MODELLING THE BUNDLING OF INTERMODAL RAIL FLOWS FROM/TO SEAPORTS

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ABSTRACT

In 2008 the OTB Research Institute of the Delft University of Technology carried out the design of rail bundling concepts for the port of Rotterdam. The central background was the concern of the port authority how to manage future magnitudes of rail transport on restricted number of tracks, in particular after the opening of Maasvlakte 2. Starting from an O/D-matrix the question was whether to bundle flows in line, hub-and-spoke, or different feeder models, also distinguishing between alternative location types (e.g. with so-called corridor-neutral or corridor-specific hubs) and physical alternatives, like rail-rail exchange by means of container transhipment or wagon (group) shunting. For all bundling solutions, namely bundling concepts imbedded in bundling scenario's, we analysed the performances, for instance number of full-trainload or partial trains, capacity effects or costs per load unit. On the basis of a multi-criteria analysis we could identify and distinguish promising bundling solutions from less promising ones. Colleague researchers from the Erasmus University used the results to, in a second step, design innovative steering and management concepts for future rail port operations.

This paper gives an outline of the policy and the service network design challenge in practice, in this framework explains the relevance of large trainloads and appropriate bundling of flows, and then describes the steps to be taken to model the bundling and identify "best" bundling solutions. Such identification will be based on direct, generalised or social costs, and be the result of optimisation, heuristic or enumerative procedures. This paper is devoted to the first step, namely preliminarily identifying best or promising bundling solutions in terms of number and size of trainloads, service frequency and potential rail share, given certain network transport volumes.

Keywords: intermodal, rail, freight, bundling, network design, hub-and-spoke, seaports

1 Framework

1.1 Research framework

The OTB research institute of the Delft University of Technology (TUD) is frequently involved in rail network design issues including the analysis of costs and benefits and the analysis and design of management concepts to plan and implement rail service networks and the related infrastructure. The network design is largely based on enumeration, which is used to design the service network alternatives, analyse and compare their performances and select the networks with the best or otherwise promising performances. Such approach has for instance been applied in the institute's contribution to the so-called Havenspoor project of the port of Rotterdam. OTB designed and analysed, starting from an O/D-matrix, the alternative train concepts in different rail scenarios for the long term and for the entire port. The enumeration took place by hand on the basis of spreadsheet elaborations.

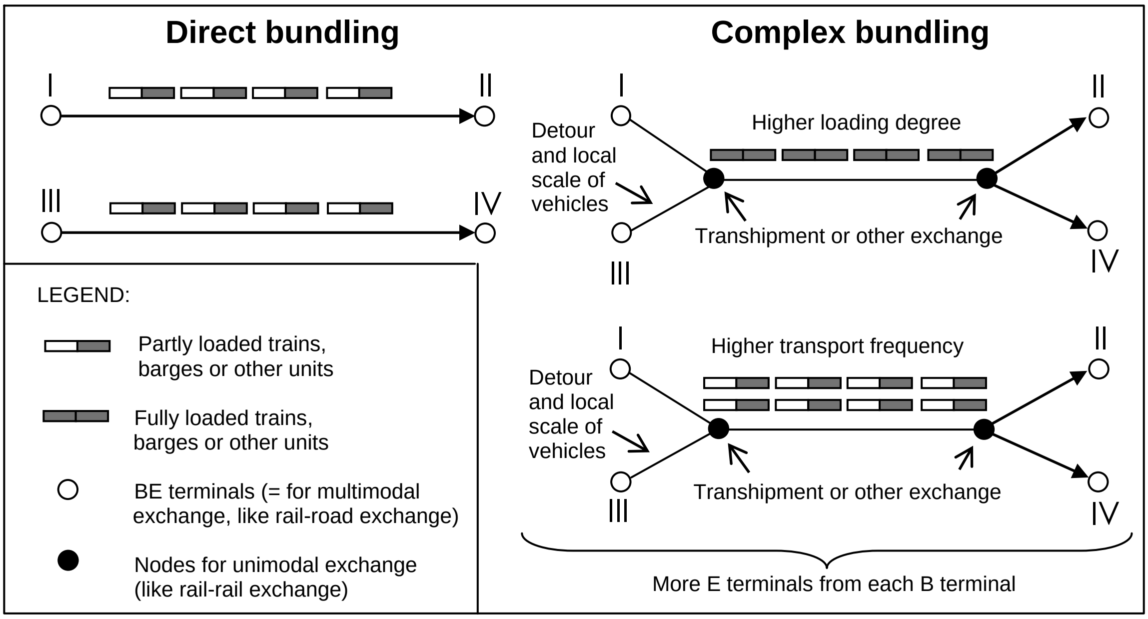
The typical result of such approach is a rough identification of best solutions, very appropriate for the strategic dimension of the policy objective at stake. The result however, will not show which sub-variant within the group of best solutions has the best performances, as the number of sub-variants is extremely large, and it would take irresponsible much time to analyse and compare all sub-variants. The challenge therefore is to automate the network design, potentially submitting it to an optimisation procedure, for which reason OTB has searched for cooperation with the faculty of Electrical Engineering, Mathematics and Computer Science of the TUD.

The paper describes the problem definition of the automated approach, and in advance the policy backgrounds, challenges and considerations. The approach starts with a clear problem articulation and is in search for the most appropriate modelling approach, hence most appropriate problem definition and type of solution. The paper focuses on the problem definition.

1.2 Policy considerations

The growth rates of freight flows from and to seaports is generally expected to remain high, despite of the current growth interruption in Europe and many other parts of the world caused by the crisis. Because of this growth there is a high urgency to make transport more sustainable, and to find ways to combat potential congestion in critical parts of the infrastructure network. A shift from road to rail, barge or short sea transport contributes to more sustainability. Such a shift will, however, only take place if these alternative modes have competitive performances. For example, take rail. It must become cheaper as rail transport will only be chosen if it can offer lower door-to-door costs; lower costs would make it attractive for more flows including shorter distance flows. Or its quality should be improved, as customers of road transport value transport quality rather high. Measures improving both costs and quality, are likely to be promising ones. An example is the acceleration of operations, potentially reducing the vehicle roundtrip time (-> lower costs) and the door-to-door time of freight (-> higher quality).

A major option to improve cost-quality ratios is to organise sufficient transport scale, meaning full trainloads on the required level of frequency and the number of destinations that can be served (network connectivity). For bulk and neobulk freight one can rather easily respond to this challenge, and many trains for these commodities are direct ones. A direct train runs directly from a begin- to an end-terminal without stopping for exchange at intermediate nodes (left bundling type in Figure 1). For general cargo and intermodal flows the challenge is more difficult to fulfil, as most of these flows are too small to fill a train on the required frequency and connectivity levels. Even from and to large nodes like large seaports this is the case. 1



* The figure only shows the main transport mode (e.g. rail) and no pre- and post haulage.
Source: Kreutzberger, 2003.

Figure 1 The principle and impacts of bundling *

In such situation there are three main solution types: 1) complex bundling of flows, 2) concentration of the rail service network, or 3) letting the flows slip away to the road sector.

Take solution 1: complex bundling is about combining different flows to a trainload. One can combine flows of different periods (like the flows from day A and day B), different categories (like intermodal and non-intermodal flows in the same train) or different directions, at least for common parts of their journeys. The result is respectively bundling in time, categorical bundling and directional bundling. The last is the most common type. Its principle is visualised in Figure 1. By transporting goods of different rail relations in the same train during part of their journey, one can enlarge the trainload (upper right picture of Figure 1), increase the service frequency (lower right picture of Figure 1) and/or access more end terminals from each begin terminal. The disadvantages of complex bundling are longer freight routes, in most complex bundling networks additional exchange at intermediate exchange nodes, and in some complex bundling networks also local rail networks with short, and therefore costly, trains.

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[1] An analysis in the framework of Havenspoor (Kreutzberger and Konings, 2008) indicates that – roughly – only about 10% of the rail flows are suitable for direct trains, if each service has 5 departures per week and the trainloads are sufficient for train lengths of at least 600m. The small share of direct trains may be astonishing at first sight, given the many existing direct container trains. The contradiction is explained by the fact that many current train services have small trainloads (implying train lengths of 400-500m instead of 600-700m) or lower transport frequencies (like 4 departures per week instead of 5).

Solution type 2, the network concentration, comes down to connecting two service areas by less rail-road terminals and train connections than in the reference situation, implying – if demand stayed the same – that there is more freight for each rail connection. The length of pre-and-post-haulage routes by truck, however, will increase. As pre-and-post-haulage is very expensive, one must avoid that the savings in rail transport are not overcompensated by the cost increases of pre-and-post-haulage. In this case also demand will drop leading to a double disadvantage. Nevertheless, network concentration has taken place on a larger scale during the last decades. Recently, there is a new interest in network concentration, namely in the world of terminal and carrier haulage: sea terminals or carriers advocate the concept of extended gateways, the outplacement of port functions to inland terminals and the intensification of rail services between the port and these inland terminals. These inland terminals are called extended gateways. Typically, not all inland terminals are raised into such status, but only a small selection of inland terminals.

Back to the complex bundling. We distinguish the following basic bundling types. Next to the direct bundling networks we have the complex bundling networks, namely hub-and-spoke networks (= HS networks), line networks (= L networks), trunk-collection-and-distribution networks[2] (= TCD networks), and trunk-feeder networks (= TF networks). Their central difference is the number of train routes (train connections). In the example of Figure 2 the number is 9 in the direct network, 3 in the HS network, and 1 in the trunk parts of the TCD-, L- and TF network. The effect of this difference is easy to illustrate for simplified networks, in which all train relations have the same transport volume. Given same network transport volumes for each bundling network:

- the service frequency varies in the proportions 1:3:9:9:9 (BE-, HS, L-, TCD-, TF network);
- or the size of trainloads differs in the proportions 1:3:9:9:9 (BE-, HS, L-, TCD-, TF network);
- or the combination of service frequencies and trainload sizes differs.

If the service frequency and trainloads are the same in all compared bundling networks, then the transport volume varies. The required volumes (in the trunk parts of the networks) are 9:3:1:1:1 (BE-, HS, L-, TCD-, TF network).

The impacts of these properties are:

- (frequency) different waiting times for load units and storage requirements at exchange nodes or elsewhere;
- (trainload) different costs per load unit;
- (rail transport volume requirements) different capability of dealing with smaller flows and achieving larger rail shares.

Of interest is also the number of additional load unit exchanges at intermediate exchange nodes, in comparison to the direct bundling network. If the exchange takes place by terminals, the network-averaged additional exchange is 0,5-1 per load unit in the HS network, zero in the L network (!), 2 in the TCD network and 1-2 in the TF network (Kreutzberger 2008).

A rough conclusion on the basis of performance analysis (detours, time, costs) is:

- that there is no best bundling type in general, but only one in the context of a certain network transport volume that can be achieved, and certain network performance requirements, like service frequency. If the volumes are sufficiently

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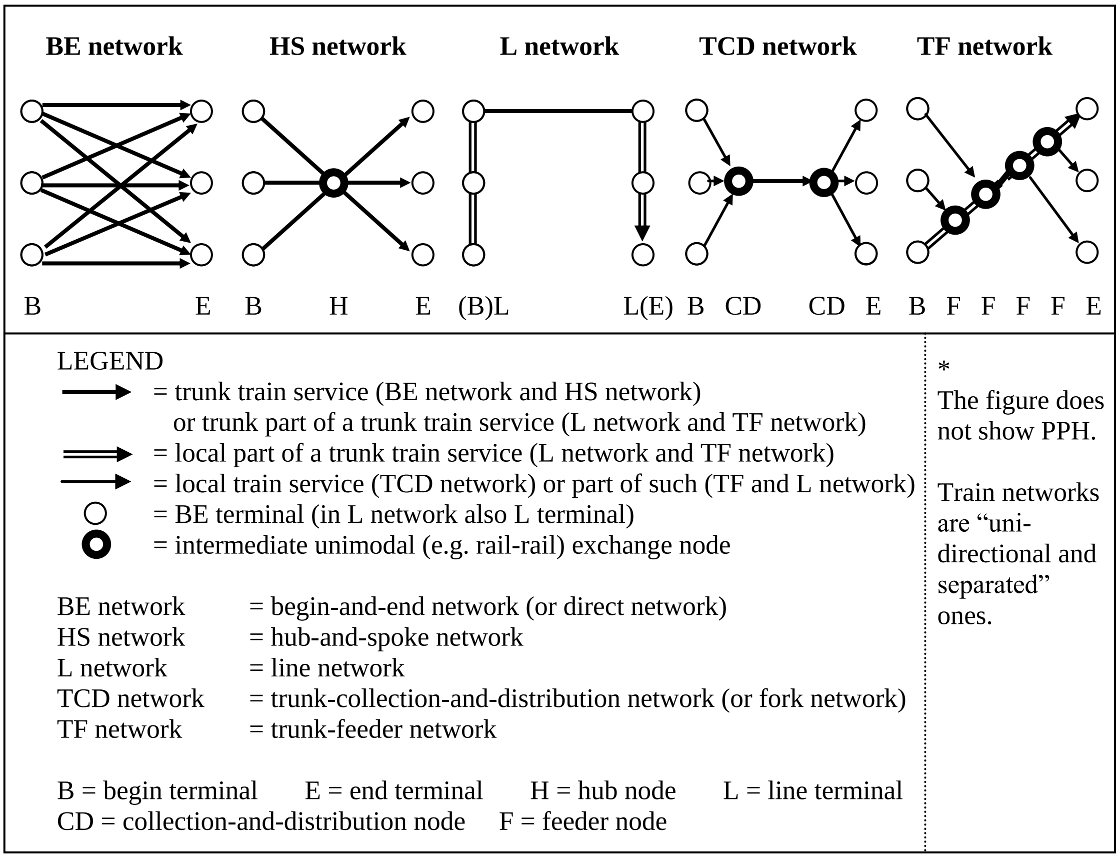
[2] = fork networks.

large, direct networks are the best. If the volumes are smaller, complex bundling is likely to provide best performances;



Source: Kreutzberger, 2008

Figure 2 Basic bundling types

- that, within the world of complex bundling, HS- and L networks are most promising for many situations; the HS network for medium network transport volumes, given the fact that they have relative small detours, no local networks and a limited amount of additional exchange at intermediate nodes; the L network for smaller network volumes, given the fact that its total number of transhipments is the same as for the direct network.

The basic bundling types can be combined to what we call composed bundling networks, which are hierarchical or multiple combinations of same or different bundling types.

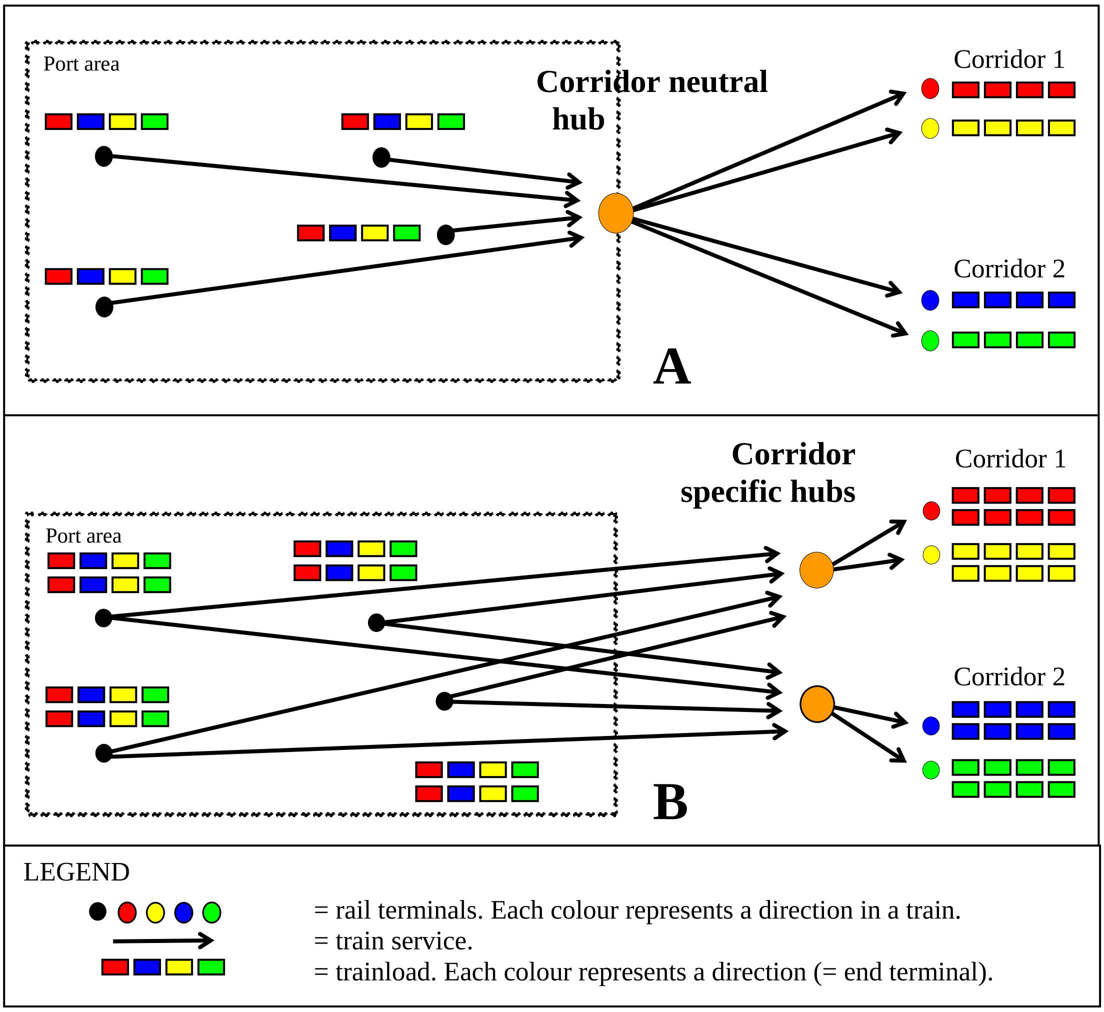
Bundling choices do not only refer to the ***functional*** dimensions of network design, as discussed above, but also to the ***physical*** dimensions. For instance, does rail-rail exchange take place by shunting of single wagons at a gravity shunting yard, or by shunting of wagon groups at a gravity or flat shunting yard, or by transhipment of load units at a true rail-rail terminal or at a rail-road terminal? A true rail-rail terminal has a different layout than a rail-road terminal. These choices partly relate to the choice of train types. Block trains – these have a constant train length and wagon composition during one journey – or shuttles – these have a constant train length and wagon composition during a sequence of journeys – are suitable for direct networks or terminal-based complex bundling networks. For shunting-based complex bundling networks:

- complete trains must be used. These change there length and wagon composition during a journey, but aim at having full trainloads during an entire journey;
- or wagonload trains must be used. These change the train lengths during the journey.

Single wagon exchange in intermodal transport is relatively expensive. The exchange of wagon groups was the backbone of intermodal transport in Europe during the 1990s, has very acceptable costs and time performances, but is not suitable for the less-than-wagongroup market. Rail-rail transhipment at true hub terminals has convincing performances for all rail markets, but has, up to now at least, nevertheless only had a very limited market penetration. Rail-rail transhipment at a rail-road terminal has poor performances (long dwell times of load units at the terminal). UIC (2008) advises not to apply such operation except for long distances. It has nevertheless been implemented on a rather large scale (under the name gateway, not to be mixed up with the concept of “extended gateways”, described above), probably because time disadvantages are hardly relevant in the maritime market and because new players in the rail freight market can use their own node infrastructure without depending on the node infrastructure of old players.

In addition bundling choices address the ***spatial configuration*** of the transport network. It has a specific impact on the functional characteristics of a network. An illustrative example of large practical relevance is the location of a hub in a HS network. Take the port of Rotterdam. For intermodal rail transport it has no hub. If flow sizes are insufficient for direct trains, L bundling is applied: inbound trains are “half” loaded at the Maasvlakte. The other “half” is added at another terminal in the port (RSC) where the train stops on its way to the hinterland.
The ongoing growth of transport volumes is accompanied by an increasing number of rail terminals in the port, making it increasingly difficult to integrate the flows by L bundling. HS bundling is a promising alternative or supplement. Now the question is where to locate the hub, 1) on the Maasvlakte where about 80% of all container transhipment takes place, or 2) at the east end of the port? 3) Or should one use an existing hub in the hinterland, such as Duisburg, Herne, Neuss, Cologne or Antwerp?

Ad 1) A hub on the Maasvlakte is good in terms of its location close to the freight gravity point. However, the location is less suitable to integrate the flows of the other rail terminals in the port and of other seaports, because this would imply detours and increase track occupation in the port. The infrastructure capacity reserves are small already.
Ad 2) A hub at the east end of the port can easily integrate the flows of all rail terminals in Rotterdam and of other seaports without causing detours and with a minimal use of tracks through the port.
Ad 3) Hubs in the hinterland (Figure 3-B) have the advantage that they already exist, at least on certain performance levels, which are not always the best ones. However, such a hub is only suitable for the flows to and from that corridor.



Source: Kreutzberger and Konings, 2008.

Figure 3 Bundling via corridor neutral hub or corridor specific hubs

Comparing option 2 (and 1) on the one side and 3 on the other side, a further distinction can be made, namely between what we call a corridor-neutral hub and a corridor-specific hub. The location of the first is suitable for all transport corridors from and to Rotterdam. A hub in the hinterland is only suitable for the involved corridor and can not play a role for any other corridor of Rotterdam. The corridor-neutral hub allows to organise more trainloads, as Figure 3 indicates, again for simplified networks. For Rotterdam, given the forecasted O/D flows, the difference is about 20%. The corridor-neutral hub can lead to about 20% more trains than the corridor-specific hubs (Figure 3-A).

2 Modelling challenge

2.3 Network design framework

In the modelling approach described hereafter, we assume a certain service frequency to be required and applied, and a certain network transport volume to be given. The latter is a temporary and pragmatic assumption, in awareness of the fact that the demand depends on the performances in relation to those of competing modes.

The **rail policy objective** is to increase:

- transport sustainability by shifting flows from the road to the rail sector;
- the utilisation of link tracks.

The **network design objective** is:

- to minimise door-to-door transport costs by choice of bundling type for transport between a given set of BE terminals in the seaport and another set of BE terminals in the hinterland;
- to achieve door-to-door rail costs which are equal to or lower than those of competing modes;
- to maximise the number of load units making use of a train path.

A central entity in the modelling is the fixed costs of trains, in particular of the train traction, and how the transported load units will pay these costs, in other words what the costs per load units are.

The question whether to and – if so – how to incorporate the fixed costs is an important element of the problem definition. We argue:

- that fixed costs need to be explicated to express scale or scope economies, hereby distinguishing our approach from approaches:
    - applying flat vehicle costs which only depend on distance (e.g. Rutten, 1995, who uses transport time to represent vehicle costs);
    - based on flat vehicle costs which – on trunk routes – are corrected by discount factors which reflect the larger size of vehicles in these routes (e.g. O'Kelly, 1986)
- that fixed costs in service network design for most European intermodal rail freight networks ought to be modelled only at the level of trains, and not on the level of node or link infrastructure. In this regard our approach differs from the hub location approach, which inserts a fixed cost for setting up and establishing hubs. For instance, O'Kelly (1986) has fixed costs for hubs instead of fixed costs for vehicles (air planes in the USA), Groothedde (2005) has fixed costs for hubs next to fixed costs for vehicles (trucks in European distribution networks);
- that the fixed costs per load unit should network-endogenously take account of the size trainloads. Other approaches relate fixed costs to the size of route flows (e.g. Mayer, 2001) or insert vehicle costs exogenously;
- that lowest fixed costs and therefore lowest total train costs per load unit are achieved in networks with the largest trainloads, not exceeding the constraint of maximal train sizes and train capacity;

- that in intermodal rail freight transport, a large trainload is a good first indicator for low average network costs per load unit (Kreutzberger 2008) and in this way for best or promising bundling networks.

This together allows us to focus on the organisation of large trainloads during the first modelling step. This rest of the paper focuses on this first step.

2.2 Organisation of large trainloads from and to large seaports

2.2.1 The modelling of trainloads

Table 1 shows an O/D matrix of intermodal rail flows from rail terminals in seaports to (a selection of) inland terminals. The flows are expressed in number of trainloads: “1” stands for one full trainload, which is the number of load units if 600m of train wagons are loaded by 80% (100% = 60 load units; 80% = 48 load units). The values are fictive. The origin terminals are divided into three clusters, two of which represent different port regions (like in Rotterdam the Maasvlakte and the rest; or in Antwerp the left bank and right bank terminals), and the third representing other ports (like Amsterdam, Moerdijk, Vlissingen, Gent Zeebrugge). If inland terminals are located in the same inland region, this is expressed by colours in the tables. More sequential columns with the same colour (yellow or white; the terminals 1 and 2; 3, 4 and 5; 6 and 7; 8 and 9; and 10) are relatively close to each other. The light green cells in Table 1 have trainloads, which are considered to be suitable for direct transport. By subtracting full trainloads from these cells, the O/D matrix for organising complex bundling train services is established (Table 2).

Table 1 Origin/destination matrix of intermodal rail flows

	From ↓	To ->	Terminal 1	Terminal 2	Terminal 3	Terminal 4	Terminal 5	Terminal 6	Terminal 7	Terminal 8	Terminal 9	Terminal 10	and so on
Terminal cluster 1 in the large seaport	Terminal	A	0,3	0,6	0,2	0,1	0,0	0,3	0,3	0,2	0,3	0,3	
	Terminal	B	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	
	Terminal	C	0,3	0,6	0,1	0,1	0,1	0,3	0,3	0,3	0,3	0,9	
	Terminal	D	0,0	0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
	Terminal	E	0,3	0,6	0,1	0,0	0,1	0,3	0,3	0,1	0,3	0,9	
	Terminal	F	0,3	0,6	0,1	0,0	0,1	0,3	0,3	0,7	1,0	0,9	
	Terminal	G	0,3	0,6	0,1	0,0	0,1	0,3	0,3	0,1	0,3	0,9	
Terminal cluster 2 in the large seaport	Terminal	H	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	
	Terminal	I	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	
	Terminal	J	0,3	0,3	0,1	0,0	0,0	0,3	0,3	0,1	0,3	0,3	
Outside of the large seaport	Terminal	K	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
	Terminal	L	0,0	0,9	0,1	0,0	0,0	0,3	0,3	0,1	0,3	0,0	
	Terminal	M	0,3	0,3	0,1	0,0	0,0	0,3	0,3	0,1	0,3	0,3	
	Terminal	N	0,0	0,0	0,1	0,2	0,2	1,3	0,0	0,1	0,5	1,0	
	Terminal	O	0,9	0,9	0,1	0,0	0,0	0,0	0,9	0,1	0,0	0,0	
	TOTAL		3,0	6,6	1,1	0,5	0,6	3,7	3,3	1,9	3,6	6,1	

(in number of trainloads *)

* 1 trainload = the load of a 600m long train with loading degree of 80% = 48 load units.

We illustrate the complex bundling options for HS networks (Subsection 2.2.2) and other bundling networks (Subsection 2.2.3).

2.2.2 HS networks

In HS networks we distinguish the network parts before and after the hub. A train to the hub carries load units for many inland terminals, represented by the combination of cells in Table 1 horizontally.

The physical bundling choices determine how many directions may be included. For wagongroup trains the number of directional groups (= wagons groups) must be limited, in order to allow shunting at a flat shunting yard. We assume four inland

Table 2 Origin/destination matrix for complex bundling
(in number of trainloads *)

	From ↓	To ->	Terminal 1	Terminal 2	Terminal 3	Terminal 4	Terminal 5	Terminal 6	Terminal 7	Terminal 8	Terminal 9	Terminal 10	and so on
Terminal cluster 1 in the large seaport	Terminal	A	0,3	0,6	0,2	0,1	0,0	0,3	0,3	0,2	0,3	0,3	
	Terminal	B	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	
	Terminal	C	0,3	0,6	0,1	0,1	0,1	0,3	0,3	0,3	0,3	0,0	
	Terminal	D	0,0	0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
	Terminal	E	0,3	0,6	0,1	0,0	0,1	0,3	0,3	0,1	0,3	0,0	
	Terminal	F	0,3	0,6	0,1	0,0	0,1	0,3	0,3	0,7	0,0	0,0	
	Terminal	G	0,3	0,6	0,1	0,0	0,1	0,3	0,3	0,1	0,3	0,0	
Terminal cluster 2 in the large seaport	Terminal	H	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	
	Terminal	I	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	
	Terminal	J	0,3	0,3	0,1	0,0	0,0	0,3	0,3	0,1	0,3	0,3	
Outside of the large seaport	Terminal	K	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
	Terminal	L	0,0	0,0	0,1	0,0	0,0	0,3	0,3	0,1	0,3	0,0	
	Terminal	M	0,3	0,3	0,1	0,0	0,0	0,3	0,3	0,1	0,3	0,3	
	Terminal	N	0,0	0,0	0,1	0,2	0,2	0,3	0,0	0,1	0,5	0,0	
	Terminal	O	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,1	0,0	0,0	
	TOTAAL		2,1	4,8	1,1	0,5	0,6	2,7	2,4	1,9	2,6	1,5	

terminals to be the maximum to be bundled in a train (Table 3). For networks with a terminal hub the limitations are less. We provisionally assume that there are no limitations. The cells can be combined randomly.

Table 3 Examples of cell combinations representing the bundling up to the hub
(maximally four cells in wagongroup trains; selection from Table 2)

	From ↓	To ->	Terminal 1	Terminal 2	Terminal 3	Terminal 4	Terminal 5	Terminal 6	Terminal 7	Terminal 8	Terminal 9	Terminal 10	and so on
Terminal cluster 1 in the large seaport	Terminal	A	0,3	0,6	0,2	0,1	0,0	0,3	0,3	0,2	0,3	0,3	
	Terminal	B	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	
	Terminal	C	0,3	0,6	0,1	0,1	0,1	0,3	0,3	0,3	0,3	0,0	

At the hub the directions are resorted, allowing the departing trains to have load units for one end-terminal. A train then has load units from different seaport terminals to a certain inland terminal, like 1, 2 or another one. In the matrix this process is expressed by combining cells within a column.

We distinguish two port clusters (like Rotterdam Maasvlakte and rest of Rotterdam; or like Antwerp left bank and right bank) and one other cluster consisting of rail terminals in other seaports. The flow bundling preferably takes place within a cluster (cluster rule 1). The advantage is the similarity in train roundtrips making it easier to let exchanging trains visit the hub at the same time. If bundling per cluster does not result in sufficient trainload, the flows of cluster 1 and 2 may be combined (cluster rule 2). If also this is not sufficient, the bundling of flows of all clusters may be considered (cluster rule 3). As the comparison of Tables 4, 5 and 6 shows, cluster rule 3 generates the largest size of trainloads (resp. 1; 1,8; 2) and number of trains (resp. 1; 2; 2), but the time characteristics of operations may be less favourable.

Whether a load can be considered to represent a trainload requires a criterion, namely from which size of trainload is considered to be feasible. If this was 1, the loads of clusters 1 and 2 in Table 5 would result in 1 train, leaving 0,8 trainloads to the road sector. If this is 0,9, the 1,8 trainloads are sufficient to organise two trains and non of the freight needs to go by truck. For this paper we chose 0,9 trainloads to be the criterion.

Table 4 Trainloads (= 1) for cluster rule 1

			To ->	Terminal 1		Load per cluster	of which by train	or by truck
		From ↓						
Terminal cluster 1 in the large seaport		Terminal	A	0,3	}			
		Terminal	B	0,0				
		Terminal	C	0,3				
		Terminal	D	0,0		1,5	1,0	0,5
		Terminal	E	0,3				
		Terminal	F	0,3				
		Terminal	G	0,3				
Terminal cluster 2 in the large seaport		Terminal	H	0,0	}			
		Terminal	I	0,0		0,3		0,3
		Terminal	J	0,3				
Outside of the large seaport		Terminal	K	0,0	}			
		Terminal	L	0,0				
		Terminal	M	0,3		0,3		0,3
		Terminal	N	0,0				
		Terminal	O	0,0				
		TOTAAL		2,1		2,1	1,0	1,1

Table 5 Trainloads (= 1,8) for cluster rule 2

			To ->	Terminal 1		Load per cluster	of which by train	or by truck
		From ↓						
Terminal cluster 1 in the large seaport		Terminal	A	0,3	}			
		Terminal	B	0,0				
		Terminal	C	0,3				
		Terminal	D	0,0				
		Terminal	E	0,3		1,8	1,8	0,0
		Terminal	F	0,3				
		Terminal	G	0,3				
Terminal cluster 2 in the large seaport		Terminal	H	0,0				
		Terminal	I	0,0				
		Terminal	J	0,3				
Outside of the large seaport		Terminal	K	0,0	}			
		Terminal	L	0,0				
		Terminal	M	0,3		0,3	0,0	0,3
		Terminal	N	0,0				
		Terminal	O	0,0				
		TOTAAL		2,1		2,1	1,8	0,3

Whichever cluster rule is applied, the cells within the envisaged cluster (combination)s can be combined randomly. Which cell combination per cluster is best, will depend on the size of the trainloads, the sorting efforts at the hub or begin terminal and on the characteristics of train roundtrips.

As up to the hub, also after the hub the exchange and train type influences what can be bundled. In case of wagongroup trains only a few begin terminals (= cells per column) can be combined. Otherwise we assume that there are no limitations. Again, the cells within the envisaged cluster (combination)s can be combined randomly. And again the best combination will be the one with the largest trainloads, and best sorting and roundtrip results.

Table 6 Trainloads (= 2) for cluster rule 3

			To ->	Terminal 1		Load per cluster	of which by train	or by truck
		From ↓						
Terminal cluster 1 in the large seaport		Terminal	A	0,3				
		Terminal	B	0,0				
		Terminal	C	0,3				
		Terminal	D	0,0				
		Terminal	E	0,3				
		Terminal	F	0,3				
		Terminal	G	0,3				
Terminal cluster 2 in the large seaport		Terminal	H	0,0	}	2,1	2,0	0,1
		Terminal	I	0,0				
		Terminal	J	0,3				
Outside of the large seaport		Terminal	K	0,0				
		Terminal	L	0,0				
		Terminal	M	0,3				
		Terminal	N	0,0				
		Terminal	O	0,0				
		TOTAAL		2,1		2,1	2,0	0,1

An alternative to cluster rule 2 or 3 or a supplement to all cluster rules is to apply “field combinations” for the bundling after the hub. In this case not only the cells within one column are combined, but instead the cells of several columns, for instance those of inland terminals 1 and 2 (Table 7). The operational meaning of such approach is that a train leaving the hub to the hinterland has load units to several inland terminals. The bundling applied in the hinterland can be L-, TCD- or TF bundling (Figure 4). The result is a HS network supplemented by L-, TCD- or TF bundling. Such bundling combinations are reasonable not only from the viewpoint of

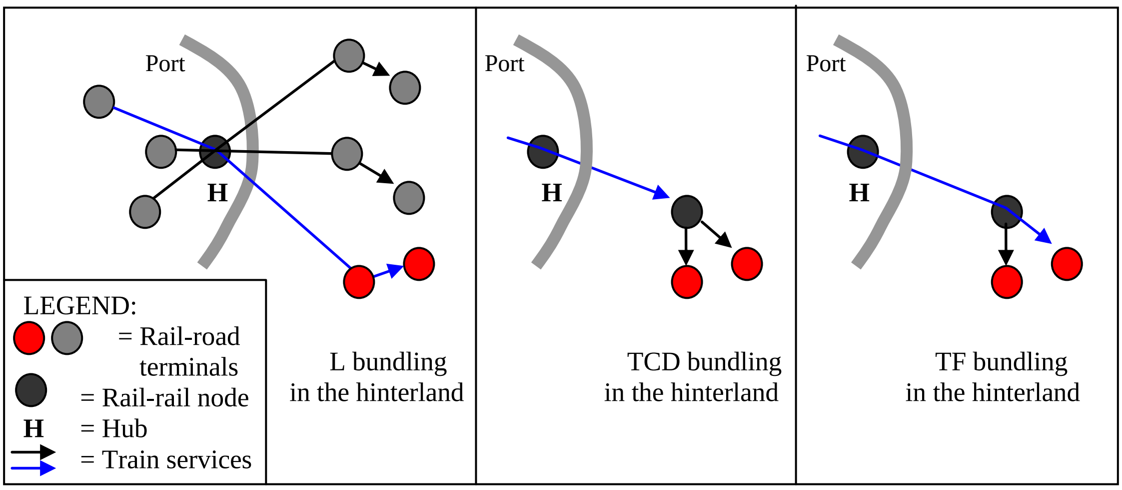


Figure 4 L-, TCD- or TF bundling in the hinterland as supplement to HS bundling

maximising the number of trains, but also to get more balance in the number of train routes at the port side of the hub and the inland side. In a pure HS network there are more routes at the inland side, implying a lower frequency or smaller trainload than at the port side. The combined HS/L-, HS/TCD- or HS/TF network has a much larger balance. The balance, however, is only relevant if the service frequency between each port terminal and hub is equal to or exceeds minimal standards, like a work daily service. Another way to put it, examining what can be bundled at the inland side of the hub, gives a good first impression for the entire hub network.

The operational condition for field combinations within HS networks is that the inland terminals are located in each others vicinity in order restrict the length of local train operations. Terminals 1 and 2 are relatively close to each other, as the yellow background in Tables 1 and 7 indicates.
The field combinations lead to (Table 7) 5,4 trainloads (= 6 trains of 0,9 trainloads each) for cluster 1, 0,9 trainloads (= 1 train) for cluster 2, and zero train(load)s for cluster 3, leaving 0,6 trainloads for the road sector. This is a better result than bundling per inland terminal (Tables 4-6). If this improvement leads to greater cost reductions than the additional costs due to the L-, TCD- or TF bundling in the hinterland, to be proven in a later step, the field combination deserves priority.
Field combinations with cluster rule 2 do not lead to better results than rule 1, while those with cluster rule 3 would result in 6,9 trainloads (7 trains) and no road transport at all.

Table 7 Trainloads (= 2) for "field combinations" and cluster rule 1

			To ->	Terminal 1	Terminal 2		Load per cluster	of which by train	or by truck
		From ↓							
Terminal cluster 1		Terminal	A	0,3	0,6				
in the large seaport		Terminal	B	0,0	0,3				
		Terminal	C	0,3	0,6				
		Terminal	D	0,0	0,6		5,4	5,4	0,0
		Terminal	E	0,3	0,6				
		Terminal	F	0,3	0,6				
		Terminal	G	0,3	0,6				
Terminal cluster 2		Terminal	H	0,0	0,3				
in the large seaport		Terminal	I	0,0	0,0		0,9	0,9	0,0
		Terminal	J	0,3	0,3				
Outside of the large		Terminal	K	0,0	0,0				
seaport		Terminal	L	0,0	0,0				
		Terminal	M	0,3	0,3		0,6	0,0	0,6
		Terminal	N	0,0	0,0				
		Terminal	O	0,0	0,0				
		TOTAAL		2,1	4,8		6,9	6,3	0,6

2.2.3 Other complex bundling

Starting from Table 2, similar approaches can be applied for other complex bundling types. Take L bundling. If the L bundling takes place in the hinterland, cells of a line in the table must be combined. If the L bundling takes place in the port, the cells of a column must be combined. If there is L bundling at both sides of the network, cells of a field in the table must be combined. The identified trainload refers to the trunk part of the network. The approach is the same for TCD- or TF bundling. The cluster rules 1, 2 and 3 are the same as for HS networks, the vicinity requirement is the same as for inland terminals in HS/L-, HS/TCD- or HS/TF networks.

2.2.4 Mix of bundling types

In practice, seldom only one bundling type or even one complex bundling type is applied. Next to direct bundling, there may be HS-, L-, TCD- and/or TF bundling. One can in the initial modelling provide all bundling types and than analyse their market shares. Such approach, however, faces the difficulty that the result influences the performances, which on its turn affects the bundling choices. The uncertainty in this iterative process is whether bundling choices and performances converge. An alternative, applied in the Rotterdam study, is to define alternative rail scenarios and compare the results. Each scenario describes a sequence of bundling types to be implemented, for instance, first HS bundling, then L bundling, than road transport. Or first direct, then TCD bundling, then HS bundling, then road transport.

3 Conclusions

The paper has given an outline of major transport policy challenges for the intermodal rail sector to and from large and other seaports and of related service network design challenges. It has pointed out the relevance of large trainloads with regard to the height of fixed costs per load unit and to a good utilisation of rail infrastructure. In combination with a conclusion from other research, namely that the size of the trainload is a good first indication of being able to achieve low transport costs, and in this sense a good first indication of a promising bundling network, the rest of the paper is devoted to the identification of promising bundling configurations in terms of trainloads. The description of the steps is a first step to automate what in former tactical studies has been carried out by hand. The bundling options in the illustrative network as described in this paper are already numerous, while this was a network with a relatively limited number of nodes (O-D pairs). Therefore, it is clear that dealing with such network design issues in practice need more advanced mathematical tools. The trainload module is planned to be a part of an integral model identifying best or promising bundling configurations on the level of direct, generalised or social costs, applying optimisation, micro-simulation or enumerative procedures.

References

Daganzo, C.F. (1999). Logistic Systems Analysis, Third edition, Springer.

Groothedde, B. (2005). Collaborative logistics and transportation networks. A modeling approach to hub network design, TRAIL Thesis Series, TNO, Delft.

Horner, M.W. and M.E. O'Kelly (2001). Embedding economies of scale concepts for hub network design, in: Journal of Transport Geography, 9, pp. 255-265.

Kreutzberger, E. (1995). Het bundelen van vervoerstromen en de verandering van knooppuntfuncties, in: Vervoerslogistieke werkdagen 1995, pp 375-396, Venlo.

Kreutzberger, E. and R. Konings (2008). Railscenario's en railconcepten voor de bundeling van spoorstromen in/van en naar de haven van Rotterdam in 2020/2030, in: Erasmus Universiteit and TU Delft: Coördinatie op het Havenspoor, Management Summary, commissioned by the Port of Rotterdam and ACtransPORT, public version of PP presentation forthcoming, Rotterdam and Delft.

Kreutzberger, E. (2008b). The Innovation of Intermodal Rail Freight Bundling Networks in Europe. Concepts, Developments, Performances, TRAIL Thesis Series nr. T2008/16, Delft.

Mayer, G. (2001). Strategische Logistikplaning von Hub&Spoke-Systemen, DUV, Gabler

Edition Wissenschaft, Darmstadt.
O´Kelly, M.E. (1986). The Location of Interacting Hub Facilities, in: Transportation Science, vol. 20, no. 2, may, pp. 92-106.
UIC (2008). Agenda 1015 for Combined Transport in Europe, January, Paris.