The shipper's perspective on distance and time and the operator (intermodal goods transport) response

Ekki Kreutzberger[1●]

[1] *Delft University of Technology, Research Institute OTB, Delft, The Netherlands*

Abstract

This paper is about distance and time in alternative bundling networks and roundtrip models. First the relevance of transport costs and time for customers of intermodal transport is reviewed. Then the paper focuses on vehicle roundtrip design in European intermodal rail networks and the perspectives to accelerate roundtrip speed. Acceleration often implies an increase of service frequency. As transport volumes often will not justify higher frequencies, the introduction of so-called complex bundling (e.g. hub-and-spoke or line services) may be an outcome. Complex bundling allows applying a relative large vehicle scale, despite of restricted flow sizes. This cost advantage is likely to overrule the cost disadvantage of longer routes in complex bundling networks. An important indication for this fact is a comparison of total network distances and times. The last part of the paper compares the distances and times of about 150 networks (different bundling concepts and network geometries). It shows that the additional length of routes of complex bundling networks is always overruled by the distance and time impact of a lower number of connections between begin- and end terminals in complex bundling networks

Keywords: Intermodal goods; Time; Distance; Networks; Bundling; Roundtrips.

1. Introduction

Distance and time are key factors in the design of transport and logistic networks as they indirectly influence the costs of vehicles, load units and goods in circulation, and node infrastructure.

Public and private transport companies are generally interested in cutting transport times by, for example, reducing distances. This could be achieved by choosing routes in an infrastructure or service network that minimize distance, by adding missing infrastructure or service links and, last not least, by increasing driving speeds on links and/or reducing node times (thereby reducing link times).

Section 3 of this paper deals with a part of this spectrum, namely, the acceleration of transport. Section 4 concentrates on the relevance of distance and time in complex bundling networks. This subject has scarcely been researched, even though bundling

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[●] Corresponding author: E. D. Kreutzberger (E.Kreutzberger@otb.tudelft.nl or sokreue@dso.denhaag.nl)

choices affect distance and time through more channels than simply the network layout (choice of route determined by infrastructure or service/vehicle). It is therefore no coincidence that roundtrip and innovative bundling are the main strategies for making intermodal transport more competitive.

The themes of Sections 3 and 4 may appear separate at first glance but are actually closely interrelated.

The paper starts (Section 2) with a brief literature review on the import of the cost and quality of transport for shippers. Section 5 presents the summary and conclusions.

2. What transport time means to the customer

Unimodal road transport is the reference point for intermodal transport. Whenever shippers or other purchasers of transport services choose a modality, route or company, they pay attention to general costs, door-to-door (DTD) costs, frequency, reliability (in terms of time, damage and loss), flexibility, maximum weight and size of the shipment, the possibility of sending partial loads (LCL-/LTL), and the quality of information (e.g. the status and position of freight). Some customers may also be interested in secondary performances[1].

People are becoming increasingly aware of the relevance of these factors in the choice of modality. Almost all the consulted studies conclude that the price/cost[2] of goods transport is the most important factor in the overall performance. CONFETERA (1997) elaborates on this a little by indicating that reliability is slightly more important in the material management phase than in the distribution phase[3] . The transport price consists of time, distance[4] and other elements (e.g. profit, taxes). IQ (2000)[5] observes that a good price matters most to users of intermodal transport. For users of road transport it is quality that matters most.

The studies are less specific on the question of which factor is most important after costs: reliability, DTD time, frequency… – all of which create extra costs for the customer, such as interest charges for goods in circulation, and buffer costs, which are not already incorporated in the transport price.

Time reliability is most important, coming ahead of transport time, according to SPIN[6] (2002), IQ (2000), CONFETRA (1997), Beuthe et al. (2003)[7] and Vandaele and Witlox (2003)[8]. The seven cases cited by Bergentino et al. (2003) [9] are characterized by

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[1] Examples: the synchronization of sequential transport services, the possibility of buffering loaded or empty units for a while, the quality of road accessibility at terminals, or the number of destination regions which a train or barge can access from a specific start terminal without increasing the pre- and post-haulage distance too much.

[2] The transport prices are costs to the customer.

[3] By 0.1 point on a scale of 1-5.

[4] The time costs are often regarded as fixed and the distance costs as variable. De Jong *et al.* (2004) apply an alternative distinction: depreciation represents fixed costs (as above), and labour represents variable costs (contrary to above).

[5] IQ = Intermodal Quality. This European study raises the question of the key performances which make a customer choose intermodal or unimodal road transport.

[6] SPIN = Scanning the Potential for Intermodal Transport.

[7] They analyse the preferences of shippers in different industrial sectors. Indicative results are presented for 6 sectors. Some make use of road, some of barge and others of multimodal transport.

[8] They analyse the preferences of shippers in different industrial sectors. Indicative results are presented for 5 sectors. Some use road, some use barge and others use multimodal transport.

relatively low frequencies. The seven companies therefore regard frequency as far more important than transport time or reliability. For road transport De Jong et al. (2004) estimate a higher trade-off for[10] a 10% increase in transport time than for a 10% decline in reliability. This result also applies to a subpopulation in the research, namely, the unimodal road transport of containers.

Some studies conclude that transport time, despite its impact on transport costs, is not important at all: SPIN (2002, page 21) states that "once taken and agreed the transit time offered by intermodal services, generally longer than road transport, has less relevance for shippers than other 'criteria'". LOGIQ (1998[11]) draws the following conclusion: "Intermodal transport … is not chosen … by companies requiring shorter lead times". In this framework De Jong et al. (2004, page 25) distinguish between shippers with their own transport and shippers with outsourced transport.

As already indicated, according to IQ (2000), users of road transport consider quality more important than price. The highest score goes to flexibility, followed by 'a good match with the logistic structure', and then followed at some distance by reliability. In intermodal transport the match with logistic structure is the most important factor, again followed at some distance by reliability. Time is the third most important factor. Beuthe et al. (2003) and Vandaele and Witlox (2003) present new techniques for analysing stated preferences, especially with regard to intermodal performance indicators and choice of modality. They draw the preliminary conclusion that DTD times, including (un)loading, account for 0%-36% or 0%-23%, depending on the sector. This is not always less than the importance accorded to reliability[12]. The high values relate to electronics and textile and the low values to chemicals, cement, packaging or plastic and steel.

The importance of time depends partly on its definition. For example, Weinreich et al. (2000) see waiting times due to (a lack of) synchronization of sequential vehicles in a chain[13] as a characteristic of 'flexibility'. Other researchers do not analyse waiting times at all. This is one respect in which the importance of time is likely to be underestimated.

On the other hand, answers to the question about the intrinsic value of time suggest that it is often overestimated. It is based on the following considerations:

- Interest charges arising from goods in circulation (= part of the storage costs). All consulted sources mentioned this component;
- According to some studies, loss of value (Weinreich et al., 2000; RECORDIT[14], D1; Daganzo, 1999) and spoilage costs (Weinreich et al., 2000) also play a role. It seems to me that, unless we are dealing with a long-term fundamental upward or downward economic trend, loss of value will eventually be compensated by gain of value. This component therefore does not appear plausible.

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[9] They interviewed seven companies, most of which are forwarders, who do not carry out physical transport. Six companies use road transport, one uses maritime roro services.

[10] The response to the questionnaire is too small to make comparable statements for other modalities.

[11] According to SPIN, 2002, p. 45.

[12] The weights of reliability are – for comparison – 0%-36% or 0-31%.

[13] For example, the synchronization of rail transport and pre- and post-haulage with the production rhythm of shippers. The night jump of trains is an example of synchronization, which is favourable for shippers who adhere to the 8-hour economy.

[14] RECORDIT investigates the external costs for three freight corridors. For each corridor an intermodal transport chain and its reference, unimodal transport, is analysed. The importance of time plays a role in the framework of congestion costs.

Spoilage does not happen under normal circumstances and should therefore be incorporated in 'reliability' rather than in 'time'.

- 'Opportunity costs' of the involved capital (Daganzo, 1999, P. 23). The shipper could have invested in other areas. Or the shipper has missed the chance to invest in more efficient distribution systems (De Jong, 2004).

Though the interest charges that shippers pay for goods in circulation capture the imagination, they are very small, ranging between 0.3 and 1.6 euros per hour and load unit (an interest rate of 6% for goods with a maximum value of 160,000 euros per load unit). Freight travelling from a Benelux harbour to a terminal in North Italy would generate DTD interest charges of 10-65 euros per load unit. The DTD transport costs are in the region of 700 euros per load unit. Hence, the time costs of goods in circulation are lower than 1-10%.

One rather important feature with regard to the time and reliability indicators is the conflation of shippers with other players in preference analyses, as is the case in De Jong et al. (2004). In this study uniform trade-offs are calculated for shippers/consignees and transporters, while – conceptually – these two groups understand the importance of time and reliability in fundamentally different ways.

These and other methodological differences between the studies explain the rather large range for the value of time. The following overviews are provided by Weinreich et al. (2000), Tavasszy et al. (2002) and De Jong et al. (2004).

Weinreich:
- 2 euros per hour and load (approx. 39 tons, value approx. 55,000 euros; Oregon, 2000). This valuation takes only interest charges into account;
- 0.3-1.2 euros per hour and ton for road transport according to PETS (Christensen et al., 1998), depending on the type of goods (e.g. short-cycle products or seasonal bulk).

Tavasszy (literature review):
- only road transport:
- 0-60 euros (2002) per hour and load (truck), excluding a few extreme values;
- 0.08-1.53 euros (2002) per hour and ton.
- rail transport: 0.03-1.21 euros (2002) per hour and ton;
- water transport: >0.05 – 0.09 euros (2002) per hour and ton (plus one very high value).

The actualization of time valuation by De Jong for the Netherlands leads to (road) 36-49 euros (2002) per hour and load, or (for large trucks) 2.12-3.25 euros (2002) per hour and ton, depending on the market segment. The high edge is for containers by road.

Beuthe et al. (2003) give a preliminary indication of the benefits of one day less transport time in the steel industry, namely 0.07 euros per ton (or 0.06 euros per hour and load unit[15]). One additional day is accepted at two euros per ton (or 1.8 euros per hour and load unit).

Bergentino et al. (2003) conclude, that in the cases they studied, the reduction in transport time is equivalent to 0.64 euros per hour and ton (range: –0.73 and +1.59). This is equivalent to about 14 euros per hour and load unit.

Summarizing, the impression is that studies which focus exclusively on shippers and intermodal transport deliver two alternative levels of value: one at   2 euros per hour and load unit (= low edge, based mainly on interest costs), the other at   2 euros per

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[15] = * 22tons/24 hours.

hour and ton (= high edge). Bergentino's average value is exceptionally high. Other studies also contain much higher values.

Apparently, the last word on the importance of time – irrespective of the importance of time in transport costs – is still to be said. One could argue, that even if intermodal customers did not assign a high value to time, the fact that road customers consider it important should be enough reason to work hard on reducing transport time in intermodal networks. This is also the conclusion of various innovation platforms (e.g. the German KV Technology Platform 2000+, 1995, or ECMT, 1998). They maintain that if intermodal rail transport is to become more competitive, it needs to resemble road transport more and therefore should achieve higher system speeds[16] etc.

Incidentally, shippers do make quite illustrative statements on the importance of time; like Volvo, who stated that a one-day reduction in journey time would save the company US$ 20 per car (World Cargo News, 1995). This is not much compared with the value of a car, but it still prompted Volvo to initiate innovative short-term sea-shipping concepts. Some of the savings would be invested in more advanced means of transport, which would help to save time.

A look at the logistic costs of companies in Europe also challenges one to draw the 'right' conclusions. Depending on the sector, transport costs work out at about 2.2% - 4.7% of the sales value. These costs are part of the logistic costs, which represent 8.8% - 13.4% (European Logistics Association and A.T. Kearney, 1993). Time reduction – in relation to transport costs – only reduces a part of these ranges.

There are moments when the importance of time manifests itself so strongly that the discussion spills over into more practical domains. Take, for example, the design of train roundtrips. Is it better to allow a train to wait a long time at a **BE terminal**[17] until a departure moment turns up which is favourable for shippers? Waiting costs time and pushes up the rail costs. But the synchronization matches the rhythm of a shipper working in an 8-hour economy. These shippers prefer trains to depart in the evening and arrive late at night or early in the morning.

The opposite model is one in which the train returns to the links as soon as possible after terminal handling, taking account, of course, of periodicity requirements (see below). The time then spent at the terminal (ideally) consists only of the time for primary and secondary handling plus minimum periodicity time and buffer time to compensate for unreliability on links and at nodes. The roundtrip takes less time, so the rail costs are lower. But the DTD time of the load unit will not necessarily be reduced as well. On the contrary, the waiting times of a load unit at the terminal or the shipper's premises may then increase, bringing higher buffer costs (buffer costs are related to compensation for lack of synchronization).

If a short time spent at a terminal means that the train departs and arrives at unfavourable times for the customer, then the train operator should compensate by lowering the prices. This compensation should be covered by (a part of) the time-cost savings of trains.

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[16] Next, the rail product should be made suitable for shorter distances and partial loads.

[17] A *BE terminal* is a begin-and-end terminal. These are located at the ends of a rail connection.

3. Roundtrip times of trains and door-to-door times of load units

The departure and arrival times of trains ought to be periodic to make them recognizable to customers. In other words, vehicles would arrive and depart at a BE terminal at the same time of day. As a result, trains would stand still for quite some time. The standstill time would depend on the distances and the average link speed.

Figure 1 shows alternative roundtrip models for distances of 300 km, 600 km, 900 km, 1200 km and 2100 km[18].

The roundtrip stake:
- (300 km) 12 or 24 hours. The time at a BE terminal D is 4 or 16 hours respectively per roundtrip;
- (600 km) 24, 36 or 48 hours. The time at a BE terminal is 8, 20 or 32 hours respectively per roundtrip;
- (900 km) 36 or 48 hours. The time at a BE terminal is 14 or 26 hours respectively per roundtrip;
- (1200 km) 48 hours. The time at a BE terminal is 18 hours per roundtrip;
- (2100 km) 72 or 96 hours. The time at a BE terminal is 20 or 44 hours respectively per roundtrip.

These roundtrips apply to the wagons of a train. If the wagons at a BE terminal have a long node time, the locomotive is ideally assigned elsewhere: it will be linked to another set of wagons, which have already been handled at the terminal, and pull them through the network, leaving its 'own' wagons behind for handling. However, in practice – and certainly in the case of new operators – the locomotive is more likely to wait for its 'own' wagons[19], even though locomotive costs weigh heavily, as the following example illustrates. For a distance of 600 km the night jump takes 48 hours (Figure 1). The roundtrip could also be realized in 24 hours. This would reduce costs by 70 euros per load unit[20]. The total rail costs then change from 340 to 280 euros per load unit[21].

As already indicated, roundtrips which are a multiple of 48 hours have night jump times and hence customer-friendly arrival and departure times for all trains: Outbound and homebound in all roundtrips. The proportion of time spent at BE terminals is between 33% and 67%. Take, for instance, the distance of 600 km with a night jump connection: in this case the train spends 2/3 of its roundtrip at BE terminals. The time at a BE terminal can often be reduced[22], but then one needs to look at the impact of periodicity and frequency. Some reductions immediately result in a new periodicity (e.g. 48 hours is reduced to 24 hours for a distance 600 km). Other reductions require an additional service to recover the diminished periodicity, because the reduced roundtrip times imply more than one departure time a day. An additional service needs to be

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[18] The arrows (1st = outbound, 2nd= homebound) have been set on the time axis in a way which makes the roundtrips easy to compare. Therefore, each roundtrip starts at 0 o'clock. In reality customer-friendly times are applied if possible: the train departs as late as possible in the evening and arrives as early in the morning as possible. In this sense the outbound arrows for distances up to 900 km (possibly even 1200 km) lie symmetrically around 0 o'clock.

[19] The operational design for different roundtrip times for wagons and locomotives is more complicated than a design for the same times. In addition, the size of the network volumes and the train operator can prohibit the acceleration of the locomotive roundtrip.

[20] A load unit in this paper is defined as a 1:1 mix of 20' and 40'cotainers, or of corresponding swap body sizes.

[21] In accordance with the RACOM rail cost model (Kreutzberger, 2003).

[22] The minimum time is the sum of time for handling and to compensate for unreliability.

inserted to guarantee the same departure times on departure days. Such an increase in frequency can, however, only take place if there is sufficient freight volume.
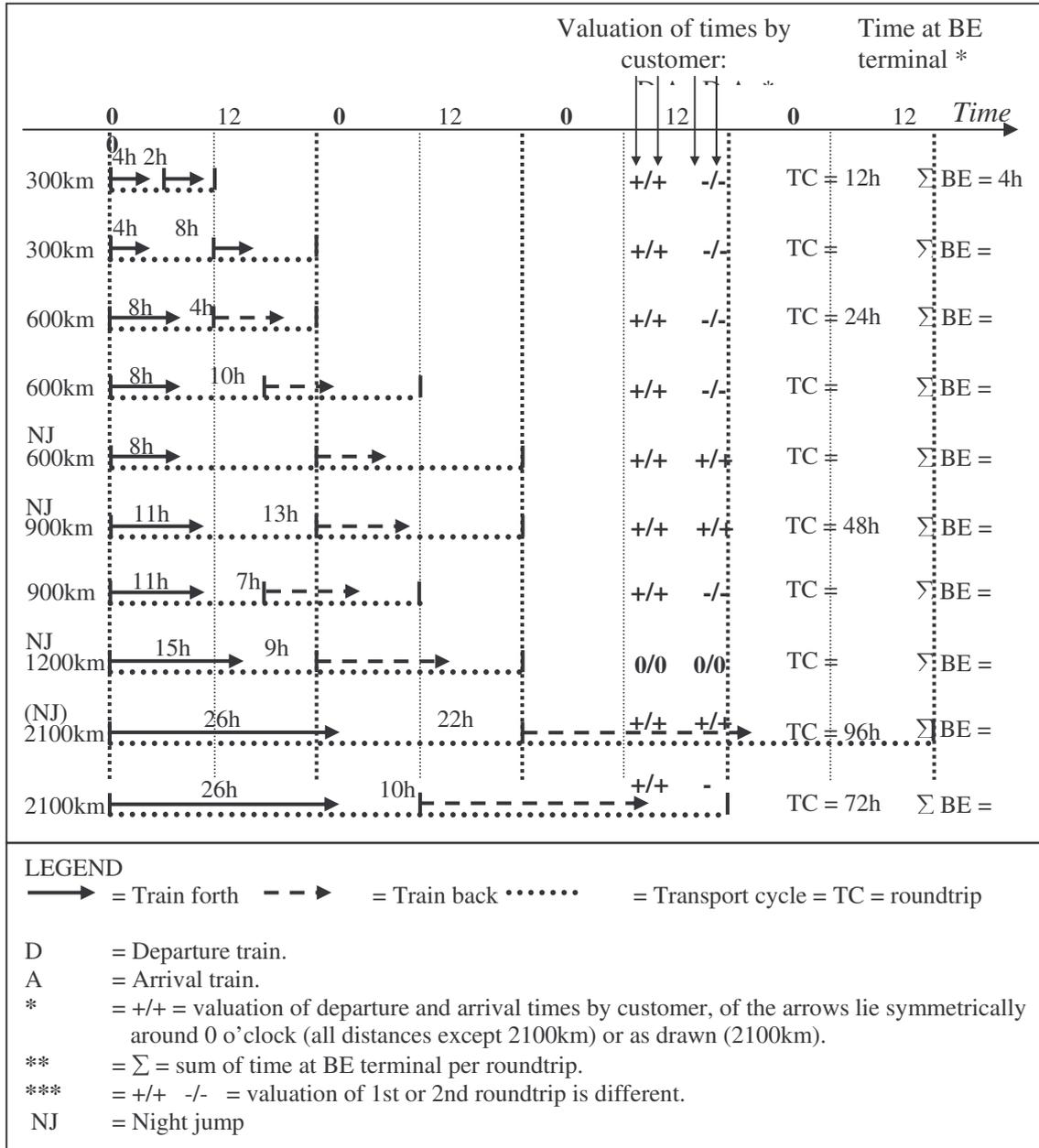
Fig. 1: Alternative train roundtrips per distance class (300 km, 600 km, 900 km, 1200 km and 2100 km) (average link speed = 80 km/hour).

At first sight, the frequencies appear to have a reciprocal value of the number of days of a roundtrip. A second look reveals that the frequency is often higher in order to achieve periodicity. The night jump with the roundtrip time of 48 hours only has a frequency of 0.5. If a counter train is inserted, the frequency is 1. Roundtrips of 36 hours require three parallel roundtrips in order to achieve periodicity. The frequency is then 2. Each second outbound train and each second homebound train then has a night jump quality. Further reduction of the roundtrip time is possible, but it implies an increase in frequency to, for instance, four or more (e.g. 12).

In practice, this is rarely possible, certainly not in BE networks. Complex bundling[23] could then be an interesting option. However, the prospect of higher frequencies may still be restricted because of competing objectives. If the network designer (train operator), when changing the bundling concept, can choose between an increase in frequency or an increase in vehicle scale[24], he will often choose vehicle scale; especially, if a frequency level of 1 (or even 2) is already present.

One could draw the following general conclusion: reduction of the roundtrip time of locomotives and wagons is highly relevant in cutting the costs and increasing the competitiveness of intermodal transport. A 24-hour reduction in the roundtrip time keeps frequency at a feasible level, certainly in combination with complex bundling. Short distances (e.g. 300 km) should not be covered purely by night jump operations, because this would waste time and significantly push up vehicle costs.

In some roundtrips vehicles will spend very short times at BE terminals. Short handling times can be facilitated by innovative operations and exchange techniques. These techniques, which are normally expensive, can also be justified for roundtrips, which do not require speed.

A differentiated pricing policy might be an interesting option here. A train operator would pay a higher transhipment price for fast handling and a quick return to the network than a train operator whose train has no need of such speed. The train operator would recoup the higher handling costs via the lower vehicle costs which are generated by saving time. The balance between higher terminal costs and lower vehicle costs should be neutral or positive.

4. The impact of complex bundling on distances and times of trains

4.1 Bundling triangle

Complex bundling is an operation in which goods with different origins (B terminals) and destinations (E terminals) are transported in common vehicles and/or load units for part of their journey. The potential advantages are lower unit costs due to scale, higher frequencies, more E terminals per B terminal and/or lower minimal network volumes[25], and eventually also an equalization in the time of exchange peaks at BE terminals. But there are also some disadvantages, notably additional exchange at intermediate nodes and longer distances (detours).

There is a quantitative relationship between three of the mentioned network design entities: network volume, vehicle scale and transport frequency. I shall call this the bundling triangle (Figure 2). A change in one of these three variables will cause a change in at least one of the others. The quantitative relation depends on the choice of bundling concept and the network concentration (= number of BE terminals).

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[23] These are consolidation networks with intermediate exchange nodes, as line networks or hub-and-spoke-networks. See also the definition in Section 4.1 and Figure 4.

[24] A combination of vehicle size and loading level.

[25] Whether these advantages can really be achieved, depends on the actual situation. Kreutzberger (2003) shows why in some situations BE networks, in others HS and in still others L, TCD or TF networks are best solutions.

Bundling networks can be compared by observing the impact of a change in the values of one of the triangle variables. In the frequency approach the frequency varies, in the volume approach the network volume varies and in the scale approach the transport scale varies[26].

Size of network volumes

Network

choices:

Which bundling concept?

Degree of network
concentration
(number of BE terminals)?

Scale of vehicles (vehicle size and loading level)

Transport frequency
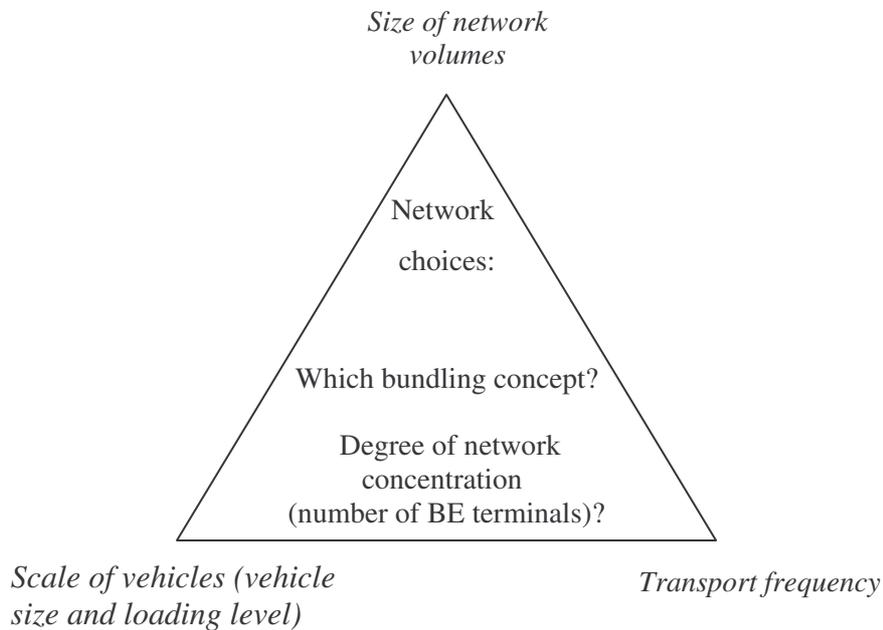
Fig. 2: The central entities of the bundling triangle**.**

4.2 Vehicle distances

In this section five bundling concepts are compared in terms of vehicle distances and times. The number of BE terminals and their location is the same in all the networks (Figure 3). Given X, Y, the number of BE terminals, the locations of intermediate exchange nodes, and the condition that only block trains/shuttles are employed in all parts of the network, it is possible to determine the vehicle distances.

The envisaged networks are so-called ***separated*** and ***directed*** networks. This implies that the outbound and homebound flows are served separately and that there are no flows between B terminals or E terminals.

If the network volume (the number of load units from left to right in Figure 3) and the scale of trains in the trunk network is the same for all the bundling networks, then the frequency of an HS network is = 1/n of that of a BE network, and the frequency of an L, TCD or TF network is 1/n2 of that of a BE network, n being the number of BE terminals on one side of the network. This is the quantitative relation in the frequency approach so far. In Part B of Figure 3 the frequency of trunk trains in the HS network is three times that of the BE network; and in the L, TCD or TF network nine times that of the BE network. In other words, in each bundling network in Figure 3 there are nine trains between the B terminals and the E terminals: in the BE network they belong to one batch, in the HS network to three batches, in the others to nine batches.

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[26] For a conceptual overview see Kreutzberger (2001 of 2003).

In Approach B the network distances can be used to determine the average detour factor of trains in complex bundling networks in comparison with the BE network; detour factors which are related to the length of routes (= route impact). These give an impression of the overall size of one of the disadvantages of complex bundling.

	Complex bundling networks			
BE network	HS network	L network	TCD network	TF network

A **Total vehicle distance in the volume or scale approach (frequency = 1)**

8166	2750	1300 *(1)*	1300 *(1)*	1508 *(2)*

B **Total vehicle distance in the frequency approach (frequency BE network = 1)**

f = 1	f = 3	f = 9	f = 9	f = 9
8166	8250	11700 *(3)*	11700 *(3)*	13572 *(3)*

C **Distances for the calculation of vehicle costs in each approach**

907	917	1100	900; 100	922; 98; 195
= netw. average	= netw. average	= netw. average	trunk netw.; local	trunk netw.; local

LEGENDA
○ = BE terminal (in L network also L terminal), for multimodal , e.g. rail-road-transhipment.
● = Unimodal exchange node (terminal, shunting yard or siding),
  e.g. for rail-rail-exchange of load units.

(1) 900+400=1300.
(2) 922+2*(195+98)=1508.
(3) 9-fold of respectively *(1)* or *(2)* .

Fig. 3: Calculation of distances of single and all-network vehicles (in vehicle kms).

The characteristics of the networks in this figure are:
- directed network;
- separated network;
- geometry: X = 900 km, Y = 100 km, 3 BE terminals on each side of the network).

As already indicated, when introducing complex bundling networks, the network designer (e.g. train operator) will often focus as far as possible on a larger scale instead of higher frequencies. In this approach, the scale approach (Part A of Figure 3), the network volumes and frequencies are the same for all networks. Only the length of the trains and/or loading levels vary.

The scale is – in comparison with the BE network – n2 for the L, TCD or TF network and n for the HS network. The scale compensates for the difference between the number of branches (trains) in the trunk network (9, 3 or 1 respectively).

In the scale approach we see that the network distances (= train kilometres) are longest for the BE network, followed by the HS network. The network distances reflect:
- the number of trains (branches): fewer trains in complex bundling networks imply smaller network distances;
- the detour factor of complex bundling networks: the larger distance in complex bundling networks implies larger network distances.

In this example the first impact is clearly dominant. The shorter net distance of all network trains expresses more economies of scale in complex bundling networks in the scale approach. The shorter distances can only be realized within the technical constraint of maximal train lengths.

The question which now arises is whether the first component also dominates in other networks[27]. This question has been investigated by means of enumeration, by analysing about 150 geometrically varied networks. The networks have, besides the mentioned X values, the Y values of 25 km, 50 km, 100 km and 200 km. The number of BE terminals at one side of the network is 2 -10. The relative width of a network is that of a square, or $(\sum Y)/X \leq 1$.

The results are shown in Figure 4. This shows the distance detour factor of all trains in a complex bundling network compared with the reference BE network. In concrete terms: the distance of all trains (in train kms) in an L network with X=600 km, Y=200 km and n=2 is 0.4 times that of all trains in a BE network with X=600 km, Y=200 km and n=2.

This 0.4 can be split into two components:
- The impact of the bundling triangle: given that n=2 and 1/n2, this factor is 0.25.
- The route impact: this led the factor to increase from 0.25 to 0.4.

Figure 4 clearly shows that in all the investigated networks the impact of the bundling triangle is greater than the route impact. This even applies to the L and TF networks, which – given the geometry of the envisaged networks – have a relatively unfavourable layout.

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[27] = with other X, Y, and/or number of BE terminals.
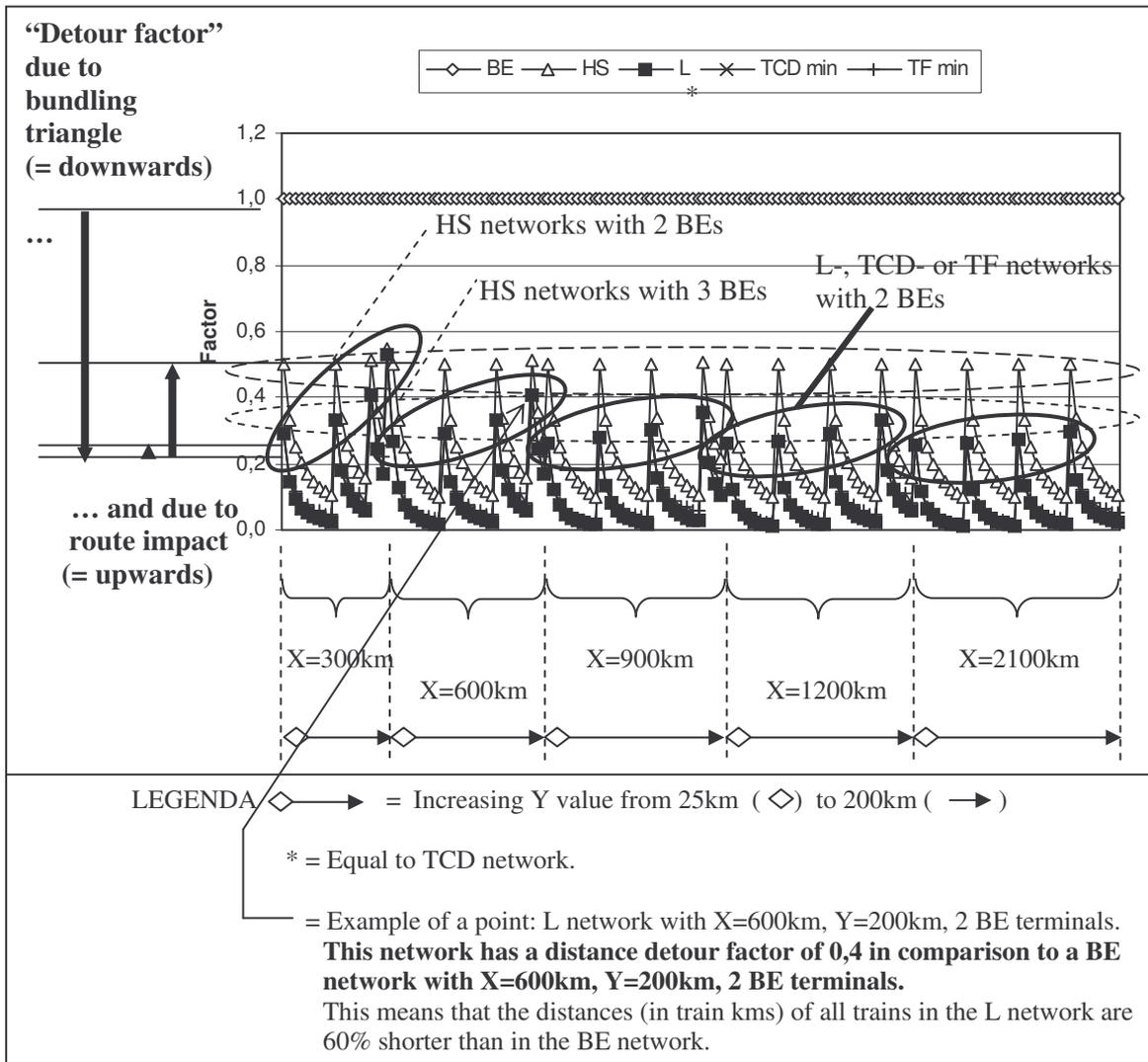
Fig. 4: Detour factors of vehicles (on the basis of Calculation A in Figure 3).

The dominance of the bundling triangle above the route length in the overall road detour factor is a key element in the advantages of scale which complex bundling can lead to. But certain comments also need to be made. The distance detour factor is valid for train kilometres but not for wagon kilometres. The trains have different scales. In the complex bundling networks the scale – within the technical constraints – is higher than in the BE network.

If the larger scale of trains only expresses the **train length**, the detour factor is only valid for the locomotive and the driver. There are no advantages of scale for wagons; the wagon kilometres are the same in all bundling networks.

However, if the larger scale of trains occurs in the direction of higher **train loading levels**, the detour factor applies to the entire train. In this case not only the locomotive or driver kilometres, but also wagon kilometres, are different per bundling concept. So, the advantages of scale apply to the whole train.

4.3 Vehicle times

The vehicle times show a similar picture, despite:
•   node times, which decrease the weight of link times;
•   the time inserted to make vehicle roundtrips periodic trips.
The impact of the bundling triangle is greater than the route impact. In the scale approach the overall time detour factor of trains in complex bundling networks is less than 1. In other words, we are dealing with scale effects[28]. The scale effects emerge for the traction and in the scale approach[29].

This picture emerges for relatively high and low average link speeds (40 km/h or 80 km/h respectively) with a relatively short duration time at BE terminals and intermediate exchange nodes[30].

4.4 Sub conclusion

In the scale approach advantages are discernible in:
•   shorter distances of network trains (locomotives, and often wagons, drivers);
•   shorter times for all network trains (possibly locomotives; wagons only to some extent).
This advantage emerges only within the technical constraints (amongst which maximal train lengths). It represents a balance between the advantages of the bundling triangle and the route detour disadvantages of complex bundling. The net impacts refer to vehicles and take account of links and nodes.

The balance in distance and time will be reflected in the vehicle costs. Cost savings from shorter network distances in complex bundling models must compensate for handling costs at terminals and other exchange nodes. If the savings are greater than the costs of node handling, the costs of complex bundling will be lower. Optionally, the time costs of shippers (Section 3) can also be included in the balance.

5. Conclusion

Low costs are the most important factors in transport performance for shippers and other customers of intermodal transport – all the more reason for investigating vehicle and transport costs[31]. This paper focuses on the analyses of vehicle costs. Time costs are strongly influenced by the vehicle roundtrip design. The vehicle roundtrip must be periodic so that the customer can recognize and understand the transport service. Next, departure and arrival times of trains, ideally, are well synchronized with the time pattern

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[28] Again within the technical scale constraints.
[29] The reduction in the number of BE terminals or links in complex bundling networks is offset by the length of trains (= number of wagons). The number of locomotives and drivers stays the same.
[30] Primary and secondary handling per half roundtrip: BE network: 4 hours at BE terminals; HS network: 4 hours at BE terminals; 2 hours at the hub; L network: 1 hour at the BE terminals, 2 hours at all L terminals; TCD network: trunk train: 6 hours at TCD nodes; pair of local trains: 2 hours at BE terminals, 3 hours at op CD terminals; TF network: trunk train: 1 hour at BE terminals, 2 hours at all F nodes; pair of local trains: 1 hour at BE terminals, 1 hour at F nodes.
[31] Amongst which the costs of freight exchange at nodes.

of shippers. In this respect the periodic night jump of train services is a customer-friendly product: the departure of trains at the end of a day and arrival at the beginning coincides perfectly with the 8-hour economy, which is applied by many shippers. Another advantage of the night jump is that freight trains use tracks at times which do not interfere with passenger rail transport.

The disadvantage of the periodic night jump is – at least for many players – the waste of time. Many trains – usually the wagons but often the locomotives as well – just stand around 'doing nothing' for two-thirds of the roundtrip time. It is possible to speed up the roundtrip. But to restore periodicity, the frequency must often be increased. The volumes will often be insufficient for this.

A possible solution is to switch to complex bundling. The goods are then moved in, for example, hub-and-spoke or line networks instead of networks with direct connections. A fast roundtrip of vehicles can be achieved by increasing the average link speeds and/or by reducing node times. The minimal node time is the handling time plus the buffer time to compensate for unreliability. The handling time can be reduced by deploying innovative operations and techniques (e.g. new generation terminals). A point of attention is that nodes serve many trains/roundtrips, only some of which need to make a quick return to the network.

The impact of complex bundling networks, especially on vehicle distances and times, is the subject of the last part of the paper. The disadvantages of complex bundling, amongst which, longer train routes and the additional time and unreliability due to intermediate exchange nodes, seem to have penetrated the minds of decision-makers. This appears to be less so when it comes to the advantages of complex bundling.

Apart from the already mentioned perspective of a higher frequency by complex bundling, there still is the perspective of more scale. The vehicle scale is visible in the form of lower total distances and times for all network trains (locomotives and/or wagons, sometimes also drivers). An analysis of about 150 geometrically varied networks, which have more or less the same layouts as actual rail networks, showed that the shorter network distances of vehicles in complex bundling networks due to a smaller number of branches weighs less than the additional distance/time due to longer routes and additional intermediate nodes.

This advantage may – when calculating costs – compensate for additional node exchange costs at intermediate nodes in complex bundling networks. This last step is not elaborated in this paper.

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