Westfalen shuttle.
A pre-condition is the perfect matching of arrival and departure times of trunk and feeder lines. In addition, the feasibility also depends on the location of the local hub (not too close to the seaport) and the regional terminals.
More scenarios are conceivable by combining basic hinterland transport scenarios, such as the incorporation of feeder services within the existing line services to a Rhine river region (figure 7).

POTENTIAL IMPACTS OF DEVELOPMENTS IN THE BARGING INDUSTRY ON NETWORK OPERATIONS

Ever growing container volumes in the seaports and the changing roles of actors involved in hinterland barge transport give cause for possible different kinds of network operations. In this context not only organisational changes in the barge sector itself are relevant, but also the changes at the main clients of barge operators, who set the conditions for revised barge operations. We will discuss some major trends and describe their probable effects on the barging network.

DEVELOPMENTS INITIATED BY THE DEEPSEA CARRIER

Carrier-owned terminals
In order to reduce logistical costs and to maintain their market share deep-sea carriers pursue a better control of the logistic chain through e.g. the development of carrier-owned (dedicated) terminals (Connekt, 2001). It is likely that the trend towards carrier-owned terminals will increase the number of «barge» terminals in the port, but due to spatial concentration of new terminal facilities port efficiency of barge hinterland transport will improve. If carrier-owned terminals are spatially clustered, time lost by sailing between terminals in the port can be reduced.

Hub-and-spoke networks at sea
Hub-and-spoke networks are increasingly implemented in deepsea traffic. The effect for a port or terminal is visible in increases in transhipment handlings and call sizes. Larger call sizes improve the conditions for hinterland transport. It enables opportunities to increase the size of barge vessels and to reduce the number of terminals to call in the seaport.

Carrier haulage
The organisational control over hinterland transport via carrier haulage is an important strategy for carriers to control the logistic chain and to generate additional revenues. Carriers will have great interest to concentrate transport volumes to a very limited number of inland terminals to take full advantage of economies of scale in sailing (large vessels) and terminal operations (including block stowage and scale benefits in repositioning and depot activi-

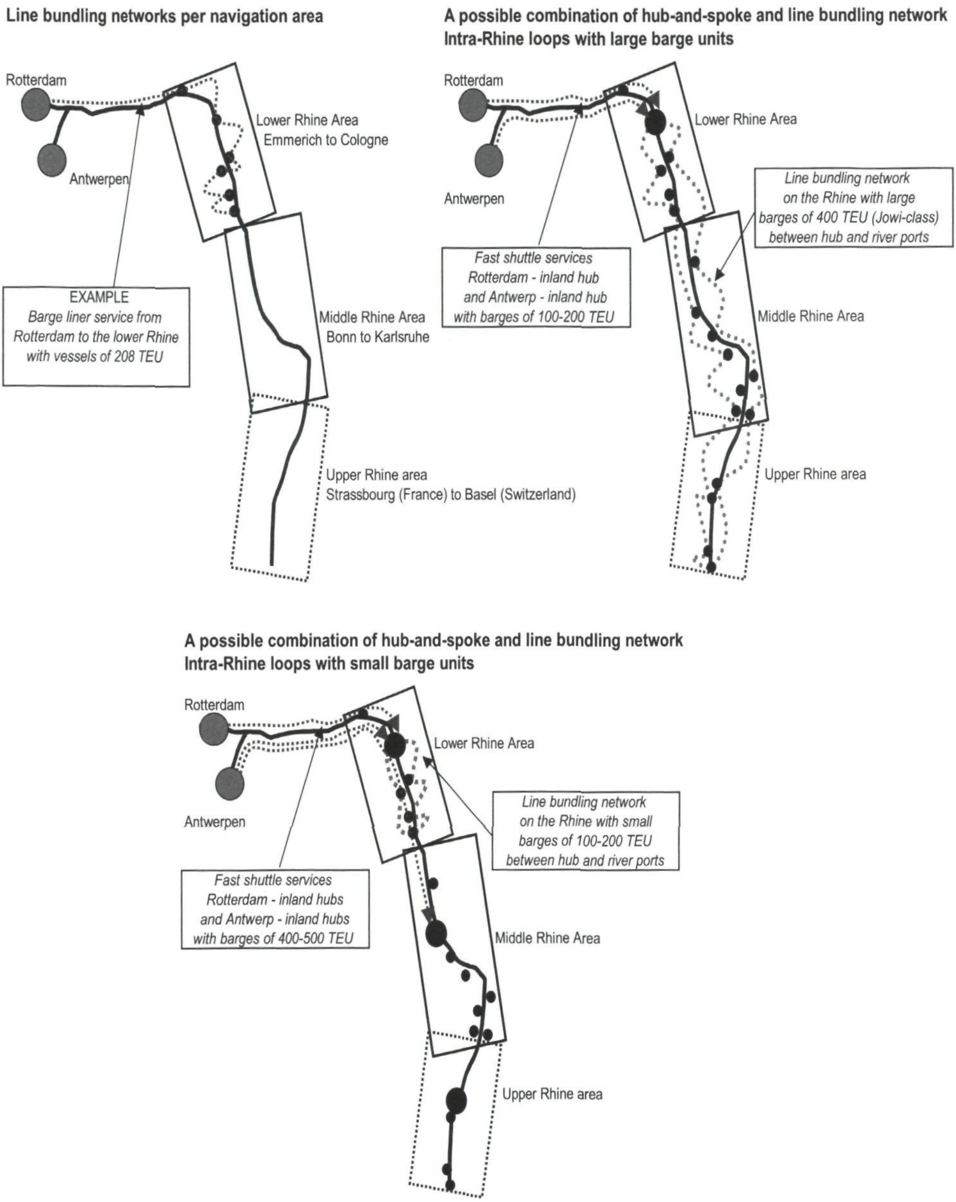

Figure 7. Examples of alternatives for the organisation of barge services on the Rhine.

ties). These conditions will encourage the development of some local hubs (large inland terminals) that will be directly served from the seaport (one-stop services). If transport volumes are large enough and carrier haulage is dominant ultimately direct point-to-point services might emerge. It is most likely that the port and inland terminals strategically located near the major load bases and to ongoing rail and barge connections will be most eligible for this hub status (e.g. Duisburg, Ludwigshaven, Mannheim and Basel).

DEVELOPMENTS INITIATED BY THE FORWARDERS AND SHIPPERS

Forwarders highly value close access to barge terminals, which, due to the widespread location of their clients, would imply a large geographical coverage of barge operations, where many terminals in the hinterland are called (fine-meshed network operations). In principle this would hinder a rationalization of the number of inland terminals and an efficiency improvement of barge transport unless some re-organisation of barge services can be implemented. The transformation of the present barge services into trunk-feeder services could possibly improve the cost efficiency while also maintaining the service level.

DEVELOPMENTS INITIATED BY BARGE OPERATORS

Concentration and hub development

The relations between barge operator and inland terminals are now becoming stronger, leading to «preferred» inland terminals. Barge operators will be inclined to call at their own, selected number of terminals, which are dedicated by global logistic mother concerns as important regional mainports. These developments fit to the model of local hub services.

Some recent initiatives might illustrate how this hub concept is already being put into practice. At present, Duisburg clearly is the example of a growing inland hub. Duisburg is located in the heart of the Ruhrgebiet area at an intersection of large waterways (Rhine river and Rhine-Herne canal) offering access to Southern and Northern corridors in the hinterland. The connections to the rail network are well developed. Last but not least the current barge handling capacity amount to 400,000 TEU with possibilities to expand this capacity to 800,000 TEU. Containers are being transported between Rotterdam and Duisburg in large vessels and transhipped at Duisburg to small vessels destined to locations along the Middle- and Upper Rhine region, such as Ludwigshaven, Karlsruhe and Basel (Scheurkogel, 2003). It is most likely that Duisburg will act as a major hub and further expand its hub function in the near future. Whether there will be room for another hub along the Rhine not only depends on local conditions (transport volume, quality of waterway infrastructure, availability of railway connections), but also depends on the performance of the Duisburg hub-concept compared to hub concepts to alternative locations.

The prospect of inland waterway hubs being set up in the future might have some important side effects for seaports. Since larger groups of containers can be carried onwards by barge in a single movement, there is less need for containers to be pre-sorted in the maritime terminal according to final destination; the inland hub becomes responsible for final distribution of the containers over a larger area. This enables container ports to considerably reduce container transit times, while avoiding potential congestion in the hinterland connections.

The basic conditions for developing hub-and-spokes networks outside the Rhine basin seem not favourable because of the high number of new terminal initiatives (see table 1) and the limited scale of many of these facilities (i.e. annual terminal capacities lower than 10,000 TEU are not exceptional). A network based on many small terminals leads to fragmentation of cargo volumes, which can partly or even completely obviate the advantages of scale. It is generally expected that in the years to come a partial rationalisation (as a result of mergers/acquisitions and terminal close downs) and specialisation (e.g. terminals focused solely on the transport of containerised waste) will take place within the terminal networks outside the Rhine basin. This would pave the way for major revisions of sailing schedules and network architecture.

Barge operators' considerations for developing barge – barge networks
In general the development of barge–barge networks faces some constraints that seem inherent to the barge transport system:
Loading/unloading times of barges are relatively long. Of course, the actual time loss will depend on the number of units to be exchanged, the available crane capacity and possible waiting times.
The impossibility of simultaneous exchanges. Direct exchange of containers between vessels is impossible, unless appropriate cranes are available and time schedules of vessels are tuned.
The importance of the loading/unloading order. The sequence of loading/unloading and the positioning of containers is critical and complex for vessels. Although excellent logistic planning may reduce this problem to some extent, this issue remains a huge challenge when applying complex bundling models in barge transport.
Whether these circumstances, and their associated time and money costs, form a real barrier depends on the specific networks considered: costs savings on the network level (for instance scale economies) may overcompensate the additional costs resulting from exchanging containers between barges.

Erosion of co-operation between barge operators
Barge operators, the larger ones (CCS and Rhinecontainer) in particular, increasingly tend to restructure their own networks and because of their size are able to do so. This erosion of co-operation would indicate at a loss of critical mass to optimise barge services in terms of vessel size and frequency, which will be partly compensated by growing transport volumes. On the other hand, individual operations make implementation of initiatives for new network operations apparently easier, as being currently demonstrated by some experiments of CCS and Rhinecontainer with trunk-feeder services.

Intermodal co-operation
In order to increase the geographical scope of barge transport beyond the natural catchment areas around the Rhine river (about 100 km on both sides) there is an increasing awareness about the role of rail transport. Inland terminals which have a barge and rail terminal will have a strong potential to develop into a major hub. Good examples are Duisburg, with a strong position in rail services to North and Middle-East Europe, and Basel as a gateway for rail traffic to Italy and South-East Europe.

CONCLUSIONS

Radical organisational changes in the barging industry combined with rising container volumes have induced spatial changes in the configuration and reach of the container barge network. Barge transport and inland terminals have won their place in the supply and collection systems for manufacturers, and as such play an undeniably important role in the further logistical development of major economic centres in the West-European hinterland.
Important challenges for the future are for barge container transport to be opened up further to other seaports, and for this mode to fit in better with intermodal hinterland activities. It is possible for barge container transport to overcome the limitations of the inland waterway network by linking up with rail transport. There are also enormous opportunities for forming better networks between the large numbers of inland terminals, many of which are very recent. A sustainable network of inland terminals is not necessarily the same as having many terminals, but it does mean a network that makes maximum use of the functional inter-

dependencies with seaports and other transport modes, offering added value in logistics activities.

Barge container transport is still closely associated with point-to-point services and line bundling services to and from the large load centres of Antwerp and Rotterdam. In view of several trends at the demand and supply side of barge transport it is very likely that barge transport operations will considerably change in near future. The functionality of inland terminals will change and also the number of terminals along the Rhine might diminish. At least a hierarchy in terminals will emerge. Some selected strategically located terminals will obtain a hub status with important exchange functions (between barges and barges and rail) and serving very large and on long distance located markets, while other terminals become subordinated to these hub terminals concentrating on serving local and regional markets.

This configuration will meet the demand for large transport volumes to a selected number of terminals which will be served directly and possibly by very large vessels (Jowi plus or push boat/barge combinations) even with high frequencies, and demand for fine-meshed transport to small terminals with fast small to medium-sized vessels.

It is difficult to give a blueprint of this configuration, in other words, to indicate which terminals will become a hub and which will become secondary terminals. It is even more difficult to forecast the service model applied for these secondary terminals. The present model of line services is conceivable, but for efficiency reasons, i.e. improving the turnaround time of vessels, it is more likely that these barge services will be offered in function of the hub services e.g. as trunk-feeder services. In consideration of the circumstances which support the development of a hub, the position of the port of Duisburg is outstanding, in terms of its natural catchment area, location as well as the present and near future capacity of intermodal infrastructure.

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1) Instead of increasing the size of operation the additional transport volumes originating from the feeder route could also be used to increase the frequency of services on the trunk route.

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