FROM BUNDLING THEORY TO NETWORK AND NODE INNOVATION: INTERMODAL RAIL FREIGHT TWIN HUB NETWORK ANTWERP/ROTTERDAM (IRTHNAR)

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ABSTRACT

Most intermodal flows are too small to be transported in direct trains. This is – maybe surprisingly – even the case for the flows from and to large nodes like Rotterdam and Antwerp. Consequently, they need to be bundled "complexly", as in hub-and-spoke, line or feeder networks. The complex bundling provides economies of bundling, scale and scope, cumulating in large trainloads, high frequencies and a high network connectivity, also for small(er) flows. The Twin-hub concept extends this idea to international bundling: Rotterdam organises flows also from Belgium, Antwerp also from the Netherlands. Acknowledging the feature of port competition, a promising configuration is to let Antwerp flows travel in Rotterdam trains to regions, where Rotterdam is (potentially) well represented; and Rotterdam flows in Antwerp trains to regions where Antwerp (potentially) has a strong position. This and a few major infrastructural requirements, such as the building of a hub terminal Rotterdam, is the subject of the project. The paper describes the policy and research challenges, and the actions of the project, and first results.
The paper begins with the presentation of a "bundling theory". This covers multiple angles of bundling, one of the core issues of the transport sector, and provides in the understanding of relevant operational, performance and policy interactions. The bundling theory has played an important role when developing the Twin-hub concept.

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

1 Introduction

Currently, a group of actors in Europe is busy with the preparation of an innovative research and development project, called “Intermodal Rail freight Twin Hub Network Antwerp/Rotterdam” (acronym = IRTHNAR or Twin hub). It essentially comes down to letting “Rotterdam” flows take a lift in Antwerp trains, wherever the trains have or could have a strong market position, and “Antwerp” flows in Rotterdam trains, wherever they have or could have a strong market position. The flows of the smaller seaports should get attached to the train services of the large ports.

This concept of network innovation is based on 1) bundling theory in combination with 2) knowledge of concrete problems and challenges of ports and intermodal transport, and 3) intuition of promising solution directions. The expected advantages are improved transport performances in terms of network connectivity, trainloads, service frequency, and infrastructure utilisation, implying scale and scope advantages. The benefiting entities are the involved seaports and their regions, the served inland terminals and their regions, the intermodal sector and – derived – the sustainability of transport and welfare in Europe.

The paper is structured in the following way. Section 2 presents the functional basics of bundling theory, as perceived by the author, and indications of the potential performance improvements. Section 3 elaborates the relation between bundling theory and that of economies of scale or scope. Section 4 draws the conclusions and including why the Twin hub concept Antwerp/Rotterdam seems to be a very promising innovation.

2 Bundling theory

2.1 Innovative

The term “bundling theory” is innovative, as bundling features in documents of researchers and practitioners typically:

- either tend to represent a special field of attention within other theories and approaches, such as (service) network design, corridor studies, train scheduling, load planning, optimising and simulation areas within operations research. Being only a special field, the structure of bundling choices, their interactions and performance effects are not elaborated;
- or tend to focus on specific constellations within the total of bundling issues; constellations such as hub locations and hub-and-spoke structures, certain types of operations or concrete challenges in practice for instance a postal aviation network.

“Special field” rather than independent main field, “specific bundling constellation” rather than a generic approach of bundling problems.

2.2 Theory ingredients

Bundling theory aims at an appropriate structuring of analytical and design activities. It discusses how the flows of different transport relations or commodities can be transported in a fashion generating scale or scope economies and minimising the efforts and other disadvantages of bundling organisation. In the centre of the theory are the so-called central bundling variables, namely size of network transport volume, number of vehicle routes (by choice of bundling type and number of begin-and-end terminals [= BE terminals] to be served), size of vehicle load, and height of transport frequency. They interact in a law-like way, namely that if the value of one variable changes, so does the value of at least one other variable. The interaction can easily be visualised by a kite structure (Figure 1). We refer to the name bundling kite-model.

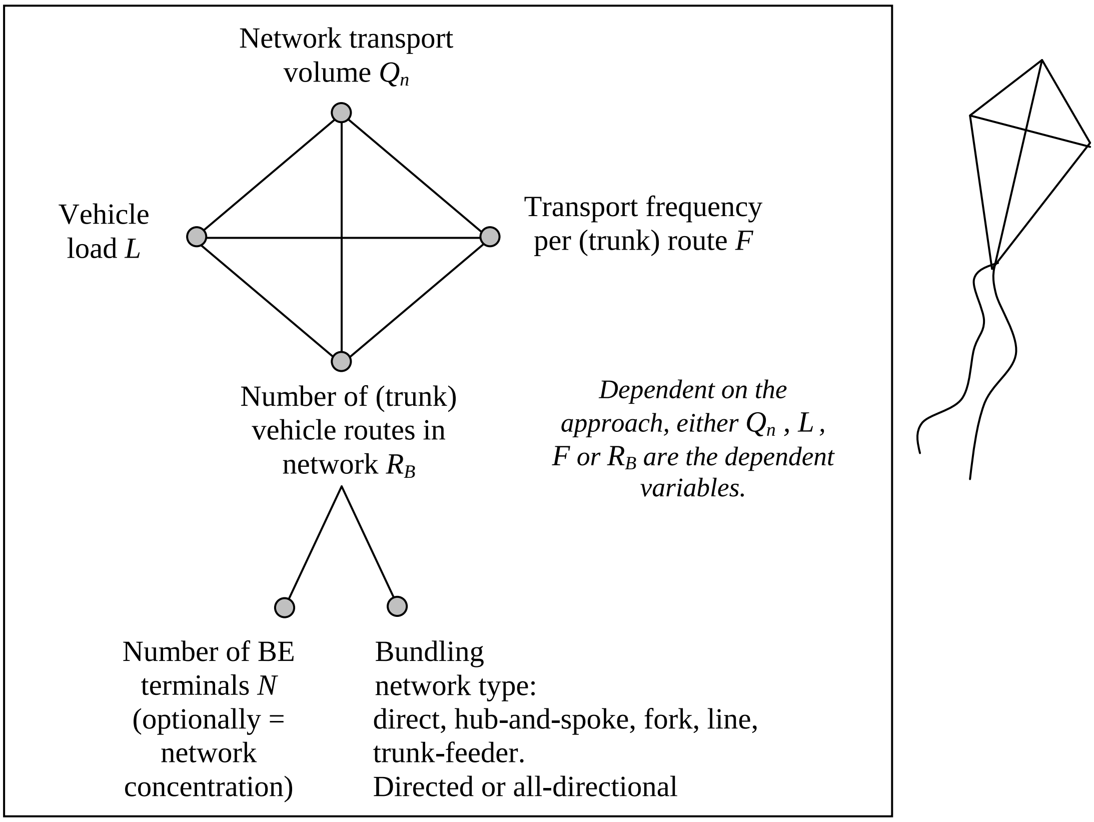


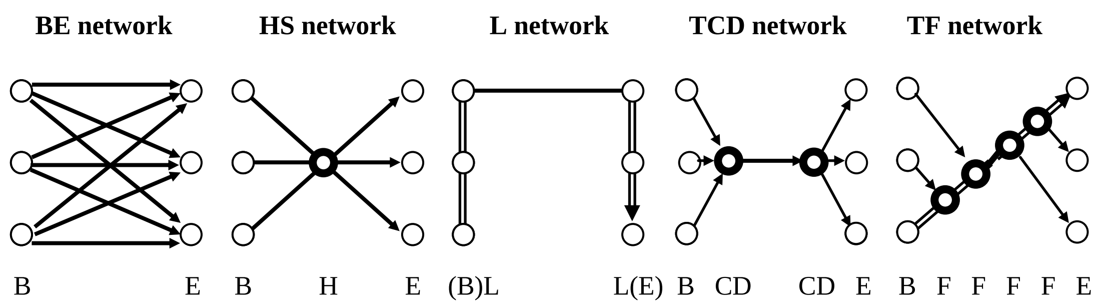
Figure 1 Interacting central bundling variables (bundling kite model)

The interactions are illustrated in Section 2.4, after having introduced some elements of a bundling typology, which is another core ingredient of bundling theory (Section 2.3).

2.3 Bundling typology

We distinguish five basic bundling types, namely direct networks (= BE networks), hub-and-spoke networks (= HS networks), line networks (= L networks), trunk-collection-and-distribution networks (= TCD networks or fork networks), and trunk-feeder networks (= TF networks). Another distinction is directed versus all-directional. In directed networks the exchanging vehicles move freight in a certain corridor direction, while the directional orientation in the all-directional networks is broader. Figure 2 shows directed versions of the basic bundling network types. Other typology distinctions are:

- whether the vehicle returns at an intermediate node passing on its load to a sequential vehicle operations with return vehicles) , or if a vehicle covers the entire transport distance between begin- and an end-terminal (operations with transit vehicles);



LEGEND
= trunk train service (BE network and HS network)
or trunk part of a trunk train service (L network and TF network)
= local part of a trunk train service (L network and TF network)
= local train service (TCD network and TF network)
= BE terminal (rail-road exchange) (in L network also L terminal)
= intermediate unimodal (e.g. rail-rail) exchange node

BE network = begin-and-end network (or direct network)
HS network = hub-and-spoke network
L network = line network
TCD network = trunk-collection-and-distribution network (or fork network)
TF network = trunk-feeder network

B = begin terminal E = end terminal H = hub node L = line terminal
CD = collection-and-distribution node F = feeder node

*
The figure does not show PPH.

The networks are directed ones.

Figure 2 Basic bundling types (directional versions)

- which physical exchange types are involved, a variable related to the vehicle type operated. For instance, in networks with transit trains, the rail-rail exchange at an intermediate is node carried out by shunting wagons at a gravity-shunting yard, shunting wagons groups at a gravity- or flat shunting yard, or transhipping load units at a terminal. The trains involved in networks with flat shunting yards are wagon group trains, each wagon group representing a directional group. The number of directions is restricted, like up tot three direction per train. In case of many directions per train (e.g.7 or 10), any shunting requires a gravity shunting yard. In case of terminal transhipment the trains can be a block train or shuttles. Block trains have a fixed train length and wagon composition during en entire journey, shuttles the same for a sequence of journeys. In practice, the term shuttle (or block train) is often related to direct bundling, but this association is mistaken. A shuttle (or block train) can also be a train type in complex bundling networks. The line trains passing the Rail Service Centre Rotterdam or the hub-trains passing the Mainhub Antwerp are examples;
- separated or diffuse networks, a distinction required for L- of TF networks. In the separated versions vehicles are either loaded or unloaded at an intermediate exchange node during the same journey, in the diffuse version the vehicles can be loaded and unloaded,
- network-simultaneous or network-sequential exchange at intermediate rail-rail nodes.

The bundling typology (for a more detailed description including gradual differences see Kreutzberger, 2008b) allows to qualify all basic bundling networks observed in practice, including what we call composed bundling networks, which are hierarchical or multiple versions of bundling networks. An example is multiple or hierarchical HS networks. Also networks analysed by O'Kelly and co-authors in different studies are composed HS-networks.

BE- or HS network only have trunk trains meaning trains with large trainloads. In terminal-based TCD- or TF networks there are other vehicles in the trunk than in the local network parts. Local trains have relative small trainloads. Terminal-based diffuse L networks more or less only have trunk trains. In the separated versions the trunk trains clearly run through "local" parts (relative small trainloads because only loading in the first and unloading in the last part of the service) and a "trunk" part of the network.

2.4 Bundling kite performances

2.4.1 Structure and mechanisms of the bundling kite model

The bundling kite model holds for all kinds of transport landscapes in practice, as illustrated for HS networks in Appendix 1. But from hereon, we restrict the focus to simplified networks, as these allow to demonstrate the quintessence of bundling choices without distraction by numerous real-life features. The simplification consists of the assumption that the flows of all network relations of a network have the same size (as in the network of Appendix 1-A). The quintessence consists of influencing the bundling characteristics or performances like:

- network volume suitability. Choosing the most appropriate type of bundling may will help to implement services with non-debatable services such as minimal vehicle load, minimal service frequency, and minimal network connectivity for a large range of network transport volumes, also small(er) ones. The impacts are relative low transport costs or generalised transport costs;
- vehicle load. Increasing the vehicle load implies that the fixed costs and also some variable costs (like variable infrastructure costs) per load unit are reduced;
- service frequency. The impact of higher frequencies are lower frequency costs, such as interest costs for goods in circulation or storage costs due to the service interval;
- network connectivity. This characteristic is about the number of end terminals accessed from a begin terminal. Given fixed service areas, a large number reduces the distance of pre- and post-haulage, a costly component in any transport chain. In case of sidings in rail networks or customers located directly along inland waterways, the begin- or end terminals will be origins and destinations respectively.

The networks in Figures 3a, b and c all have three begin terminals and three end terminals, implying 9 vehicle routes in the direct network, 3 in the HS network and 1 in the L network (1 would also be present in the not-shown TCD- and TF network): The number of vehicle routes in the three networks is 9:3:1, a difference that needs to be compensated by other values. In the Network volume approach (Figure 3a) service frequency and vehicle loads are the same in all bundling networks, and the imbalance due to the number of vehicle routes is absorbed by the network transport volume. This is 9:3:1. The policy implication is that the direct bundling network requires relatively large network volumes, the HS network medium-sized ones, and the L network small ones. In other words, the complex bundling networks enable transport landscapes with relatively small volume to achieve similar transport

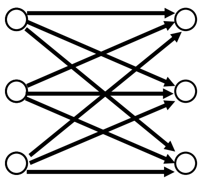
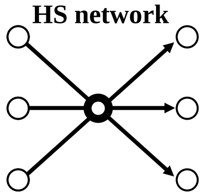
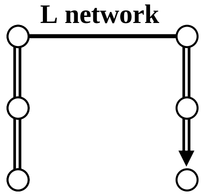
Bundling type *B*	**Number of vehicle routes** *R*	**Services/w** *F*	**Vehicle load** *L*	**Network volume/w** V_n
				LEGEND: see Figure 2.
BE network 	9 routes	* 6 services	* 60 load units	= **3240 load units**
HS network 	3 routes	* 6 services	* 60 load units	**= 1080 load units**
L network 	1 route	* 6 services	* 60 load units	= **360 load units** on the trunk part

Figure 3a Bundling network performances in the network volume approach

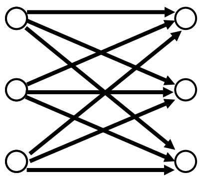
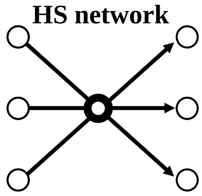
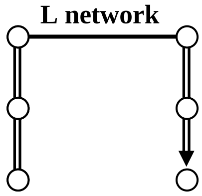
Bundling type *B*	**Number of vehicle routes** *R*	**Services/w** *F*	**Vehicle load** *L*	**Network volume/w** V_n
				LEGEND: see Figure 2.
BE network 	9 routes	* 6 services	* **20 load units**	= 1080 load units
HS network 	3 routes	* 6 services	* **60 load units**	= 1080 load units
L network 	1 route	* 6 services	* **180 load units**	= 1080 load units on the trunk part

Figure 3b Bundling network performances in the vehicle load approach

LEGEND: see Figure 2.

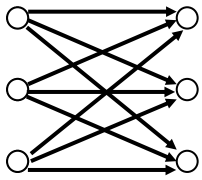
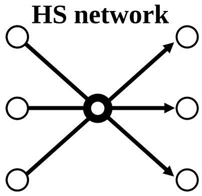
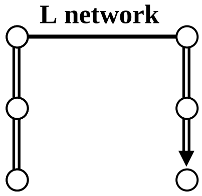
Bundling type *B*	Number of vehicle routes *R*	Services/w *F*	Vehicle load *L*	Network volume/w V_n
BE network 	9 routes	* **2 services**	* 60 load units	=1080 load units
HS network 	3 routes	* **6 services**	* 60 load units	= 1080 load units
L network 	1 route	* **18 services**	* 60 load units	= 1080 load units on the trunk part

Figure 3c Bundling network performances in the frequency approach

performances in terms of frequencies and vehicle loads that otherwise only networks with large flows can have.

Figure 4 shows the typical markets for bundling alternatives, per field applying the network transport volume approach (frequencies and vehicle loads are the same per field). The market segmentation in terms of required network transport volumes is very visible.

In the vehicle load approach the network transport volumes and service frequencies are the same in all compared bundling networks (Figure 3b). The different number of vehicles routes is compensated by the different size of vehicle loads. These are 1:3:9 in the direct, HS- of L network, in the given example 20, 60 or 180 load units a week respectively. Twenty load units means a very short train. Its costs per load unit will be unacceptable high. Sixty load units is the equivalent of a fully loaded 600m long train, meaning that the trainload is slightly below the European maximum (ca. 700m) and the train costs per load unit will be very low. One hundred and eighty load units is a trainload, which in Europe cannot be moved by trains. This load would be satisfying for American trains or certain European barges (300 TEU barges).

In the frequency approach the network transport volume and vehicle loads are the same in all compared bundling networks. The different number of vehicle routes absorbed by the service frequency, which is 2, 6 or 18 services a week in the direct, HS- or L network respectively. Two weekly services is a poor performance for the most relations in Europe, 6 a very good performance, 18 an unrealistic high level.

LUs in 1 direction	**2 departures / work day**									**1 departure / work day**									**2 departures / week**								
Number BE terminals →	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2,500,000								BE	BE																		
2,000,000							BE	BE																			
1,500,000							BE											BE									
1,000,000					BE											BE	BE										
500,000			BE											BE												BE	BE
475,000			BE											BE												BE	BE
450,000			BE											BE											BE	BE	
425,000			BE										BE	BE											BE	BE	
400,000			BE										BE												BE	BE	
375,000													BE												BE	BE	
350,000									HS				BE											BE	BE		
325,000								HS	HS				BE											BE	BE		
300,000		BE						HS	HS				BE											BE	BE		
275,000		BE					HS	HS	HS			BE												BE			
250,000		BE				HS	HS	HS	HS			BE												BE			
225,000		BE				HS	HS					BE											BE	BE			
200,000					HS	HS						BE											BE				
175,000				HS	HS	HS												HS				BE	BE				
150,000				HS	HS						BE						HS	HS				BE					
125,000	BE		HS	HS							BE				HS	HS	HS	HS				BE					
100,000	BE	HS	HS											HS	HS	HS					BE						
75,000		HS											HS	HS							BE						
50,000	HS									BE	HS	HS								BE				HS	HS	HS	HS
25,000	3B	3B	3B	3B	3B	3B	3B	3B	3B	HS									BE		HS	HS					
12,500										3B	3B	3B	3B	3B	3B	3B	3B	3B	HS								
6,250																			3B	3B	3B	3B	3B	3B	3B	3B	3B

HS net techni-cally in-feasible

Core area of HS net

HS net has rather short

LEGEND
3B (see beneath) = L, TCD or TF networks

The table shows in which markets networks with certain vehicles types achieve a "full" load.

Input variables are:

- network transport volume;
- number of BE terminals;
- bundling concept;
- frequency;
- number of service days a week.

Output variables are:

- train loads.
- markets with "full"train-loads

Figure 4 Bundling market diagram rail (700m trains, train loading degrees ≥ 70%, 250 days/year)

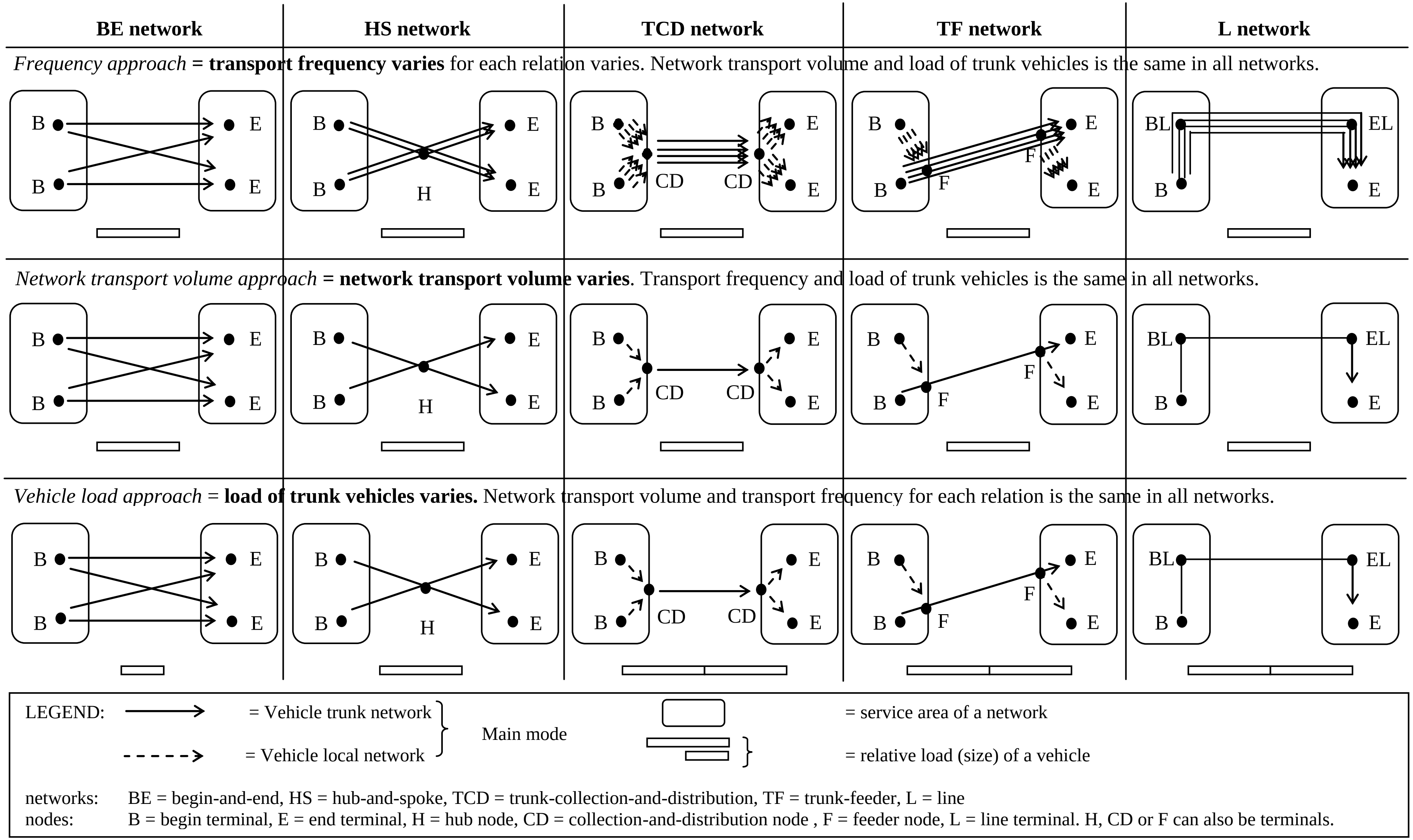


Figure 5 Frequencies, network transport volumes and the vehicle loads in different approaches
(directed and separated networks; only main mode = no PPH in picture)

Not shown, although equally valid, is the BE terminal approach, in which the network transport volume, service frequency and vehicle load is the same in all compared bundling types. Then also the number of vehicle routes must be the same, but the number of BE terminals will vary. Such situation is imaginable in network design when choosing between direct or HS bundling. For instance, with four vehicle routes one could realise a direct network with 2 BE terminals at each side of the network, or a HS network with 4 BE terminals at each side. Which type is better, now depends on network characteristics, which we have not yet discussed, namely the length of routes (complex bundling networks haven longer routes) and the presence of exchange costs at an intermediate exchange node in complex bundling networks. These performances advocate direct bundling. The potential disadvantages of network concentration (= longer pre- and post-haulage distances) have already been pointed out above. This disadvantage – pre- and post-haulage is relatively very costly per kilometre – may overrule the disadvantages of the HS network. Whether it does depends on the spatial characteristics of the transport landscape.

The three approaches are visualised in Figure 5. Each arrow represents a vehicle service. Two arrows per relation is to say that the service frequency is the double. The (relative) vehicle load is displayed by rectangles beneath each network.

The illustrated quantitative relation between the central bundling variables can be generalised for our simplified networks as in Equations 1 (vehicle load approach), 2 (frequency approach) and 3 (network volume approach). The suffix $_B$ indicates that a variable is bundling-type specific.

Vehicle load approach:

$$L_B = \frac{V}{R_B * F} \leq L_{\max} \qquad (1)$$

in which:

L_B = Load of a trunk vehicle in the trunk part of bundling network type *B* (e.g. in number of load units or tonnes)

V = Network transport volume in the trunk part of a network (e.g. in number of load units or tonnes)

F = Frequency (number of departures per time unit)

$L_{\max}$ = Maximal vehicle load

R_B = Number of trunk routes in bundling network type *B* (2)

$$= \begin{cases} N^2 & \text{for } B = \text{BE network} \\ N & \text{for } B = \text{HS network} \\ 1 & \text{for } B = \text{TCD network} \end{cases}$$

N **=** number of BE terminals at one side of the network

Frequency approach:

$$F_B = \frac{V}{R_B * L} \qquad (3)$$

in which:

F_B **=** Frequency in bundling network type B (number of services per time unit)

L = Load of a vehicle in the trunk part of each network.

Network transport volume approach:

$$V_B = L * R_B * F \qquad (4)$$

in which:

V_B = Network transport volume in the trunk part of bundling network type *B*

For cost calculations the R_B must be substituted by bundling factor B_B, which takes account of the transport volume impacts of an entire trunk route, whereas R_B of only the trunk part of a route. In the local parts of L train routes or of trunk train routes in TF networks the loading degree is a fraction of the loading degree in the trunk parts of both routes[1]. B_B in TCD networks is 1, in L and TF networks larger.

$$\bar{L} = \frac{V}{Bf_B * F} \leq L_{\max} \qquad (5)$$

From the bundling kite perspective, there is no best bundling type, but only one in relation to the characteristics of a transport landscape, such as the available or achievable network transport volumes, or such as the kind of performance requirements. For certain combinations of transport volumes and performance requirements the direct network, for others the HS network, and again for others the L, TCD or TF network are a best solution. On the other hand, the elaborations demonstrate that restricting the focus to direct bundling, mainly because of the expectation of less impedances at intermediate nodes, can have quite fatal consequences.

Evidently, the larger vehicle load, higher service frequency or same performance for smaller network transport volumes, represents scale, scope or other economies advantages. We present a new structuring in this field (Section 3), but will first discuss other properties of bundling choices., namely transport distance and time.

2.4.2 Comparison with other studies and models

The mechanisms generating cost economies as structured in the bundling kite model, differ largely from numerous studies and network design models. These can with regard to the cost economies of transport services be divided into three main categories: the first group instead of modelling cost economies assigns flat transport prices which depend only on the distance to links. A second group of models initially uses flat prices but for inter-hub connections corrects these by means of discount factors. The third group incorporates cost economies for the whole network. How this happens depends on the model's further structure and cost functions.

A common thread through the *first group* is the dominance of the shortest route as the structuring principle, measured in distance, time or flat costs. An example is a study by Rutten (1995) aiming to show the advantages of alternative consolidation in intermodal freight transport. In his assignment model "… distance or time is the sole measure of cost and the entire freight flow is assigned to the shortest distance or time path for each origin-destination pair" (page 214). In capacitated networks the principle of the shortest route is chosen, restricted only by infrastructural capacity constraints, due to which not always the shortest route can be followed.
An example of the *second group* is a study by Klincewicz (1991) who, following O'Kelly (1986), minimised the total costs of HS networks in a location model on the basis of distance-based linear unit costs on links. Link costs are proportional to distance and independent of transport volumes, which as far as links are concerned comes down to minimising distances or time. However, the initial unit costs of the inter-hub parts of services are corrected by a discount factor, initially only for the inter-hub links of the network, from a certain stage of model development on by applying differentiated discount factors for all links (Bryan, 1998, according to Horner and O'Kelly, 2001). A problem of the second approach is, as Horner and

[1] Unless we are dealing with freight-balanced L services (Chapter 5) or corresponding F trains in TF networks.

O'Kelly (2001, p. 255) criticise, the "exogenous nature of the discount factor. That is, most hub and spoke models assume that the level of interhub discount is not dependent on the amount of flow using the link".
The *third group* of models differs at this point, by relating costs to flow or vehicle load. The core idea is that fixed service or node costs per freight unit decline, the freight makes use of the services. Mayer (2000) describes the degression of total transport costs in dependency of the flow size between two nodes, a critical relation, because increasing flow sizes do not always reduce transport costs per freight unit, but can instead cause an upwards cost step, due to the need of a further vehicle with a low utilisation, making transport more expensive instead of cheaper. Groothedde (2005) corrects the variable and fixed costs by a factor μ_s, which is derived from utilisation rates of the "segments" of a route and displays cost economies. For the NODUS model, Jourquin and Beuthe (described in TERMINET; FUCAM, 1998) calculate costs as the quotient of fixed and variable costs on the one hand and the loading degree of the vehicle $\overline{L}$ on the other side. Essentially these two approaches do the same, and the clue to the appropriateness of their modelling of cost economies lies in the μ_s or $\overline{L}$. How is this related to the network structure and performance environment (like frequencies), which variables can function as decision variables, and how consistent are the interactions? Many studies could be more explicate in this regard.

Often it seems, although researchers may describe operational and performance interactions very well including ones in the field of bundling (as Crainic, 2003), that network design has no theory of why a network should have a certain structure (including the number of vehicle routes). Instead, given or varied networks are tested and the ones with best or near-to-best performances identified.

2.5 Other characteristics of complex bundling networks

Next to the presented advantages complex bundling networks have potential disadvantages, namely longer routes, in many cases additional handling costs at intermediate exchange nodes, longer operational times due to the longer routes and additional handling, and – in some cases – the presence of local networks. Longer routes unavoidably imply higher distance costs.

2.5.1 Longer routes

Fortunately the detours of complex bundling are restricted. An analysis for simplified networks – this time the geometry of the networks is simplified leading to networks as shown in the previous figures – reveals that within the main mode network the routes of HS networks are less than 10% longer than of direct networks, also if wide network shapes are in picture (Kreutzberger, 2008a). A brief look to Figures 2 and 3 confirms the plausibility of this finding, as also direct networks contain long routes, representing diagonals through the network. For other complex bundling types the detours are larger, and the challenge in this regard may be to select more longitudinally shaped transport landscapes.

2.5.2 Additional handling

The amount of additional handling at intermediate nodes in complex bundling networks depends on the type of bundling and other bundling characteristics. In directed terminal based networks with transit vehicles the additional handling at intermediate exchange nodes is:

- 0 in direct networks;
- 0,5-1 of each vehicle load in HS networks, or more precisely (*N*-1)**N* load unit transhipments, *N* being the number of BE terminals at each side of the network;

- 0 in L networks! The L terminals require handling time, but the number of rail-road transhipments is the same as in the direct network, a property in favour of this bundling type;
- 2 in TCD networks;
- 1-2 in TF networks.

As far as hubs are concerned, wagon shunting still is the dominant operation, but hub terminals are slowly upcoming. The Mainhub Antwerp is the pioneer in this field, building the first true hub terminal in the world; “true” due to its layout. The terminal does not (yet) represent a high-performance hub terminal, as developed in research and development projects in the 1990s. These dispose over an internal sorting and transport system which supports the crane movements and reduces train and load unit dwell times at the hub; optionally the operations are also robotised.
As far as rail-rail exchange is concerned, instead of transhipping load units one can exchange wagons along with their load units at flat shunting yards, if *N* and hence the number of involved trains is restricted, say up to 3. On the basis of operational timetables (Deutsche Bahn, 1998; Railion, 2001) and one source (Gaidschik *et al*., 1994), the quality and costs seem to be quite acceptable. Wagon group trains were the “backbone” of the European intermodal rail business in the 1990s (UIC, 2008; Kombiverkehr et al., 2007). The advantage of terminal based operations is that they are not restricted to the wagon group market, but also function in less-than-wagon-group markets, with – roughly – comparable quality and cost performances.
Externally achievable information about the costs of shunting single wagons at gravity shunting yards is scarce. One source (Symonds, 2001) suggest that this is quite costly. The time required for operational times of gravity shunting is substantially larger than for terminal transhipment.
Last but not least there is the emergence of so-called gateway terminals. This name refers to rail-rail transhipment at BE terminals, which primarily are designed for rail-road transhipment. Their popularity amongst rail operators is due to the independency they provide. Many terminals are controlled by the rail operators, contrary to the shunting yards being in hands of the classical railway companies or the infrastructure providers. In addition, the gateway network increases network connectivity substantially. However, the exchange quality of gateway terminals for rail-rail flows is poor, as the majority of flows go to or come from the service area of the terminal. The night-jump (like) arrival and departure times of the trains in many cases imply long dwell times, like 12 hours. Therefore UIC concludes that this rail-rail exchange configuration is only acceptable for very long distances.

As far as rail-road exchange at intermediate exchange nodes is concerned – only present in L networks – the future is clearly a terminal one, because wagon (group) exchange at these nodes requires local traction which also is very expensive. Terminal exchange currently also depends on local traction unless the trunk train is diesel powered, or the electric train enters the terminal with momentum or backs up into the terminal. Here the world is waiting for the commercial breakthrough of one of the many ideas to abolish the burden of electric power lines above terminal tracks, like the ones developed in the innovative projects Commutor (Jalard, 1993a and b), Transmann (Deutsche Bahn, 1993) or MetroCargo (ILOG, 2006)

2.5.3 Additional operational time

Vehicle routes in complex bundling networks have longer operational times due to the detours and the dwell times at intermediate exchange nodes. The time factors showing the ratio of operational time in complex bundling networks in comparison to direct ones, are larger than the distance factors. For HS networks the time is up to 30% larger; for distance this was only 10%.

The operational time, however, does not automatically imply an increase of cost-effective time. This is only the case for the operational door-to-door time of freight of customers applying the 24-hour economy. In the 8-hours economy the cost-effective time evolves stepwise, while the operational time increases. Also for timetabled vehicles like trains, the operational time is not the cost-effective time. The reason is the periodicity of vehicle roundtrips. The transport service, which the customer understands and appreciates, has same departure times on departure days, and same arrival times on arrival days. The periodicity implies a roundtrip time of 24 hours or a multiple of this, if the maximal frequency is to be 1 departure per day. If the periodical roundtrip is also to have evening departures and morning arrivals, like in night-jump operations, the periodical roundtrip time is (a multiple) of 48 hours. Or many distances, taking account of the average link speed, such periodical roundtrips represent a waste of time. Imagine the operational roundtrip to be 32 hours (including node dwell times), its periodical roundtrip time to be 48 hours, than 1/3 of the roundtrip time consists of waiting. Instead the operator may want to reduce the periodical roundtrip time, like to 36 hours. Now the roundtrip productivity is high, but the roundtrip time only leads to periodical departure and arrival times, of there are two daily departures. In general, shorter periodical roundtrip times than (a multiple) of 24 or 48 hours imply a higher service frequency than one departure a day. So this is only an option if the network transport volume allows such level of service, or if a bundling type is chosen, which reduces the network volume requirements to acceptable levels despite of the relative high transport frequencies.

Kreutzberger (2008) has elaborated the mechanisms of load unit and vehicle time, and – to the author's knowledge – he is the first to have elaborated the cost-effective time of freight of shippers applying the 8-hour economy. Although, sound information about the proportion of the 8-hour economy in the world of shippers in Europe is missing[2], the impression is that it plays an important role [3].
For trains, there are basic studies addressing the mechanisms and performances (like Lehner, 1978) and the progression of roundtrip productivity in dependency of increasing operational time.
Nevertheless, in transport modelling, there often is no distinction between vehicle time and freight time, and "the transport time" is modelled as for load units in the 24-hour economy. Examples are Daganzo (1999), Groothedde (2005) and Janic (2003 and 2007).

The important consequence of the stepwise progression of cost-effective freight or train time as operational time increases, is that for certain operational times any operational progression is none cost-effective and therefore useless. For other operational times, a substantial cost-reduction can be achieved, if only a restricted operational acceleration takes place. For bundling the same conclusion means that the dwell time of load units or trains at intermediate exchange nodes in many cases has no negative effects on (time) transport costs. In other cases the urgency to accelerate operations, including the exchange operations at intermediate nodes, is large. Such backgrounds may advocate high-performance hub terminals. Whether this applies, also depends on the type of goods involved and the related performance requirements.

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2 An example is the result of our informal information inquiry in 2008 at two Dutch and four German research organisations specialised in logistic research, the German ones also active for the Bundesvereinigung Logistik (BVL). The organisations could not provide information about the proportions of the 24- and 8-hour economy despite of their extensive study (Straube *et al*., 2005). The study of Colon (1997), carried out in the name of the Dutch transport organisation EVO, emphasizes the trend towards a 24-hour economy, but except for two examples (abattoirs and flowers) mainly focuses the transport sector and the legislation of truckers' driving times.

3 "The basic principle is still production and sales in the daytime and transport overnight" (Woxenius *et al*., 2007, page 14). Some flashlights with regard to standard production and working hours in Europe: "Overall, it appears that the 24-hour economy is not yet widespread in the Netherlands". (Smulders, 2006). Similar statements are the result of research of the Dutch SCP (2004). In Belgium, "developments in the various industries and the evolution of working times within them did not result in a general increase of non-standard work hours, at least not on weekdays". As far as the 24-hour society is concerned, however, "the organisation of work in Belgium and other European countries appears to be moving in that direction" (Glorieux *et al*., 2008). The last two sources are not goods-specific.

2.5.4 Performance requirements

This part of the bundling theory points out which performances the bundling network is to provide. For intermodal (bundling) networks the general perception is that intermodal transport is chosen for its low door-to-door costs, while road transport gives preference to transport quality (Cardebring, *et al*. 1998). From the commercial and societal viewpoint rail performances need to be improved in order to achieve a modal shift. Cost reductions would let break-even distances decline, while also quality improvements would attract freight from the road. It is this type or arguments that play a role in discussions about whether hub exchange should take place at high-performance hub terminals, and to which extent gateway transhipment is acceptable. The high quality ambitions of the innovation approaches of the 1990s in Germany (e.g. KV Technologieplattform 2000+) and France (Jalard, 1993 a and b) still seem to be relevant for modal shift. At the same time, a real commercial breakthrough in the field of high-performance bundling is still missing, and the willingness to pay for high-quality rail transport is very restricted, also for high-value goods (RUPS and NEA, 2003). Intermodal rail prices are under pressure, as many rail companies in Europe do not cover the costs of their intermodal operations. This is or was the case for the former national railway companies, the UIC companies.[4] New private operators have entered the intermodal market, like European Rail Shuttle, Rail4Chem or BLS Cargo. They make a profit, but are mainly active in the very profitable corridors, leaving the more difficult markets including the more difficult bundling markets to the UIC railway companies (Hughes, 2003; Woxenius and Bärthel, 2008). Service frequencies tend to be none-negotiable, meaning that the frequency approach hardly applies: “Less-than-daily services are not attractive” in intermodal transport (European Council for Applied Sciences and Engineering, 2000). On the other hand we have: “The marginal utility to shippers of an additional departure declines once a daily service is offered (Notteboom, 2008).

3 Economies of bundling, concentration, scale, scope, network and density

3.1 Contradictive definitions

Bundling touches upon the notions of economies of scale, scope, density and network, which describe the emergence of cost and other advantages (and disadvantages) as flow sizes increase. The theories are in development and characterised by deviations of definitions, as can easily be illustrated by some examples. We will, after giving examples, provide our own definitions in order to discuss the network design options which deal with a changing number of BE terminals with the required clarity.

Economies of scale describe cost advantages (returns) caused by an increasing transport volume of a same set of products, for instance transport services. If the outputs of a certain production increase faster than its inputs, we are dealing with scale advantages. Or as Jara-Diaz *et al*. (2001) put it: “There are economies of scale if an increase by the same proportion in all origin-destination pairs provokes an increase in costs by a smaller proportion”. Blauwens *et al*. (2001, pp. 358 and 359) distinguish scale advantages on the level of transport vehicles, infrastructure and an entire transport vehicle fleet. “Scale advantages on the level of vehicles are related to the fact that the transport capacity increases faster than the construction costs. … A larger capacity of e.g. roads proves to lead to significantly fewer cost increases. … As far as scale advantages on the level of an entire vehicle fleet are

[4] Germany (DB Cargo according to Deutscher Bundestag, 1995), Italy (Trenitalia according to Laguzzi, 2001), France (SNCF Fret according to Hahn, 1998; CNC according to Delavelle et al., 2003), the UK (Freightliner according to ECMT, 2003), Railion Netherlands up to 2005 (Kennisinstituut voor Mobiliteitsbeleid, 2007), InterFerryBoats in the NARCON network in Belgium, (Van Petegem according to Verberckmoes, 2007), and Europe (ICF according to Müller, 2005).

concerned the costs per unit of product must be compared between transport companies of different sizes".[5] The vehicle and fleet scale advantages refer to the purchase or the operation of vehicles respectively.
For Daganzo (1999) economies of scale arise when more goods share the fixed costs of a vehicle ("shipment") c_f, whereas variable costs per additional unit of transport c_v are the same for any flow size, as shown below. The number of vehicles is denoted by n, the vehicle load by V and the average vehicle load by $\bar{v}$.

Transport costs per unit of goods $= c_f * \frac{n}{V} + c_v = c_f * \frac{1}{\bar{v}} + c_v$

Some studies mention the number of "points served" as a characteristic/subject of scale economies, as it is considered to be distinctive and sufficiently simple in terms of manageable calculation efforts.
Panzar and Willig (1977) and Baumol (1977) "redefined economies of scale in a way that explicitly allowed multiple outputs within the same production process, and differentiated scale from scope effects" (Antoniou, 1991). "Scope economies emerge if the average costs of the combined production of product y1 and y2 are lower than the costs of a separate production of y1 and y2" (De Wit and Van Gent, 1996[6]). An example is an airline operating goods and passenger traffic, in common aircraft and/or by common computer reservation systems (Keeler and Formby, 1994). Similarly (Harmatuck, 1991): "Economies of scope exist when a carrier can produce a combination of TL and LTL services at less cost than any combination of specialising firms" (TL = truckload; LTL = less than truckload). The "multi-product" character of the production is a central feature of scope economies. Complex bundling, for instance HS networks, is often given as an example. The transport from A to B is for the customer different than from A to D, even if the same vehicle is used (De Wit and Van Gent, 1996). "Hence, benefits from economies of scope are the result of a careful combination of complementary processes and services" (Beuthe and Kreutzberger, 2001).

Economies of density are often defined indirectly, rather than in comparison with other cost economies. For example, studies distinguish density economies from scale economies by the fact that the first do not include returns due to the changing number of served points; the networks do not change. Instead the returns refer to geographical concentration patterns (Baily and Baumol, 1984,[7]), visible by larger traffic density (Mouwen and Rietveld, 2006), frequency (De Wit and Van Gent, 1996) and/or larger vehicle sizes. Talley (2001, page 317) with reference to a study by Harris (1997) stated that "railroads exhibit economies of density, where density was measured as revenue ton-miles of rail service per mile of fixed track". In such cases density economies refers more to infrastructure than to transport operations.
Blauwens *et al*. (2001, blz. 359) present a rather direct definition, which also focuses on transport operations: "Density advantages indicate that *variable* costs increase less than proportionally to increasing output, given a constant capital stock. … In this sense density advantages are the short term equivalent of scale advantages."[8] The authors do not give any examples, although one can think of the link infrastructure costs of trains, if these are charged as costs per train-kilometer. These are clearly variable costs. They are large per unit of freight if train loads are small, and small if train loads are large.

Jara-Diaz *et al*. (2001) observe the following contradiction: adding "points served", in other words new services to the network is said to be part of economies of scale. On the other hand, multiproduct (economies of scope) is about providing transport services for several relations. So scale and scope economies are both about services for different relations. The

[5] Translation by author.
[6] Translation by author.
[7] According to Keeler and Formby (1994).
[8] Translation and italic highlighting by author.

authors elaborate that economy of scope and scale are interrelated concepts, and (Jara-Diaz *et al*., 2001, p. 339): "…what is presently referred to as economies of density is actually economies of scale". A similar statement came from Hurdle *et al*. (1989[9]): the "… definition of 'density' is closer to what is generally considered as 'scale', while that of 'scale' resembles 'scope'". Jara-Diaz *et al*. (2001, p. 339) conclude: "This poses a demanding challenge for the future, which is to reveal the relation between other network related variables and the possible presence of economies of scope …. In our opinion, this approach encompasses various dimensions, beginning with the study of the process of transportation production itself. A fresh view of what inputs and outputs are, and what the technical process of transformation of the former into the latter is, would greatly help in re-establishing a research agenda for this topic" (page 339).

Part of the confusion about defining different types of cost economies is due to the envisaged level at which cost advantages are expected. Keeler and Formby (1994", page 24) conclude: "Economies of density were sometimes referred to as economies of scale at the … route level".

3.2 Consistent structuring of cost economies

Can a consistent picture be constructed, integrating the different, partly contradictory observations and conclusions given in the literature? We are convinced that this is possible, if the structuring responds to the following requirements: distinguish between the *cause* and the *level* of increasing transport volumes, let the cause give the name to the achieved returns, and analyse the returns on the level at which they emerge. The last point requires a disaggregation of cost calculations to those levels. For instance, mixing costs of nodes and links or transport services and infrastructure must be avoided.

The cause of cost economies can well be explained on the basis of Figure 6. It focuses on returns on the level of vehicle load. Other returns like frequency increases can be elaborated in a comparable way.

a) Switching from situation 2 to 1 in Figure 6, in other words concentrating the network by reducing the number of BE terminals while the service areas and network transport volumes stay – roughly – the same, leads to a reduction in the number of trunk routes. This is the case in the HS network, and even more for the BE network. The smaller number of trunk routes implies – the frequency does not change – that vehicle loads increase and cost advantages emerge[10]. Given the increase in the route transport volume (intensity) one could speak of *economies of density*. As the real cause is the network concentration, we refer to the term *economies of network concentration*. For TCD, L, or TF networks the number of trunk routes does not change, therefore cost advantages do not emerge.
b) Whenever an operator changes the bundling network (from left to right or vice versa in any part of Figure 6) the number of trunk routes changes while the network transport volume stays roughly the same. One could also associate this change with *density economies*. But as the cause is the choice of bundling type, we consider the term *economies of bundling* most appropriate. When switching within the group of TCD, TF or L networks, the number of trunk connections remains stable and additional cost advantages are absent.
c) The simple increase of network transport volumes without other changes (in other words we stay inside any network in Figure 6) generates higher frequencies and/or vehicle load, without the number of trunk routes changing. We are then dealing with *economies of scale*.

[9] According to Antoniou (1991).
[10] Unless the vehicle capacity is exceeded.

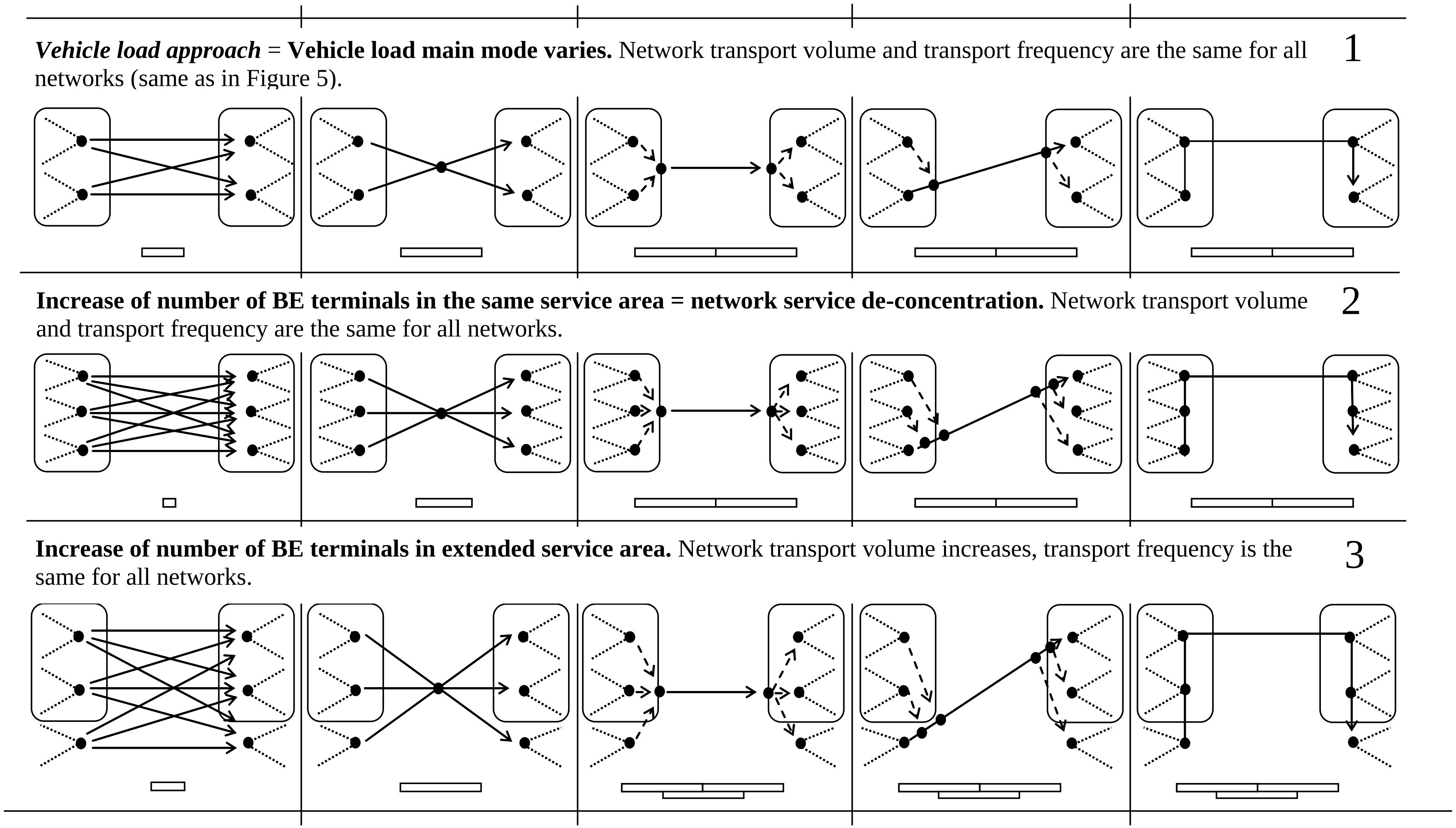

Figure 6 Cost economies related to the change of number of BE terminals. Figure only shows the main mode

d) An increase in the number of BE terminals and the service area (from situation 1 to 3 in Figure 6) truly increases the service area and network transport volume. This can lead to larger vehicle loads, in which case cost advantages emerge. The multi-product quality of the network is strengthened: adding different services (directions) to the network strengthens the multi-product quality of the network. We are then dealing with *economies of scope*.

These results partly deviate from other studies. Cost advantages, which could only be related to density economies, are not present in our overview. It appears to be – also given the examples from other studies – that density advantages mainly refer to infrastructure, not to transport services.
It is very important that other studies directly couple a change of BE terminals (points served) to a change of trunk vehicle routes. If one takes several bundling alternatives into account, such coupling does not hold. The number of trunk routes, highly relevant for vehicle load and other network performances, can change when the number of BE terminals does not change.

If the number of BE terminals changes, in some bundling networks (L-, TCD- and TF network) the number of trunk routes does not change. For the aggregation of network characteristics to a simple variable as "points served", the conclusions of Jara-Diaz (2001, p. 330) apply: "Aggregation of output over any dimension (commodity, time or space) involves losing information associated with the transport processes … The loss of information due to aggregation over any dimension may cause serious problems … when estimating or analysing a cost function".

Elaborating point d (switch from situation 1 to 3 in Figure 6), network transport volume *V* increases proportional to the addition of points served. Vehicle load *L* changes according to Equation 6. The prime $'$ in V' stands for adjusted values, while the original value (= reference) is denoted without prime.

$$L_B' = L_B * \frac{V'}{V} * \frac{R_B}{R_B'} * \frac{F}{F'} \leq L_{\max} \qquad (6)$$

If frequency remains unchanged, vehicle load changes in accordance to $\frac{V'}{V} * \frac{R_B}{R_B'}$. If the addition of trunk routes leads to $\frac{V'}{V} * \frac{R_B}{R_B'} > 1$, then vehicle load increases. This is the case for the TCD-, TF and L networks. But $\frac{V'}{V} * \frac{R_B}{R_B'} = 1$ as for the HS network, or even $\frac{V'}{V} * \frac{R_B}{R_B'} < 1$ as for the BE network. In the HS network with our simplified network volume assumptions the advantage of adding service area is absorbed by the additional vehicle route. The vehicle loads remain constant. In the BE network the enlargement of the service area implies an above-proportional addition of vehicle routes, letting the vehicle load shrink. For all bundling types the network connectivity improves.

The abstract conclusions can be tested for the situations in Figure 6 (from situation 1 to 3).

BE network: $L_{BE}^{'} = L_{BE} * \frac{3}{2} * \frac{4}{9} \;=\; 0,67 * L_{BE}$.

HS network $L_{HS}^{'} = L_{HS} * \frac{3}{2} * \frac{2}{3} \;=\; 1 \; * L_{HS}$.

TCD-, TF- or L network: $L_{B}^{'} = L_{B} * \frac{3}{2} * \frac{\leq 1}{\leq 1} \;=\; 1,5 \; * L_{B}$.

So far our suggestions to structure cost economies and some indicative results for simplified networks. In reality, the results depend on the real volumes of the areas served, and for HS bundling a change from situation 1 to 3 may increase vehicle loads because the freight generating power of the included service area is large. This expectation is the starting point of the Twin hub network Antwerp/Rotterdam. In addition, numerous trains do not have a maximal trainload, but significantly less. Adding a spoke can improve the average loading degree, if the spoke itself has large trainloads.

4 Conclusions: the Twin hub network Antwerp/Rotterdam

From the theoretical and practical arguments and considerations of Sections 1-3, in awareness of the bundling network evolution and innovation trends in Europe of the last 20 years, and having been involved in analysis and design of train and bundling networks for large and small seaports in this region, the project idea has of the Twin hub network Antwerp/Rotterdam for intermodal rail flows has been borne. Its basic idea is:

- that most flows from and to the mainports – maybe surprisingly – are too small to be moved by direct trains;
- that the network volume of the smaller seaports are well served by the pallet of good train services from and to the mainports. Independent train services are possible for some relations and on the long term;
- that the currently applied type of complex bundling in Rotterdam, namely line bundling via the Rail service centre Rotterdam, makes insufficiently use of the track infrastructure, as the trains are only loaded half during most of their port journey;
- that hub-and-spoke bundling is an excellent alternative or supplement for the line bundling in Rotterdam;
- that the Twin-hub concept extends the service area of each hub into the other country, but only for complementary train corridors. The expectation is that this increases bundling economies and represents win-win policy;
- that the hub-and-spoke advantages and their enlargement by the Twin-hub setting benefits not only the seaports and their regions, but also the served inland terminals and their regions. There is a perspective that also inland terminals can be served which do not have enough substance if they are only connected to one of the hubs (Figure 7);
- that no train in the Twin-hub setting should visit two hubs during a journey;
- that the Rotterdam hub should be a true hub-terminal, optionally – dependent on the research results – even a high-performance hub terminal;

- that the issue of high-performance hubs has been explored in the 1990s, but that more precise information about its unavoidability has not been published, and still needs to be investigated;
- that the switch from basic to high-performance hub terminal could also be an option for Antwerp, as its Mainhub is approaching saturation;
- that from the viewpoint of flow integration by means of the Rotterdam hub, its location should be at the east end of the port. This location most likely is not in conflict with Maasvlakte internal bundling;
- that a pilot should be started demonstrating the benefits;
- that the pilot is dealing with suboptimal link (both mainports) and node (Rotterdam) infrastructure in the initial phase. The use of rail-road terminals and even wagon group trains exchanging at Kijfhoek may be a temporal outcome;
- that a research and development project should be started addressing the total spectrum from flow analysis, modal shift analysis, service network design in the Twin hub-setting, the development of business plans, and the analysis of privat and societal costs and benefits;
- that in such a project the port authorities of the mainports and other ports ideally cooperate, just as the hub-and-spoke train and bundling services may be provided by more than one company. The latter is innovative, as most hub-and-spoke bundling from an to ports takes place within one company or a family of companies and involves only the seaports of one country.

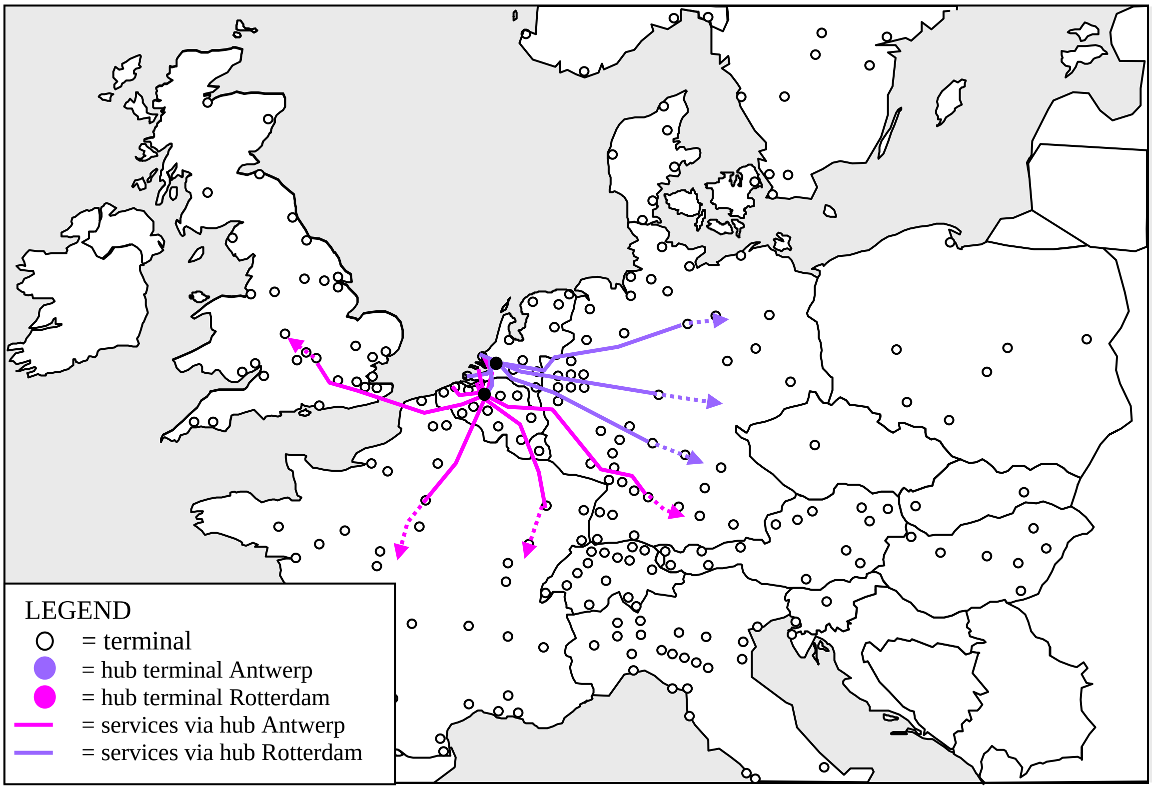

Figure 7 Example of potential Twin hub train services from/to European inland terminals

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Appendix 1 Illustrations of the general validity of the bundling kite model