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The importance of frequency for combined transport of containers

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VAKGROEP TRANSPORT EN RUIMTELIJKE ECONOMIE

THE IMPORTANCE OF FREQUENCY FOR COMBINED TRANSPORT OF CONTAINERS

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Abstract

In this paper a comparison is made between direct road haulage and combined transport (inland navigation with oncarriage by truck) for the transport of containers from a seaport to the hinterland. The analysis is based on the concept of *total logistics costs*, a central concept in the theory of logistics. It is shown that the frequency of sailings between the seaport and the inland terminal is a key factor determining the competitiveness of combined transport *vis-à-vis* direct road haulage.

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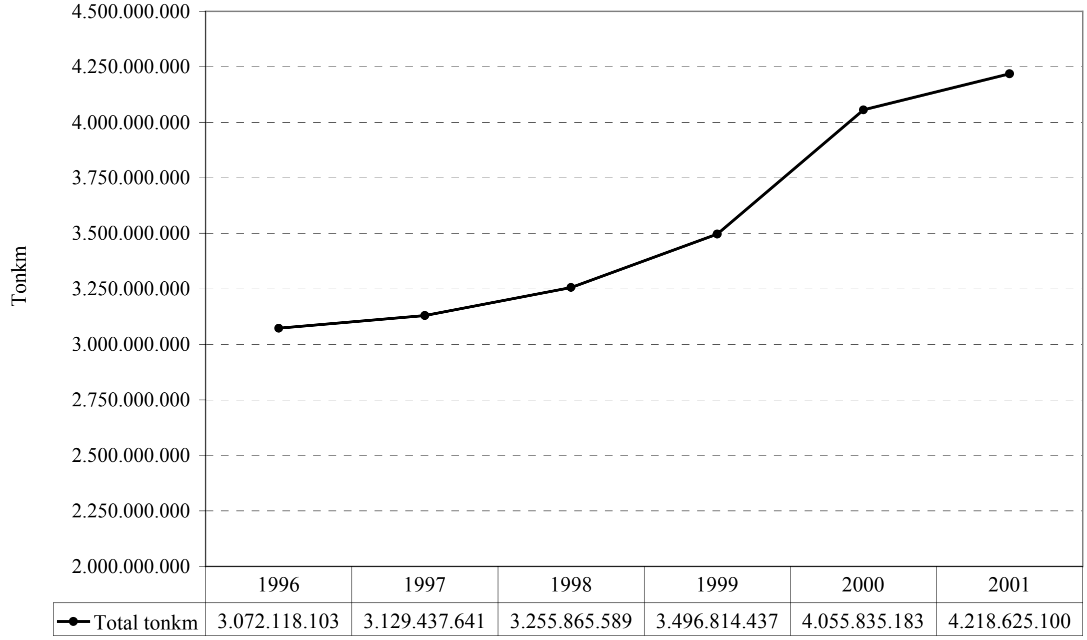
1. INTRODUCTION

Over the last couple of years, freight transport on the Flemish inland waterways has been witnessing a genuine revival. According to Promotie Binnenvaart Vlaanderen (2002a), freight traffic on the Flemish inland waterways increased from 3.26 billion tonkm in 1998 to 4.22 billion tonkm in 2001, which represents an average annual increase of about 9%. This contrasts sharply with the period 1996-1998, when average annual growth amounted to merely 3% (see Figure 1).

Figure 1: Traffic evolution on the Flemish inland waterways (1996-2001)



	1996	1997	1998	1999	2000	2001
—●— Total tonkm	3.072.118.103	3.129.437.641	3.255.865.589	3.496.814.437	4.055.835.183	4.218.625.100

Source: Promotie Binnenvaart Vlaanderen (2002a)

The strong growth of inland navigation in recent years can be explained by a number of factors. First of all, the Belgian inland navigation sector was fully deregulated as from 30 November 1998. With this deregulation Belgium anticipated on a European Directive[1] which stated that chartering and pricing in the national and international transport market by inland waterways in the Community had to be completely liberalised by 1 January 2000 (Dullaert *et al.*, 1998; Blauwens *et al.*, 2002). Hence, the system of chartering by rotation *(tour-de-rôle)* was abolished and prices could be freely negotiated.

Also in 1998 a Public-Private Partnership (PPP) programme concerning the construction of quay walls along Flemish inland waterways was initiated. The programme comprised the intervention of the Flemish Region in the costs of building infrastructure (loading and unloading quays) for companies that want to use inland navigation for the transport of their goods flows. From the very beginning, the programme experienced great success within the industry. By May 2002 no less than 79 requests had been submitted, corresponding with a potential traffic volume of about 223 million tons for a period of 10 years[2]. The lion's share of this volume concerns the transport of dry and liquid bulk goods (109 million tons) and containers (71 million tons). According to the most recent statistics available, all but one of these requests have got formal approval and 23 quays are in operation (see Table 1).

Table 1: Overview PPP-programme concerning the construction of quay walls along the Flemish inland waterways (situation as in May 2002)

	Requests submitted		**Requests approved**		**Quays in operation**	
Sector	**no.**	**tonnage**	**no.**	**tonnage**	**no.**	**tonnage**
Waste	12	29.350.000	12	29.350.000	1	3.910.000
Dry bulk	39	65.665.100	38	65.170.100	13	20.014.000
Containers	11	71.373.970	11	71.373.970	5	27.807.000
Indivisible parts	3	1.174.000	3	1.174.000	1	528.000
General cargo	7	12.382.000	7	12.382.000	2	3.755.000
Liquid bulk	7	43.089.200	7	43.089.200	1	7.534.000
Total	**79**	**223.034.270**	**78**	**222.539.270**	**23**	**63.548.000**

Note: the tonnages refer to a period of 10 years

Source: Promotie Binnenvaart Vlaanderen (2002b)

A third important stimulus for inland navigation was the decision by the Flemish Government to drastically reduce the navigation rights on the Flemish inland waterways as from 1 January 2000. The reduction by 90% to about 0.00025 euro/tonkm certainly played an important role in the traffic increase of about 16% on the Flemish inland waterways by the end of 2000 (see Figure 1).

One of the markets where inland navigation has been very successful in recent years, is container transport. Whereas the Flemish inland container terminals handled 75,138 TEU in 1998, this figure had risen to 195,649 TEU in 2001, i.e. an average annual increase of about 38% (Promotie Binnenvaart Vlaanderen, 2002a). Inland navigation clearly positions itself as an ever stronger competitor for road haulage as far as container transport from and to the seaports is concerned. For example, the share of inland navigation in container transport from and to the port of Antwerp increased from 22.7% in 1995 to 29.9% in 2001. During the same period, road haulage saw its share decline from 72.1% to 61.3% (see Table 2). It is expected that, partially as a consequence of the above-mentioned PPP-programme and the ever worsening congestion on the highways, this modal shift will continue in the future.

Table 2: Modal split hinterland distribution of containers in the port of Antwerp (transhipment excluded)

	1995	1996	1997	1998	1999	2000	2001
Road haulage	72.1	69.5	65.8	64.6	62.8	60.6	61.3
Inland navigation	22.7	24.3	27.1	27.6	27.9	29.3	29.9
Rail transport	5.2	6.2	7.1	7.8	9.3	10.1	8.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Agha-Sea (2002)

In this paper a comparison is made between direct road haulage and combined transport (inland navigation with oncarriage by truck) for the transport of containers from a seaport to the hinterland. The analysis is based on the so-called inventory-theoretic approach to modal choice in freight transport. Section 2 provides a brief introduction to this approach. In section 3 a total logistics costs model is developed. Explicit attention is paid to the frequency of sailings between the seaport and the inland terminal, and its influence on the competitiveness of combined transport vis-à-vis direct road haulage.

2. THE INVENTORY-THEORETIC APPROACH TO MODAL CHOICE

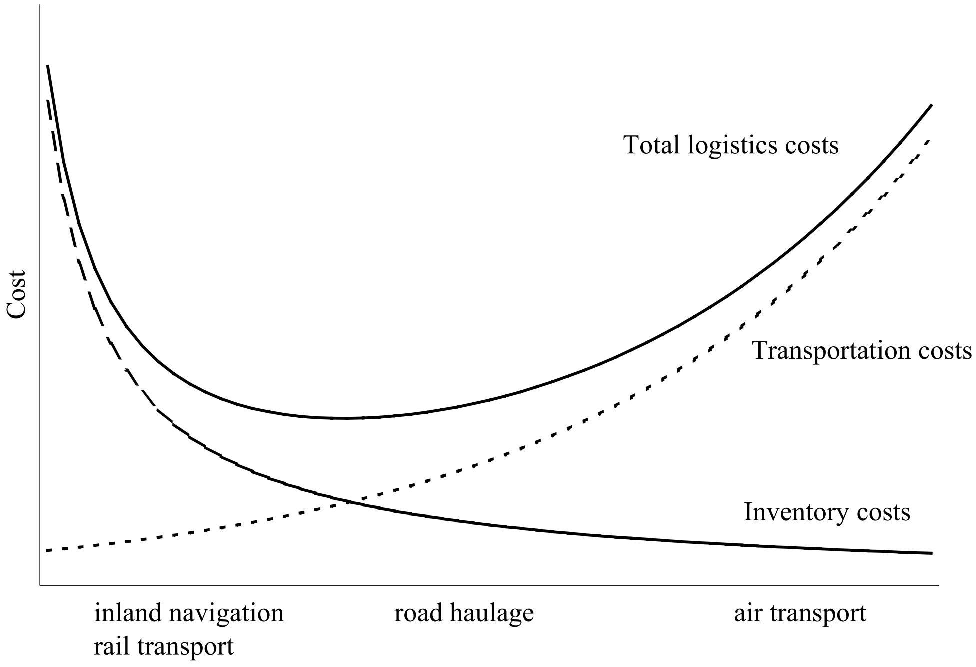
In the transportation/logistics literature, the issue of modal choice in freight transport has been widely discussed during the last couple of decades. As a result, a whole series of freight transport demand models has been developed. An interesting overview of these models can be found in McGinnis (1989), who distinguishes four categories, namely (1) the classical economic model, (2) the inventory-theoretic model, (3) the trade-off model and (4) the constrained optimization model.

This paper exclusively deals with those models belonging to McGinnis' (1989) second category[3]. An inventory-theoretic model of freight transport is a model that analyses modal choice from a *total logistics costs* perspective (Coyle *et al.*, 1996; Ballou, 1999). This implies that, when a shipper/receiver has to decide which transport mode to use for incoming goods flows, all costs in the supply chain that are affected by this decision should be taken into account. The most obvious example of these costs, which immediately comes to mind when comparing different freight transport modes, are of course the transportation costs. But besides these, attention should also be given to so-called *non-transportation logistics costs* such as inventory carrying costs, costs of goods handling and packaging, order costs, costs of facility location, etc.

The inventory-theoretic approach to modal choice explicitly recognizes that cost trade-offs occur in the supply chain, i.e. different logistics costs are in conflict with each other (Ballou, 1999, p. 39). A good example of this is the trade-off between transportation costs and inventory costs, depicted in Figure 2. Merely from the viewpoint of transportation costs, the best option for a shipper/receiver is using a slow transport mode with a high carrying capacity (cf. economies of scale), such as inland navigation or rail transport. Such transport modes, however, increase the shipper's inventory costs. If one wants to minimize the inventory costs, one should use a fast transport mode with a low capacity, such as road haulage or air transport. Such transport modes, however, are characterized by high transportation costs.

Hence, the shipper/receiver is faced with a cost trade-off in the supply chain. Which transport mode will eventually be cheapest from the viewpoint of total logistics costs will be case-specific and can therefore not be said beforehand. It will depend on such factors as the value of the goods (low-value bulk goods vs. high-value containerized goods), the level of the inventory carrying charges (interest, depreciation, insurance, …), the lead times of the different transport modes (fast and reliable vs. slow and unreliable), the annual volume to be transported, etc.

Figure 2 : Trade-off between transportation costs and inventory costs



Source: Ballou, 1999, p. 39

Regarding the inventory-theoretic approach to modal choice in freight transport, the work by Baumol and Vinod (1970) may be considered pioneering. In their paper, the choice process of a transport mode is shown to involve a trade-off among freight rates, speed (average delivery time) and dependability (variance of delivery time). Explicit attention is paid to the impact of the speed and reliability of a transport mode on the inventory costs. Following Baumol and Vinod (1970), many other authors have applied the inventory-theoretic framework to modal choice in freight transport. It is beyond the scope of this paper to discuss all these works here. For a literature review, see Tyworth (1991) and Vernimmen & Witlox (2001).

3. DEVELOPMENT OF A TOTAL LOGISTICS COST MODEL

In this section the total logistics costs are calculated for direct road haulage and combined transport (inland navigation with oncarriage by truck) for the transport of containers from a seaport to the hinterland. The following notation will be used throughout the rest of this paper:

v = value of a container load (euro)
R = annual volume (containers)
D = demand per day, a random variable with mean D
and variance d
h_t = in-transit carrying charge (percent per year)
h_w = warehouse carrying charge (percent per year)
TC_r = transportation costs road haulage (euro per container)
TC_{ct} = transportation costs combined transport (euro per container)
Q_r = shipment size road haulage (containers)
Q_{ct} = shipment size combined transport (containers)
L_r = lead time road haulage, a random variable with
mean L_r and variance l_r
L_{ct} = lead time combined transport, a random variable
with mean L_{ct} and variance l_{ct}
K = safety factor corresponding with the tolerated stockout risk
s = number of sailings per week between the seaport
and the inland terminal

3.1 Calculation of total logistics costs

Based on the parameters defined above, we can now calculate the total logistics costs for road haulage *(TLC_r)* and combined transport *(TLC_{ct})*:

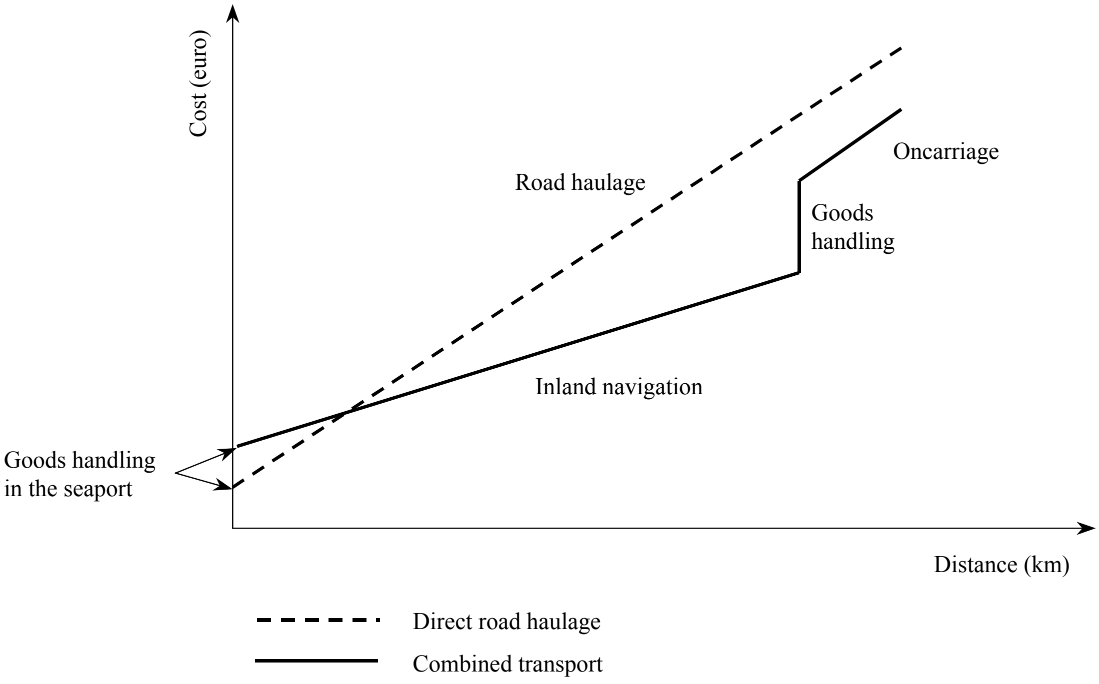
$$TLC_r = TC_r + \left(\frac{1}{R}\times\frac{Q_r}{2}\times v\times h_w\right) + \left(\overline{L}_r\times v\times\frac{h_t}{365}\right) + \left(\frac{1}{R}\times v\times h_w\times K\times\sqrt{\left(\overline{L}_r\times d\right)+\left(\overline{D}^2\times l_r\right)}\right) \quad \textbf{(1)}$$

$$TLC_{ct} = TC_{ct} + \left(\frac{1}{R}\times\frac{Q_{ct}}{2}\times v\times h_w\right) + \left(\overline{L}_{ct}\times v\times\frac{h_t}{365}\right) + \left(\frac{1}{R}\times v\times h_w\times K\times\sqrt{\left(\overline{L}_{ct}\times d\right)+\left(\overline{D}^2\times l_{ct}\right)}\right) \quad \textbf{(2)}$$

The first term in the total logistics costs formula represents the transportation costs. These will depend on the distance from the seaport to the destination in the hinterland. Note that the transportation costs of combined transport consist of three parts: (1) the transportation costs for inland navigation from the seaport to the inland terminal, (2) the costs of goods handling at the inland terminal, i.e. the transfer of the container from the inland vessel to a truck, and (3) the transportation costs for the oncarriage of the container by truck to its final destination. According to Macharis and Verbeke (2001, p. 46), if the distance between the seaport and the inland terminal is 55 km, these three costs account for 25%, 30% and 45% of the total transportation costs, respectively. Hence, the oncarriage from the inland terminal to the final destination constitutes an important element of the total transportation costs of combined transport (see also Figure 3).

Figure 3: Transportation costs and costs of goods handling

road haulage vs. combined transport



Source: Macharis and Verbeke (2001)

The second term refers to the costs of cycle stock. On average, half the shipment size $Q/2$ is in cycle stock. Multiplying this quantity with the value of a container load v and the annual warehouse carrying charge h_w yields the annual costs of cycle stock. Dividing this figure by the annual volume R yields the costs of cycle stock per container.

The third term represents the costs of inventory in-transit, which depend on the average lead time $\overline{L}$. Note that the in-transit carrying charge h_t may differ from the warehouse carrying charge h_w (Tyworth and Zeng, 1998, p. 91).

The last term in the total logistics costs formula refers to the costs of safety stock. The expression under the square root represents the standard deviation of demand during lead time and it applies only if there is independence both between lead time and daily demand and between successive daily demands (Blauwens *et al.*, 2002, p. 208. See also Allen *et al.*, 1985 and Zinn *et al.*,1992). The parameter K is called the *safety factor* and its value depends on the tolerated risk of running out of stock during lead time. Assuming that demand during lead time is normally distributed, an assumption which is often made in logistics applications, one can easily look up the K-value which corresponds with the tolerated stockout risk – tables of the normal distribution can be found in any handbook of statistics. Table 3 presents some K-values for different stockout risks. As one can see, successive decreases in the stockout risk by one percentage point lead to ever higher increases in the safety factor. This translates itself into ever higher costs of safety stock for the shipper/receiver.

Table 3: Values of *K* for different risks of running out of stock during lead time

Stockout risk	*K*	Stockout risk	*K*
10 %	1.28	4 %	1.75
9 %	1.34	3 %	1.88
8 %	1.41	2 %	2.05
7 %	1.48	1 %	2.33
6 %	1.55	0.5 %	2.58
5 %	1.64	0.1 %	3.09

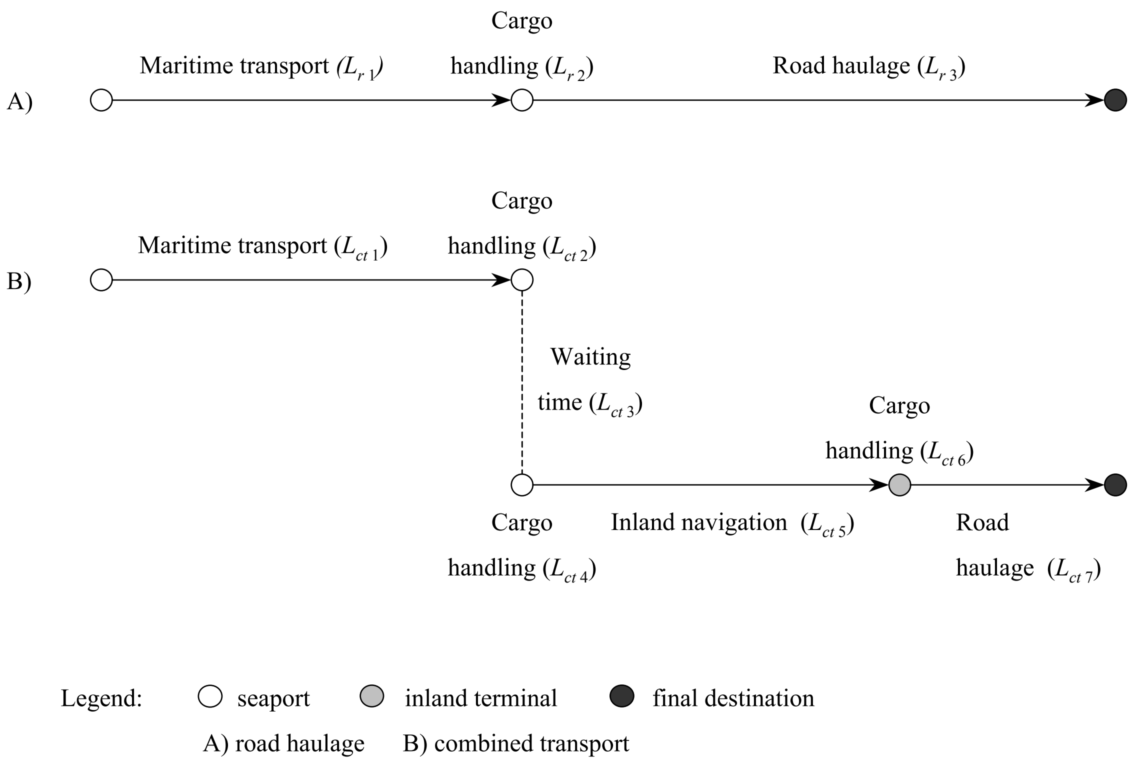
Source: Blauwens *et al.* , 2002, p. 195

Hence, the trade-off between inventory costs and transportation costs is apparent. If a shipper/receiver wants to reduce his inventory costs (e.g. in a Just-In-Time environment), he should opt for a transport mode with a low capacity and able to deliver fast and with a high reliability. A good example of such a transport mode is road haulage. On the other hand, such a transport mode is usually characterized by higher transportation costs than a slow, high-capacity transport mode, such as inland navigation or rail transport.

3.2 The impact of the frequency of sailings on total logistics costs

In this section we will analyse the impact of a change in the frequency of sailings between the seaport and the inland terminal on the total logistics costs of combined transport. Figure 4, which represents the different components of the total lead time for road haulage (panel A) and combined transport (panel B), will be helpful to understand the calculations that will follow.

Figure 4: Different components of total lead time *L*



In the case of direct road haulage the total lead time L_r consists of three components, namely (1) maritime transport, (2) transfer of the container from the container vessel to a truck, and (3) road haulage from the seaport to the final destination. These three components are indicated with L_{r1}, L_{r2} and L_{r3}, respectively.

For combined transport things are a bit more complicated. Total lead time L_{ct} consists of seven components, namely (1) maritime transport, (2) unloading of the container vessel, (3) waiting time until the arrival of an inland vessel, (4) loading of the inland vessel, (5) inland navigation from the seaport to the inland terminal, (6) cargo handling at the inland terminal, i.e. the transfer of the container from the inland vessel to a truck, and finally (7) road haulage from the inland terminal to the final destination. These seven components are indicated with L_{ct1}, L_{ct2}, L_{ct3}, L_{ct4}, L_{ct5}, L_{ct6} and L_{ct7}, respectively.

We are now able to analyse the impact of a change in the frequency of sailings on the total logistics costs of combined transport. Suppose that the frequency of sailings between the seaport and the inland terminal is s sailings per week. This implies that the time between two sailings of an inland vessel is, on average, $7/s$ days. The average waiting time for a sailing of an inland vessel is then:

$$\overline{L}_{ct3} = \frac{7}{2s} \text{ days} \qquad \textbf{(3)}$$

Hence, the higher the frequency of sailings, the lower the average waiting time for a sailing of an inland vessel. Note that L_{ct3} is the only component of total lead time L_{ct} that is influenced by a change in s. The other six components do not vary with the frequency of sailings. Hence, total lead time L_{ct} can be written as:

$$L_{ct} = \sum_{i=1}^{n} L_{cti} + \frac{7}{2s} \qquad n \in \{2, 4, 5, 6, 7\} \qquad \textbf{(4)}$$

This implies that there exists an inverse relationship between the number of sailings s and the total lead time L_{ct}: the lower s, *ceteris paribus*, the higher L_{ct}. For the shipper/receiver, this translates itself into higher costs of inventory in-transit and higher costs of safety stock (see relation **(2)**).

The frequency of sailings s influences the total logistics costs of combined transport in yet another way, since it not only affects average lead time $\overline{L}_{ct}$ but also the lead time variance l_{ct}. This will be shown in the following calculations. If we assume that the different lead time components of combined transport (i.e. maritime transport, cargo handling, waiting times and land transport) are independent of each other, then the total lead time variance l_{ct} is simply the sum of the variances l_{cti} of the different lead time components, or:

$$l_{ct} = \sum_{i=1}^{n} l_{cti} \qquad n \in \{2, 3, 4, 5, 6, 7\} \qquad \textbf{(5)}$$

It can be shown mathematically[4] that the variance l_{ct3} of the waiting time for a sailing of an inland vessel is equal to one twelfth of the square of the time between two sailings, or:

$$l_{ct3} = \frac{(7/s)^2}{12} \qquad \textbf{(6)}$$

Hence, the higher the frequency of sailings, the lower the variance of the waiting time for a sailing of an inland vessel. Note that l_{ct3} is the only component of the total lead time variance l_{ct} that is influenced by a change in s. The other six components do not vary with the frequency of sailings. Hence, analogously with the total lead time L_{ct}, the variance of lead time l_{ct} can be written as:

$$l_{ct} = \sum_{i=1}^{n} l_{cti} + \frac{(7/s)^2}{12} \qquad n \in \{2, 4, 5, 6, 7\} \qquad \textbf{(7)}$$

This implies that there also exists an inverse relationship between the number of sailings s and the total lead time variance l_{ct}: the lower s, *ceteris paribus*, the higher l_{ct}. This, in turn, increases the costs of safety stock (see relation **(2)**).

Table 4 gives an overview of the values of L_{ct3} and l_{ct3} for different frequencies of sailings between the seaport and the inland terminal. From this table we see that the impact of a reduction in the frequency of sailings gets bigger and bigger if the frequency is reduced further and further. A reduction from seven to six sailings per week increases L_{ct3} and l_{ct3} by hardly 0.08 days and 0.03 days², respectively. A further reduction to five sailings per week increases L_{ct3} and l_{ct3} by 0.12 days and 0.05 days², respectively. If one goes a step further and decreases the frequency to four sailings per week, L_{ct3} and l_{ct3} increase by another 0.18 days and 0.10 days², respectively. In other words: successive reductions in the frequency of sailings result in ever slower and less reliable combined transport. This translates itself into ever higher inventory costs for the shipper/receiver[5].

Table 4: Value of L_{ct3} and l_{ct3} for different frequencies of sailings between the seaport and the inland terminal

sailings per week (s)	L_{ct3} (days)	l_{ct3} (days²)
7	0.50	0.08
6	0.58	0.11
5	0.70	0.16
4	0.88	0.26
3	1.17	0.45
2	1.75	1.02
1	3.50	4.08

3.3 An example

This paragraph contains an example in which the concept of total logistics costs is illustrated. The data necessary for the calculations are presented in Table 5 (for the meaning of the different parameters, see above). The total logistics costs of road haulage and combined transport are presented in Table 6.

Table 5: Data for total logistics costs calculation

v	50000	Q_r	1
R	182	Q_{ct}	1
D	0.5	L_r	13
d	0.1	L_{ct}	14
h_t	20	l_r	2
h_w	25	l_{ct}	3
TC_r	300	K	1.64
TC_{ct}	250	s	7

Table 6: Total logistics costs road haulage and combined transport (euro per container), based on parameter values Table 4

	Road Haulage	Combined Transport number of sailings per week						
		7	6	5	4	3	2	1
Transportation costs	300.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Costs of cycle stock	34.34	34.34	34.34	34.34	34.34	34.34	34.34	34.34
Costs of inventory in-transit	356.16	383.56	385.84	389.04	393.84	401.83	417.81	465.75
Costs of safety stock	151.12	165.16	165.77	166.69	168.22	171.17	178.43	209.21
Total logistics costs	**841.62**	**833.06**	**835.95**	**840.07**	**846.40**	**857.33**	**880.58**	**959.31**

From Table 6 we see that, for the specific parameter values presented in Table 5, the frequency between the seaport and the inland terminal has to be at least five sailings per week if combined transport wants to be cheaper than direct road haulage. If the frequency is only four sailings per week or less, the lower transportation costs of combined transport are more than offset by higher inventory costs. Under these circumstances, a shipper/receiver that explicitly takes into account the impact of a modal choice decision on total logistics costs should prefer direct road haulage to combined transport.

One can also interpret the figures in Table 6 in another way: the lower the frequency of sailings between the seaport and the inland terminal, the larger the gap in the transportation costs that is required if combined transport wants to be cheaper than direct road haulage. Yet, it is well-known that this gap will only be significant if the distance between the seaport and the inland terminal is sufficiently large. For short distances between the seaport and the inland terminal, the transportation costs of road haulage and combined transport will not differ much. This is illustrated in Figure 3: the larger the distance between the seaport and the inland terminal, *ceteris paribus*, the longer one can profit from cheap inland navigation, and the lower the transportation costs of inland navigation will be with respect to those of road haulage (see also Beuthe and Kreutzberger, 2001). In other words, if the distance between the seaport and the inland terminal is small, a high frequency of sailings is crucial if combined transport wants to be able to compete with direct road haulage.

3.5 Sensitivity analysis

Table 7 presents the total logistics costs for different values of a container load (the other parameter values remain unchanged – cf. Table 5). The last column indicates the minimum frequency of sailings that is required for combined transport to be cheaper than direct road haulage.

Table 7: Total logistics costs (euro per container)
for different values of a container load

	TLC Road Haulage	TLC Combined Transport							minimum frequency
		Number of sailings per week							
v		7	6	5	4	3	2	1	*(s)*
20,000	516.65	483.22	484.38	486.03	488.56	492.93	502.23	533.72	2
40,000	733.30	716.45	718.76	722.06	727.12	735.87	754.46	817.45	4
60,000	949.95	949.67	953.14	958.08	965.68	987.80	1,006.69	1,101.17	7
80,000	1,166.60	1,182.90	1,187.52	1,194.11	1,204.24	1,221.73	1,258.92	1,384.89	>7
100,000	1,383.25	1,416.12	1,421.90	1,430.14	1,442.79	1,464.67	1,511.16	1,668.62	>7

From Table 7 we see that the higher the value of a container load, *ceteris paribus*, the higher the frequency of sailings that is needed to keep combined transport cheaper than direct road haulage. This is obvious: high-value container loads increase the share of the inventory costs in the total logistics costs. If the value of a container load amounts to 20,000 euro, the inventory costs represent at most 53% of the total logistics costs of combined transport. Under these circumstances, a frequency of two sailings per week already suffices to keep combined transport cheaper than direct road haulage. For container loads with a value of 100,000 euro, on the other hand, the share of the inventory costs is at least 82% of the total logistics costs of combined transport. In that case, even a daily frequency between the seaport and the inland terminal is insufficient to keep combined transport cheaper than direct road haulage.

Table 8 presents the total logistics costs for different values of the safety factor *K*. The value of *K* ranges from 0.84 (i.e. a stockout risk of 20%) to 3.09 (i.e. a stockout risk of 0.1%) (see also Table 3). The last column again indicates the minimum frequency of sailings that is required for combined transport to be cheaper than direct road haulage.

Table 8: Total logistics costs (euro per container)
for different values of the safety factor *K*

	TLC	TLC Combined Transport							minimum
	Road	Number of sailings per week							frequency
K	Haulage	7	6	5	4	3	2	1	*(s)*
0.84	767.91	752.20	755.09	758.76	764.34	773.84	793.54	857.25	4
1.28	808.45	796.81	799.56	803.48	809.47	819.76	841.41	913.38	5
1.64	841.62	833.06	835.95	840.07	846.40	857.33	880.58	959.31	5
2.33	905.20	902.55	905.70	910.20	917.17	929.35	955.65	1,047.33	7
3.09	975.24	979.09	982.51	987.45	995.13	1,008.67	1,038.34	1,144.29	>7

Hence, the lower the tolerated risk of running out of stock (i.e. the higher *K*), the higher the frequency of sailings that is required if combined transport wants to be cheaper than direct road haulage. This is obvious: the lower the tolerated stockout risk, *ceteris paribus*, the higher the shipper's safety stock and the higher the share of the safety stock costs in the total logistics costs. If one tolerates a stockout risk of as much as 20% (*K*-value of 0.84), the share of the safety stock costs in the total logistics costs of combined transport is at most 12.5%. Under these circumstances, a frequency of four sailings per week already suffices to keep combined transport cheaper than direct road haulage. If one tolerates a stockout risk of only 1% (*K*-value of 2.33), on the other hand, the costs of safety stock represent at least 26% of the total logistics costs of combined transport. In that case, only a daily frequency of sailings will result in combined transport being cheaper than road haulage.

4. CONCLUSION

In this paper a comparison was made between direct road haulage and combined transport (inland navigation with oncarriage by truck) for the transport of containers from a seaport to the hinterland. Both transport modes were compared with regard to their total logistics costs, which consist of transportation costs and inventory costs.

It was shown that the frequency of sailings between the seaport and the inland terminal is a key factor determining the competitiveness of combined transport *vis-à-vis* direct road haulage. A low frequency of sailings results in slow and unreliable combined transport and increases the shipper/receiver's inventory costs.

Given the fact that numerous studies have indicated the importance of reliability for shippers/receivers[6], we can logically expect shippers to make the modal shift from road haulage to combined transport only if the frequency of sailings is sufficiently high.

It speaks for itself that the arguments put forward in this paper also apply to other forms of combined transport, e.g. container transport by rail from seaports to the hinterland: in some cases (particularly for relatively short distances) a high frequency is a prerequisite if combined transport wants to be able to compete with direct road haulage.

Endnotes

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[1] "Council Directive 96/75/EC of 19 November 1996 on the systems of chartering and pricing in national and international inland waterway transport in the Community", Official Journal L 304, 27/11/1996, pp. 12-14.

[2] To put this in perspective, the total amount of loadings and unloadings along the Flemish waterways (ports excluded) amounted to nearly 34 million tonnes in 2001 (Promotie Binnenvaart Vlaanderen, 2002a). Hence, if all the requests that have got formal approval are also effectively realized, freight traffic on the Flemish inland waterways will increase substantially.

[3] For an overview of the other categories, see McGinnis (1989). Other ways of categorizing freight transport demand models can be found in Cunningham (1982) or Winston (1983).

[4] Readers interested in the mathematical derivation of this result are referred to the appendix.

[5] As can be seen from Table 4, a change in the frequency of sailings has, relatively speaking, a larger impact on the variance of the waiting time for a sailing of an inland vessel than on the average waiting time. For example, a halving of the frequency leads to a doubling of L_{ct3}, while l_{ct3} increases four-fold.

[6] See for example McGinnis (1990), McGinnis *et al.* (1995), Pedersen and Gray (1998) and Menon *et al.* (1998).

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APPENDIX: THE CONTINUOUS UNIFORM DISTRIBUTION

Lemma

If the random variable X is continuously and uniformly distributed in $[a,b]$ then:

$$Var(X) = \frac{(b-a)^2}{12}$$

Proof

If X is continuously and uniformly distributed in $[a,b]$ then (Van Nuffelen, 1998, p. 292):

$$E(X) = \int_a^b X \frac{1}{b-a} dX \qquad \text{and} \qquad E(X^2) = \int_a^b X^2 \frac{1}{b-a} dX$$

Since $Var(X) = E(X^2) - [E(X)]^2$, we have

$$Var(X) = \int_a^b X^2 \frac{1}{b-a} dX - \left(\int_a^b X \frac{1}{b-a} dX \right)^2$$

If we work out the integrals, we have

$$Var(X) = \frac{1}{b-a} \left[\frac{X^3}{3} \right]_a^b - \left(\frac{1}{b-a} \left[\frac{X^2}{2} \right]_a^b \right)^2 = \frac{b^3 - a^3}{3(b-a)} - \left(\frac{b^2 - a^2}{2(b-a)} \right)^2$$

This yields

$$Var(X) = \frac{b^2 + ab + a^2}{3} - \left(\frac{b+a}{2} \right)^2 = \frac{4b^2 + 4ab + 4a^2}{12} - \frac{3b^2 + 6ab + 3a^2}{12} = \frac{(b-a)^2}{12}$$