BRUSSELS ECONOMIC REVIEW - CAHIERS ECONOMIQUES DE BRUXELLES
VOL. 46 - N°2 SUMMER 2003

THE INVENTORY-THEORETIC APPROACH TO MODAL CHOICE IN FREIGHT TRANSPORT: LITERATURE REVIEW AND CASE STUDY

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ABSTRACT

This paper analyses modal choice in freight transport from the viewpoint of a shipper/receiver. The analysis is based on the well-known concept of "total logistics costs". This implies that explicit attention is paid to all costs in the supply chain that are influenced by the choice of transport mode.

After a literature review on the inventory-theoretic approach to modal choice, a case study is presented to illustrate the concept of total logistics costs. A comparison is made between road haulage and inland navigation for the transport of bulk goods. The trade-off between transportation costs and inventory costs is shown: while inland navigation has lower transportation costs than road haulage, its inventory costs are higher. Due to the fact that the goods are of relatively high value, inland navigation turns out to be more expensive than road haulage. However, it is shown that the balance would turn in favour of inland navigation when a smaller vessel type than the current one would be used.

RÉSUMÉ

Cet article est consacré à l'analyse du choix modal pour le transport de fret. L'analyse est fondée sur le concept de "coûts logistiques totaux". Ceci implique une attention particulière à tous les coûts dans la chaîne d'approvisionnement, ces derniers étant influencés par le choix du mode de transport.

Après une revue de littérature concernant le choix du mode de transport en fonction des coûts logistiques totaux, une étude de cas est présentée pour illustrer le concept. Une comparaison est faite entre le transport routier et la navigation intérieure pour le transport de marchandises en vrac. La compensation entre les coûts de transport et les coûts de stockage est montrée: la navigation intérieure a des coûts de transport inférieurs à ceux du transport routier, mais ses coûts de stockage sont plus élevés. Étant donné que les marchandises sont d'une valeur relativement élevée, la navigation intérieure s'avère être plus coûteuse que le transport routier. Cependant, il est montré qu'il serait préférable d'avoir recours à la navigation intérieure lorsque l'on utilise un type de navire avec une capacité inférieure à celle des navires actuellement utilisés.

JEL CLASSIFICATION: L92.

KEYWORDS: transport, logistics, modal choice, inventory theory, case study.

Mots-clés: transport, logistique, choix modal, coûts de stockage, étude de cas.

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The authors would like to thank Prof. dr. G. Blauwens, Prof. dr. E. Van de Voorde, dr. W. Dullaert and an anonymous referee for their useful suggestions and comments on an earlier version of this paper. All errors remain the responsibility of the authors. Research funded by the Fund for Scientific Research of the Flemish Community (Grant No. U/P/TPR/OZF58000) and by the Faculty of Applied Economics of the University of Antwerp (Grant No. U/P/TPR/OZR23000).

INTRODUCTION

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 the following four categories: *the classical economic model*, the *inventory-theoretic model*, the *trade-off model* and the *constrained optimisation model.*

This paper exclusively deals with those models belonging to McGinnis' second category[1]. An inventory-theoretic model of freight transport is a model that analyses modal choice from the viewpoint of *total logistics* costs (cf. Sheffi *et al.*, 1988; Coyle *et al.*, 1996; Ballou, 1999). This means that, when comparing different freight transport modes, a shipper/receiver should not only consider the cost of transportation itself, but also take into account all other costs in the supply chain that are affected by the choice of transport mode. Examples of these so-called *non-transportation logistics* costs are the costs of goods handling and packaging, the inventory carrying costs, the costs of facility location, etc[2].

Or, as Dehayes (1969) put it: "The choice of transport mode directly affects all other elements of the logistics system (e.g. packaging, production, planning, warehousing, facility location, information processing and inventory control). Consequently, the transport method must be selected to provide for efficient operation of the entire system" (quoted in Bardi, 1973, pp. 23-24).

In a study conducted by the Flemish Economic Alliance (1999) concerning the alternative modes for freight transport (i.e. all modes except road haulage) it is shown that, besides the transportation costs as such, shippers also consider reliability, flexibility and average delivery time of a transport mode as being very important factors when making a modal choice decision. Factors of secondary importance are safety, capacity, density of the transport network, regulation/legislation and environmental considerations[3].

While it is clear that not all of these elements can be expressed and modelled in terms of logistics costs, some elements can. This will be analysed in the following sections.

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[1] For a detailed discussion of all four categories, we refer to McGinnis (1989). Other ways of categorizing freight transport demand models can be found in Cunningham (1982) or Winston (1983). See also Abdelwahab and Sargious (1992).

[2] According to Perl and Sirisoponsilp (1988, p. 22), transport decisions can be classified into three hierarchical levels of managerial logistics decisions. The choice of a transport mode and the choice of type of carriage is considered a *strategic* transport decision. The selection of a specific carrier within the chosen mode and the determination of shipment frequency (or shipment size) is a *tactical* transport decision. Finally, typical transport decisions at the *operational* level include the assignment of loads to vehicles and the routing and scheduling of vehicles and crews.

[3] See also Bardi (1973), Saleh and Das (1974), Evans and Southard (1974), Gilmour (1976), Stock and La Londe (1977), Piercy and Ballou (1978), McGinnis et al. (1981), Chow and Poist (1984), Bagchi et al. (1987), McGinnis (1989), McGinnis (1990) and Jeffs and Hills (1990).

Section 2 provides an extensive literature review on the inventory-theoretic approach to modal choice in freight transport. Section 3 contains a case study in which the concept of total logistics costs is illustrated. Section 4 summarises the main findings and suggests some avenues for further research.

1. THE INVENTORY-THEORETIC APPROACH TO MODAL CHOICE: LITERATURE REVIEW

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 three variables, namely freight rates, average delivery time and variance in delivery time.

The total logistics costs (TLC) of a transport mode are formulated as follows (Baumol and Vinod, 1970, p. 419):

$$TLC = r.T + u.t.T + \frac{a}{s} + \frac{w.s.T}{2} + w.K\sqrt{(s+t).T} \qquad (1)$$

Where TLC = total logistics costs of a transport mode (on an annual basis)

r = transport cost per unit (including freight rate, loading and unloading, insurance,...)

T = total amount transported per year (in units)

u = in-transit carrying cost per unit per year

t = average time needed to complete a shipment (in years)[4]

a = cost of ordering and processing per shipment

s = average time between shipments (in years)

w = warehouse carrying cost per unit per year (may differ from u)

K = a constant, depending on the specified probability of no stock-outs during lead time

The first term in equation (1) refers to the annual transportation costs incurred by the shipper (sometimes these costs are referred to as the *out-of-pocket* costs). The second

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[4] The parameter t refers to the well-known concept of lead time. The latest edition of the APICS Dictionary (Cox and Blackstone, 2002) defines lead time as "the time between recognition of the need for an order and the receipt of goods. Individual components of lead time can include order preparation time, queue time, processing time, move or transportation time, and receiving and inspection time". Hence, lead time involves much more than the pure transportation time between the origin and the destination (see also Tyworth and Zeng, 1998).

term adds the annual in-transit carrying costs. The next term gives the annual ordering costs. The fourth term refers to the annual costs of cycle stock and the final term contains the annual costs of safety stock.

Clearly, Baumol and Vinod's (1970) approach takes account of both transportation costs and inventory costs. In the following paragraphs the different components of the total logistics costs will be briefly discussed. Emphasis will be placed on the relation between these costs and the modal choice decision.

1.1. TRANSPORTATION COSTS

As far as the transportation costs are concerned, Baumol and Vinod (1970) assume *a* constant shipping cost r per unit. In other words, transportation costs do not vary with volume per shipment or with distance. Obviously, this assumption is not very realistic. In reality, due to the existence of *economies of scale*, transportation costs per unit decrease with increasing shipment size[5].

In order to solve this problem, Langley (1980) adapted the model of Baumol and Vinod (1970) by describing a number of alternative relationships between the quantity shipped and the transportation cost per unit. If Q represents the Economic Order Quantity (EOQ), the following relationships can be formulated (Langley, 1980, pp. 112-117):

- a proportional relationship: $r = a - bQ$
- an exponential relationship: $r = a + bc^Q$ with $0 < c < 1$
- an inverse relationship: $r = a + \frac{b}{Q}$
- a discrete relationship, where per unit transportation rates are constant over specific ranges of Q, and decrease as certain minimum shipment volumes are reached[6].

With respect to the transportation costs for freight transport modes, Ballou (1999) provides the following figures: inland navigation costs about 0.73 cents per ton-mile, oil pipeline transport 1.40 cents per ton-mile, rail transport 2.50 cents per ton-mile, road haulage (LTL) 25.08 cents per ton-mile and air transport (domestic) 58.75 cents per ton-mile. Hence, the transportation costs are clearly to the advantage of slow and high-capacity transport modes. If shippers would only take into account the transportation

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[5] For a discussion of economies of scale in road haulage and inland navigation, see Blauwens *et al.* (2002, pp. 73-78). Note that, as far as economies of scale are concerned, there can be differences between the user and the producer of transport, since the price paid by the shipper is not always a function of the cost to the carrier.

[6] For other assumptions regarding transportation costs per unit, see Sheffi *et al.* (1988), Tersine *et al.* (1989), Swenseth and Godfrey (1996) and Tyworth and Zeng (1998).

costs in their modal choice decision, the fast and small-capacity modes such as road haulage or air transport would capture only a very small part of the total transport market.

As mentioned before, however, a comparison of different modes should not be limited to a comparison of just one criterion (e.g. the transportation costs). There are other logistics costs that are influenced by the choice of transport mode, and the concept of total logistics costs tells us to explicitly take into account these other costs as well. A good example of these so-called *non-transportation logistics* costs are the inventory costs. They will be discussed in the following paragraph.

1.2. INVENTORY COSTS

From equation (1), we see that the total inventory costs consist of four elements, namely (1) order costs, (2) costs of inventory in-transit, (3) cycle stock costs, and (4) costs of safety stock.

1.2.1. Order costs

The calculation of the annual order costs is rather straightforward: since s is the average time between shipments (in years), $1/s$ orders are placed every year, with an associated order and processing cost of a per order.

Clearly, one can reduce the annual order costs by keeping the annual number of orders low, i.e. shipping goods in large quantities. The impact of these costs, however, should not be overestimated. In most cases nowadays, the order and processing costs only play a minor role in the total logistics costs. With the introduction of large-scale automation and computerization in logistics, ordering and processing have indeed become much less labour-intensive (Blauwens *et al.*, 2002, p. 202).

Another way to reduce the order costs, is grouping orders for different parts into one large shipment *(consolidation)*. In this case, the aggregate order cost is less than the sum of the individual order costs when the items would be ordered separately. However, when considering whether or not to consolidate items into a larger shipment, one has to keep in mind that this has an effect on a whole series of logistics costs. Not only the order costs are affected, but also the transportation costs and other inventory costs[7].

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[7] For an overview of the effects of consolidation on total logistics costs, see Masters (1981), Jackson (1985) and Buffa (1986a, 1986b, 1987).

1.2.2. Costs of inventory in - transit

According to Baumol and Vinod (1970, p. 415), "freight in transit can be considered to be, in effect, an inventory on wheels, a working capital inventory perfectly analogous with goods in process in the factory".

The calculation of these costs is also straightforward. Multiplying the in-transit inventory cost per unit per year u by the average time t (in years) to complete a shipment yields the in-transit inventory costs per shipment[8]. Multiplying this figure by the number of shipments per year yields the annual in-transit inventory costs.

It is obvious that the in-transit inventory costs encourage the use of fast transport modes, such as road haulage or air transport. As mentioned before, however, this comes at a cost, in that these transport modes are usually characterised by high transportation costs (cf. supra).

1.2.3. Cycle stock costs

As can be noted in equation (1), average cycle stock at the destination is equal to half the shipment size: $s.T$ units are delivered each time, with these units gradually being used up until the next shipment arrives. Multiplying the average inventory $(s.T)/2$ by the annual warehouse carrying cost w gives us the annual cycle stock costs at the destination.

In the case where there are cycle stocks at the origin as well (e.g. as a result from goods being assembled and waiting to be shipped to the destination), the fourth term in equation (1) would double to $w.s.T$ (see also Larson, 1988). Baumol and Vinod (1970) do not include cycle stock at the origin in their cost model. In this respect, Sheffi *et al.* (1988, pp. 144-145) argue that, if the origin is sending goods to many different destinations, resulting in an outbound shipment frequency that is much higher than the inbound shipment frequency at each of the destinations, cycle stock at the origin can indeed be neglected[9].

While the in-transit inventory carrying costs encourage the use of *fast* transport modes (cf. supra), the cycle stock costs encourage the use of transport modes with a *small capacity*. After all, the use of such modes decreases the average time between shipments s, which in turn decreases the cycle stock costs. Given that fast transport modes normally transport small quantities (think for example of air transport), the distinction between these two logistics costs is not always clear. In essence, however, these two elements are of a completely different nature and should not be confused (Blauwens *et al.*, 2002, p. 187).

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[8] As mentioned before, the parameter t refers to the total lead time, which involves more than the pure transit time between the origin and the destination. Hence, the concept "in-transit inventory" should be interpreted accordingly.

[9] See also Blumenfeld *et al.* (1985a), Blumenfeld *et al.* (1985b), Horowitz and Daganzo (1986) and Blauwens *et al.* (2002).

1.2.4. Costs of safety stock

A final element of the inventory costs are the costs incurred by holding safety stock or buffer stock at the destination. The safety stock is the inventory a company holds in addition to cycle stock as a buffer against delays in receipt of orders or changes in customer buying patterns. Holding safety stock may help a firm to avoid the negative, customer-related consequences of being out of stock (Coyle *et al.*, 1996).

Assuming that the stochastic elements in their problem satisfy a Poisson distribution, Baumol and Vinod (1970) calculate the safety stock as follows (see also Whitin, 1953):

$$K \times \sqrt{(s+t).\,T} \tag{2}$$

Two important parameters for determining the safety stock are the average lead time t and the average time between shipments s. The larger these two variables, *ceteris paribus*, the larger the safety stock. The parameter K is a so-called *Poisson multiplier* (Larson, 1988).

Das (1974, p. 183) argues that the Poisson-assumption may be inaccurate and, if not satisfied, results in an overestimation of the required level of safety stock. Therefore, an alternative way to compute the safety stock is needed. A useful approach is to assume that the safety stock depends on the distribution of demand during lead time, which in turn depends on the distribution of lead time and the distribution of demand during a fixed interval, assuming that all distributions are stationary and independent (Cawdery, 1976, p. 971)[10].

Under the assumptions that demand during lead time is normally distributed[11] and that the shortage criterion is to keep the probability of a stock-out during any lead time period below a specified value p, the level of safety stock can be calculated as follows (see also Fetter and Dalleck, 1961, pp. 105-108):

$$SS = K \times \sigma \tag{3}$$

Where SS = the safety stock

K = the so-called *safety factor*, i.e. the value such that the area under the standard normal curve to the right of K is equal to p (defined above)

σ = the standard deviation of demand during lead time

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[10] See also McFadden (1972) and Danish (1972).

[11] This assumption is often made in logistics applications. However, it has been criticized in the recent literature (cf. infra).

computation of K

It is obvious that the level of safety stock increases with decreasing probabilities of stock-out during lead time and vice versa. To illustrate, Table 1 gives an overview of some values for p and K.

TABLE 1. SOME VALUES FOR p AND K

p	K	p	K
50%	0.00	4%	1.75
40%	0.25	3%	1.88
30%	0.52	2%	2.05
20%	0.84	1%	2.33
10%	1.28	0.5%	2.58
5%	1.64	0.05%	3.30

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

From Table 1 we see that if one is willing to accept a stock-out during lead time with a probability of 50%, there is no need to hold any safety stock ($K = 0$). In that case, a shipment is planned to arrive when inventory level has fallen to zero. Hence, in one out of two cases, there will be a shortage prior to shipment arrival. Reducing the probability of stocking out during lead time to 40% requires a safety stock of 0.25 times the standard deviation of demand during lead time. A further reduction of the stock-out risk to 30% requires about a doubling of this safety stock level ($K = 0.52$). If a stock-out may only occur in 5% of the cases, the safety stock increases to 1.64 times the standard deviation of demand during lead time. If one is only willing to accept a stock-out risk of 0.05% (i.e. a stock-out only occurs once every 2,000 deliveries), safety stock should be equal to 3.30 times the standard deviation of demand during lead time.

computation of σ

The standard deviation of demand during lead time can be computed as a function of four variables, namely average lead time M_t, variance of lead time V_t, average demand M_d and variance of demand V_d. If lead time is independent from demand[12] and demand

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[12] This assumption of independence between lead time and demand will characterize most real-life situations. When lead time and demand are not independent, the standard deviation of demand during lead time is equal to $\sqrt{M_t^2 V_d + M_d^2 V_t + \sigma_t \sigma_d}$, where σ_t and σ_d represent the standard deviation of lead time and of demand, respectively (see Allen *et al.*, 1985).

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itself is not autocorrelated[13], the standard deviation of demand during lead time can be computed as follows (Das, 1974, p. 184)[14]:

$$\sigma = \sqrt{M_t V_d + M_d^2 V_t} \tag{4}$$

Equation (4) clearly shows the impact of both the speed and the reliability of a transport mode on the safety stock: the faster and the more reliable a transport mode (i.e., the smaller M_t and V_t), *ceteris paribus*, the smaller the safety stock which is needed at the destination (see also Tyworth, 1991). If, in the extreme (but unrealistic) case, M_t and V_t would both be equal to zero, there would be no need to hold safety stock (cf. the concept of *just-in time* deliveries) – it is obvious that a stockout during lead time cannot occur in a situation where lead time is always zero. In this case, order arrivals would coincide with the point in time where stock level reaches zero (Howard, 1974/75, p. 97).

1.2.5. The assumption of normality of demand during lead time

From the above, it is clear that modelling the distribution of demand during lead time is essential to evaluate the effects of speed and consistency of a transport mode on inventory holding costs (Tyworth, 1991, p. 304).

In the inventory literature, two basic methods of modelling the lead time demand distribution are identified. One method is to model this distribution directly from empirical data. Although this can be a reasonable approach, potential limitations make it undesirable for theoretical and practical reasons (Bagchi *et al.*, 1984; Silver and Peterson, 1985; Tyworth, 1991).

The other method is to model the lead time and demand elements individually, and then construct a so-called *compound statistical distribution* of demand during lead time (Bagchi *et al.*, 1983, 1984, 1986; McFadden, 1972; Mentzer and Krishnan, 1985; Tyworth, 1991; Tyworth, 1992). In this respect, Lu *et al.* (1962, p. 503) argue that "if both demand and lead time are stochastic, it is usually more convenient to collect the necessary data for estimating the means of demand (per unit time) and lead time than estimating directly the mean and the standard deviation of demand during lead time".

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[13] Autocorrelation measures the extent to which values for a single variable are correlated over time. If demand is autocorrelated, this means that the demand observed in one day depends on the demand in previous days. For a discussion of the effect of autocorrelation on customer service, see Zinn *et al.* (1992). See also Ray (1980).

[14] For a similar calculation, using the coefficient of variation instead of the variance, see Gross and Soriano (1969, pp. 68-69). Another way of calculating safety stock, which uses the variance of demand forecast errors instead of the variance of demand, can be found in Zinn and Marmorstein (1990). See also Tyworth (1992).

The conventional procedure used in transport selection models to estimate the effects of average lead time and lead time variability on inventory costs is as follows (Tyworth, 1991, p. 304): assuming that demand during lead time is normally distributed, Fetter and Dalleck's (1961) "numerical method" can be used to calculate the mean and standard deviation of demand during lead time. Following inventory theory, the safety stock can then be calculated as proportionate to the standard deviation of demand during lead time (see equation (3)).

Although widely used in the literature, Tyworth (1991) indicates some important conceptual and practical limitations to this second approach. First of all, "almost all transportation selection models that deal with stochastic lead time and demand, bypass efforts to model demand and lead time to construct the compound distribution of demand during lead time". Instead, "they directly assume that demand during lead time is normally distributed and that one can estimate the mean and variance of both lead time and demand (...) This approach is very useful from a practical viewpoint, since it eliminates the need to model the functional form of demand and lead time to construct lead time demand" (Tyworth, 1991, p. 308)[15]. However, "the use of the normal distribution to characterize lead time demand is, in general, unwarranted". In effect, "the theoretical or empirical justification for the general use of the normal distribution assumption is lacking". Moreover, "incorrectly assuming that demand during lead time is normally distributed can be costly" (Tyworth, 1991, p. 308-309)[16].

Therefore, there exist many other assumptions concerning the distribution of demand during lead time. Examples include the Negative Binomial distribution, resulting from a Poisson distributed demand and a Gamma distributed lead time (Cawdery, 1976)[17] and an approximate Gamma distribution, resulting from a normally distributed demand and Gamma distributed lead time (Tyworth, 1991)[18].

Kottas and Lau (1979) have developed an approach in which a four-parameter distribution is used to characterize demand during lead time. Such a distribution has more capability to fit diverse non-normal shapes than distributions with fewer parameters (Tyworth, 1992, p. 102). Tyworth (1992) goes a step further, in that he presents a "paradigm shift" in which the technically difficult task of constructing a compound distribution of demand during lead time is no longer required. Instead, his method is based on the convex combination of period demand distributions constructed over the range of

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[15] See also McFadden (1972), Eppen and Martin (1988), Lau (1989) and Tyworth (1992).

[16] See also Burgin (1975), Speh and Wagenheim (1978), Nahmias and Demmy (1982), Tadikamalla (1984), Mentzer and Krishnan (1985), Eppen and Martin (1988), Lau (1989), Tyworth *et al.* (1991b), Tyworth (1992), Keaton (1995) and Tyworth and O'Neill (1997).

[17] See also McFadden (1972), Bagchi *et al.* (1986) and Danish (1972). It is important to notice that Cawdery (1976) and McFadden (1972) analyze lead time in the context of inventory control. Their papers, however, do not deal with modal choice in freight transport. Lead time therefore does not include transportation times – cf. infra.

[18] For an overview of other compound distributions of demand during lead time, see Bagchi *et al.* (1984, 1986). See also Bott (1977) and Lau (1989).

possible lead times. When certain conditions are met, Tyworth's (1992) approach enables one to accurately estimate the effects of speed and consistency on safety stock *without* knowledge of the shape of the lead time demand distribution. This is a major advance (Keaton, 1995, p. 107).

As far as lead time is concerned, Tyworth (1991, p. 311) indicates that an explicit distinction should be made between shipping time and lead time (cf. supra): "lead time includes both ordering time and shipping time. Ordering time, which comprises preparation, transmittal and processing elements, may represent 40 per cent or more of the lead time". Therefore, "by treating shipping time as lead time, transportation selection models underestimate lead time and thus the standard deviation of demand during lead time (...) The result is an underestimation of safety stock costs"[19].

1.3. TRADE-OFFS BETWEEN TRANSPORTATION COSTS AND INVENTORY COSTS

From the above discussion it should be clear that, in many cases, a trade-off exists between transportation costs and inventory costs: if one wants to economize on the transportation costs by shipping in large quantities with a slow transport mode (e.g. inland navigation instead of road haulage), one has to keep in mind that this leads to an increase in both the in-transit inventory costs and the inventory costs at the destination[20]. For an overview of other cost trade-offs in logistics, the reader is referred to Herron (1975, p. 253).

Lang *et al.* (2000) analyse the trade-off between transportation costs and inventory carrying costs for the case of road haulage versus rail transport. They argue that "if the rate of use of the product is high and the value of the product is relatively low, the additional inventory associated with the larger rail shipment sizes can be more than offset by their lower transport costs. If, on the other hand, the value of the product is high and it is used slowly, the cost of additional inventory associated with a large rail shipment size may exceed the differential in transport rates between truck and rail" (Lang *et al.*, 2000, p. 4; see also Swan and Tyworth, 2001). In the present paper, the effect of the value of the goods on the total logistics costs is analysed in the case study (cf. infra).

Similar "Total Logistics Costs" models as the one developed by Baumol and Vinod (1970) can be found in Buffa and Reynolds (1977), Constable and Whybark (1978), Liberatore (1979), Buffa and Reynolds (1979), Langley (1980), Blumenfeld *et al.* (1985a), Allen *et al.* (1985), McFadden *et al.* (1985), Buffa (1986a, 1986b and 1987),

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[19] See also Tyworth and Zeng (1998), Swan and Tyworth (2001) and Lau (1989).

[20] See also Ballou and DeHayes (1967), Buffa and Reynolds (1977), Burns *et al.* (1985), Blumenfeld *et al.* (1985b), Sheffi *et al.* (1988), Larson (1988) and Arcelus and Rowcroft (1991).

Sheffi *et al.* (1988), Larson (1988), Perl and Sirisoponsilp (1988), Tersine *et al.* (1989), Campbell (1990), Tyworth (1991), Allen and Liu (1993), Tyworth and O'Neill (1997), Tyworth and Zeng (1998) and Swan and Tyworth (2001).

2. A CASE STUDY: ROAD HAULAGE VERSUS INLAND NAVIGATION FOR BULK GOODS

In this section, a case study is presented in which the concept of total logistics costs is illustrated. The case study deals with a shipper who shifted from road haulage to inland navigation for incoming goods flows (bulk goods). Due to confidentiality reasons, the name of the company and the commodity type cannot be disclosed. Whether or not the modal shift is justified from the viewpoint of total logistics costs will be analysed in the following paragraphs. First, the transportation costs of both modes are discussed. Then the inventory costs are treated. The fixed costs are discussed thereafter. The case study data are presented in Table 2.

TABLE 2. CASE STUDY DATA

	Road haulage	**Inland navigation**
Transportation costs (per tonne)	10.91 euro	8.43 euro
Shipment size	25 tonnes	1,200 tonnes
Average lead time	0.20 days	4.17 days
Lead time variance	0.05 days^2	0.46 days^2
Value of the goods (per tonne)	620 euro	620 euro
Annual inventory costs	15%	15%
Fixed costs (per tonne)	0.09 euro	0.47 euro
Annual volume to be shipped	55,000 tonnes	55,000 tonnes
Average daily demand	150 tonnes	150 tonnes
Variance in daily demand	15 tonnes^2	15 tonnes^2

2.1. TRANSPORTATION COSTS

As can be seen from Table 2, the modal shift from road haulage to inland navigation resulted in a drastic decrease of the transportation costs. Shipping the goods in a 1,200-tonne inland vessel is more than 20% cheaper than shipping them in a 25-tonne truck. Hence, merely from the viewpoint of the transportation costs the modal shift is clearly justified. A rational shipper who only takes into account the transportation costs would never choose road haulage in this specific situation.

2.2. INVENTORY COSTS

The cost of keeping goods in inventory comprises four elements (Blauwens *et al.*, 2002, pp. 182-185): interest costs, depreciation costs, insurance costs and warehousing costs. In this specific case study, the annual inventory costs amount to 15% of the value of the goods. Since this value is 620 euro per tonne, inventory costs are 93 euro per tonne per year. This amount applies both to the inventory in-transit and the inventory at the destination. We can now calculate the in-transit inventory costs, the cycle stock costs and the costs of safety stock.

2.2.1. In-transit inventory costs

The average lead time of road haulage, loading and unloading included, is about 5 hours or approximately 0.20 days. The in-transit inventory costs are therefore (0.20 days × $\frac{93}{365}$ euro per tonne per day) = 0.05 euro per tonne.

Of course, transport by inland navigation requires a longer lead time. Based on available facts[21], the average lead time of this transport mode amounts to 4.17 days, loading and unloading included. This rather long lead time can be explained by several factors. First of all, it takes about 45 hours or 1.88 days to load (30 hours) and unload (15 hours) the vessel. Secondly, the vessel has to pass quite a lot of locks on the route to its destination, which inevitably leads to waiting times. Finally, inland navigation is confronted with waiting times resulting from regulations that prohibit navigation on the channels on particular days of the week. The in-transit inventory costs for inland navigation amount to (4.17 days × $\frac{93}{365}$ euro per tonne per day) = 1.06 euro per tonne.

2.2.2. Cycle stock costs

As discussed above (see equation (1)), the average cycle stock at the destination is equal to half the shipment size. In the past, when 25-tonne trucks were used to transport the bulk goods, the average cycle stock was 12.5 tonnes. This led to cycle stock costs of 1,163 euro per year. Since the annual volume to be transported is 55,000 tonnes, the cycle stock costs amounted to 0.02 euro per tonne, a very low amount.

It is obvious that the modal shift to inland navigation resulted in a substantial increase in the costs of cycle stock. Shipping the bulk goods in quantities of 1,200 tonnes each time makes that, on average, 600 tonnes are in cycle stock. This leads to cycle stock costs of 55,800 euro per year or 1.01 euro per tonne.

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[21] The barge operator provided us with a detailed overview of all the voyages he had so far made for the company under consideration. This overview contains the times of departure and arrival for a total of 119 voyages.

2.2.3. Safety stock costs

In the past, i.e. when road haulage was used, safety stock at the shipper's premises amounted to 250 tonnes. This safety stock should be seen in relation to the total incoming goods flow of the product considered, which is 127,000 tonnes. Safety stock costs are therefore equal to 23,250 euro per year or 0.18 euro per tonne.

We now have to calculate how the shipper should adjust his safety stock when making the modal shift to inland navigation. Assuming that demand during lead time is normally distributed and that the shipper does not wish to accept a higher stockout risk when making the modal shift, the safety stock for inland navigation can easily be derived from the safety stock for road haulage. This is illustrated in the following calculations.

Recall from equations (3) and (4) that the level of safety stock can be calculated as:

$$SS = K \times \sqrt{M_t V_d + M_d^2 V_t}$$

Switching from road haulage to inland navigation only affects the average lead time M_t and the lead time variance V_t. There is no reason to assume that average demand M_d and variance in demand V_d will be affected by a modal shift.

Based on the demand and lead time parameters (see Table 2), the standard deviation of demand during lead time can be calculated using the above equation. For road haulage this results in a value of 33.59 tonnes, whereas for inland navigation the value is 102.04 tonnes. Hence, in order to keep the stockout risk constant (i.e., keeping the same value for the safety factor K), the shipper should increase the safety stock from 250 tonnes to $\left(250 \times \frac{102.04}{33.59}\right) = 760$ tonnes. This leads to safety stock costs of 70,680 euro per year or 0.56 euro per tonne.

2.3. FIXED COSTS

A final element of the total logistics costs are fixed costs, i.e. costs that do not vary with the level of stock. In the case of inland navigation, these costs consist of investments in infrastructure (construction of an unloading quay) and superstructure (unloading equipment), as well as warehouse insurance costs.

As far as the construction of the unloading quay is concerned, the shipper benefited from the so-called "*80/20-agreement*" with the Flemish Government. This is a form of Public-Private Partnership (PPP) where the Flemish Government bears 80% of the investment costs for the quay, with the shipper paying the remaining 20%[22]. Under the "80/20-agreement", the shipper can make use of the quay wall, while the Flemish Government remains the owner of it. In return, the shipper has to pay a yearly "user fee" to the Government. In this specific case-study, the user fee amounts to roughly 0.02 euro per tonne. Following the construction of the quay wall, the shipper also had to guarantee that a certain minimum volume would be transported by barges in the future.

This Public-Private Partnership programme, which was launched in 1998, has so far been very successful within the industry. By July 2003 no less than 85 requests for the construction of a quay wall had been submitted, corresponding to a potential traffic volume of about 230 million tonnes over a period of 10 years[23]. The lion's share of this volume concerns dry and liquid bulk goods (111 million tonnes) and containers (73 million tonnes). According to the most recent statistics available, all but two of these requests have obtained formal approval and 34 quays are in operation (Promotie Binnenvaart Vlaanderen, 2003b).

Taking into account the total investment costs and the appropriate depreciation terms for the infrastructure and superstructure, it was found that the fixed costs equalled 0.09 euro per tonne for road haulage and 0.47 euro per tonne for inland navigation. In the case of inland navigation, the largest share of the fixed costs is formed by the investments in the quay and the unloading equipment. Obviously, both costs do not apply to road haulage.

2.4. TOTAL LOGISTICS COSTS

On the basis of the elements described and calculated above, we can now calculate the total logistics costs for road haulage and inland navigation. These total logistics costs, which comprise transportation costs, inventory costs and fixed costs, are presented in Table 3.

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[22] The subsidy only applies to the infrastructure costs. The investments in superstructure (e.g., cranes, terminal tractors, warehouses, ...) are fully borne by the shipper. The share of the Flemish Government in the total investment costs (i.e. infrastructure + superstructure) is limited to 50%.

[23] To put this in perspective, in 2002 the amount of unloadings and loadings along the Flemish waterways (ports excluded) amounted to 27.5 million tonnes and 6.5 million tonnes, respectively (Promotie Binnenvaart Vlaanderen, 2003a). Hence, if all the requests that have obtained formal approval will also be effectively realised, freight traffic on the Flemish inland waterways will increase substantially in the years to come.

TABLE 3. TOTAL LOGISTICS COSTS ROAD HAULAGE AND INLAND NAVIGATION (EURO PER TONNE)

	Road haulage	Inland navigation
Transportation costs	10.91	8.43
In-transit inventory costs	0.05	1.06
Cycle stock costs	0.02	1.01
Costs of safety stock	0.18	0.56
Fixed costs	0.09	0.47
Total Logistics Costs	11. 26	11.53

It can be seen from Table 3 that, despite its significantly lower transportation costs, inland navigation turns out to be the more expensive transport mode from the viewpoint of total logistics costs. Its advantage in transportation costs is more than offset by its disadvantage in inventory costs. This can be explained by several factors. First of all, the bulk goods considered are of relatively high value (620 euro per tonne), which implies that the inventory costs form an important part of the total logistics costs (especially for inland navigation). Second, switching from road haulage to inland navigation involves a substantial increase in the shipment size (from 25 tonnes to 1,200 tonnes), which in turn leads to a large increase in the cycle stock costs. Finally, the modal shift leads to a significant increase in the average lead time (from 0.19 days to 4.17 days), which affects both the in-transit inventory costs and the safety stock costs.

Table 4 shows that for bulk goods with a (very) low value, transport by inland navigation would actually be cheaper than road haulage. For bulk goods with a value of 50 euro per tonne, e.g., inland navigation would be about 17% cheaper than road haulage. Its larger shipment size and longer lead time indeed lead to higher inventory costs, but the value of the goods is so low that this increase does not offset its advantage in transportation costs.

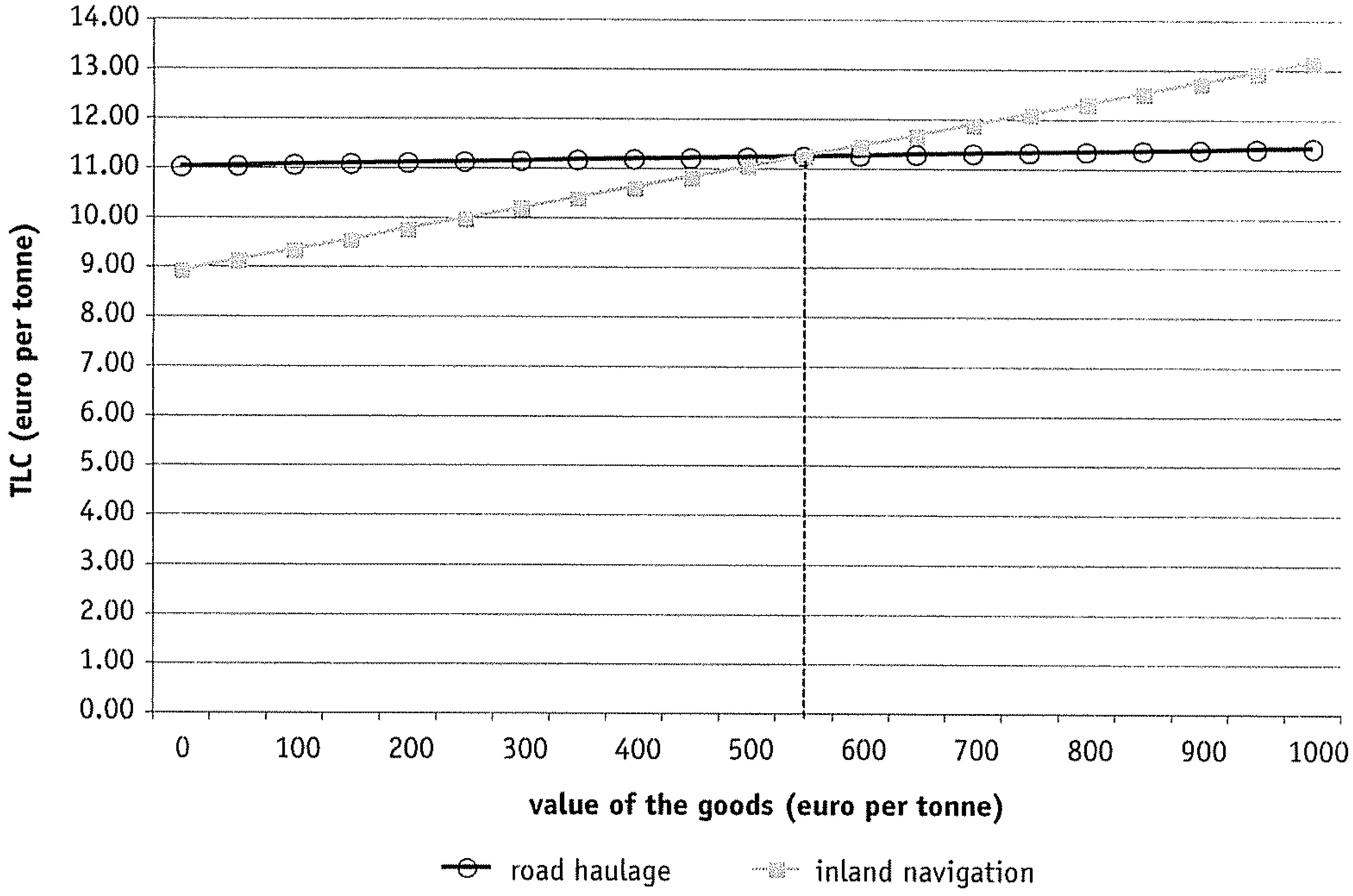
As the value of the goods increases, the gap between both transport modes narrows. The break-even value of the goods, i.e. the value where both modes have the same total logistics costs, is about 550 euro per tonne. From this point onwards, the higher inventory costs of inland navigation more than offset its lower transportation costs, and the balance turns in favour of road haulage (see also Figure 1). For bulk goods with a very high value of 1.000 euro per tonne, e.g., inland navigation would be about 15% more expensive than road haulage.

TABLE 4. TOTAL LOGISTICS COSTS AS A FUNCTION OF THE VALUE OF THE GOODS (EURO PER TONNE)

Value (euro per tonne)	TLC Road haulage	TLC Inland navigation	Δ TLC
50	11.02	9.11	17.32%
100	11.04	9.32	15.55%
150	11.06	9.54	13.78%
200	11.08	9.75	12.03%
250	11.10	9.96	10.28%
300	11.12	10.17	8.53%
350	11.14	10.39	6.80%
400	11.16	10.60	5.07%
450	11.19	10.81	3.34%
500	11.21	11.02	1.63%
550	11.23	11.24	-0.09%
600	11.25	11.45	-1.79%
650	11.27	11.66	-3.49%
700	11.29	11.87	-5.18%
750	11.31	12.09	-6.87%
800	11.33	12.30	-8.55%
850	11.35	12.51	-10.22%
900	11.37	12.72	-11.89%
950	11.39	12.93	-13.55%
1,000	11.41	13.15	-15.21%

Note: $\Delta \text{ TLC} = \dfrac{\text{TLC road haulage} - \text{TLC inland navigation}}{\text{TLC road haulage}} \times 100\%$

FIGURE 1. TOTAL LOGISTICS COSTS AS A FUNCTION OF THE VALUE OF THE GOODS



2.5. TOTAL LOGISTICS COSTS FOR OTHER VESSEL TYPES

In the case-study discussed above, there was only one option for the shipper/receiver regarding the carrying capacity of the inland vessel, namely 1,200 tonnes. For this vessel type, the modal shift from road haulage to inland navigation involved an increase in the total logistics costs (see Table 3). One could wonder, however, whether a shipment size of 1,200 tonnes is optimal here. Perhaps the balance would turn in favour of inland navigation if a vessel with a different carrying capacity would be used. We therefore calculated the total logistics costs for five different inland vessel types used on the European waterways, namely a *Spits* (capacity 300 tonnes), a *Kempenaar* (600 tonnes), a *Dortmund-Emskanaal vessel* (*DEK-vessel*) (1,000 tonnes), a *Rijn-Hernekanaal vessel* (*RHK-vessel*) (1,350 tonnes) and a *Rhine vessel* (2,000 tonnes). The ship currently used is an *RHK-vessel.*

Given the different carrying capacities of these ships, one can immediately indicate one element of the logistics costs that will be influenced by the choice of vessel type, namely the costs of cycle stock. Indeed, the larger the vessel type, *ceteris paribus*, the larger the costs of cycle stock (cf. supra). So, in order to keep the cycle stock costs as low as possible, the shipper should choose to transport the goods by a *Spits.*

Moreover, the larger the size of a vessel, the longer it takes to load and unload it[24]. Since loading and unloading times are elements of the total lead time M_t, the choice of vessel type also has an impact on the costs of inventory in transit and the costs of safety stock: the larger the vessel type, *ceteris paribus*, the larger these two inventory costs.

Hence, from the viewpoint of the inventory costs, things are quite obvious: the shipper should use the smallest vessel possible. In this case, that would be a *Spits* with a capacity of 300 tonnes. One should keep in mind, however, that the choice of vessel type also has an impact on the transportation costs. In order to calculate the transportation costs for the five vessel types, we used the calculations in Blauwens *et al.* (2002, pp. 80-81). Using the *hour coefficient* and *the kilometre coefficient* for each vessel, and for the specific circumstances of this case study, we found that the transportation costs of a *Spits* are, on average, about 20% higher than those of the vessel type currently used. A *Kempenaar* is about 2% more expensive. A *DEK-vessel* and a *Rhine vessel*, on the other hand, are about 10% cheaper.

The total logistics costs for the five vessel types are given in Table 5. One sees that the current *RHK-vessel* is not optimal from the viewpoint of total logistics cost. A *Kempenaar* and a *DEK-vessel* are cheaper. Using a *Spits* or a *Rhine vessel*, on the other hand, would increase the total logistics costs. For a *Spits* this would be the result of higher transportation costs, whereas for a *Rhine vessel* this would be the result of higher inventory costs (see also Figure 2).

If one compares the total logistics cost of these five vessel types with the total logistics costs of road haulage (11.26 euro per tonne), one sees that both the *Kempenaar* and the *DEK-vessel* have lower costs than road haulage. If the shipper wants to minimise the total logistics costs, he should use the *DEK-vessel*.

TABLE 5. TOTAL LOGISTICS COSTS FOR DIFFERENT VESSEL TYPES (EURO PER TONNE)

	Spits	Kempenaar	DEK-vessel	RHK-vessel	Rhine vessel
Transportation costs	10.16	8.61	7.62	8.43	7.61
In-transit inventory costs	0.71	0.82	0.98	1.06	1.38
Cycle stock costs	0.25	0.51	0.85	1.01	1.69
Safety stock costs	0.56	0.56	0.56	0.56	0.56
Fixed costs	0.47	0.47	0.47	0.47	0.47
Total Logistics Costs	12.15	10.97	10.48	11.53	11.71

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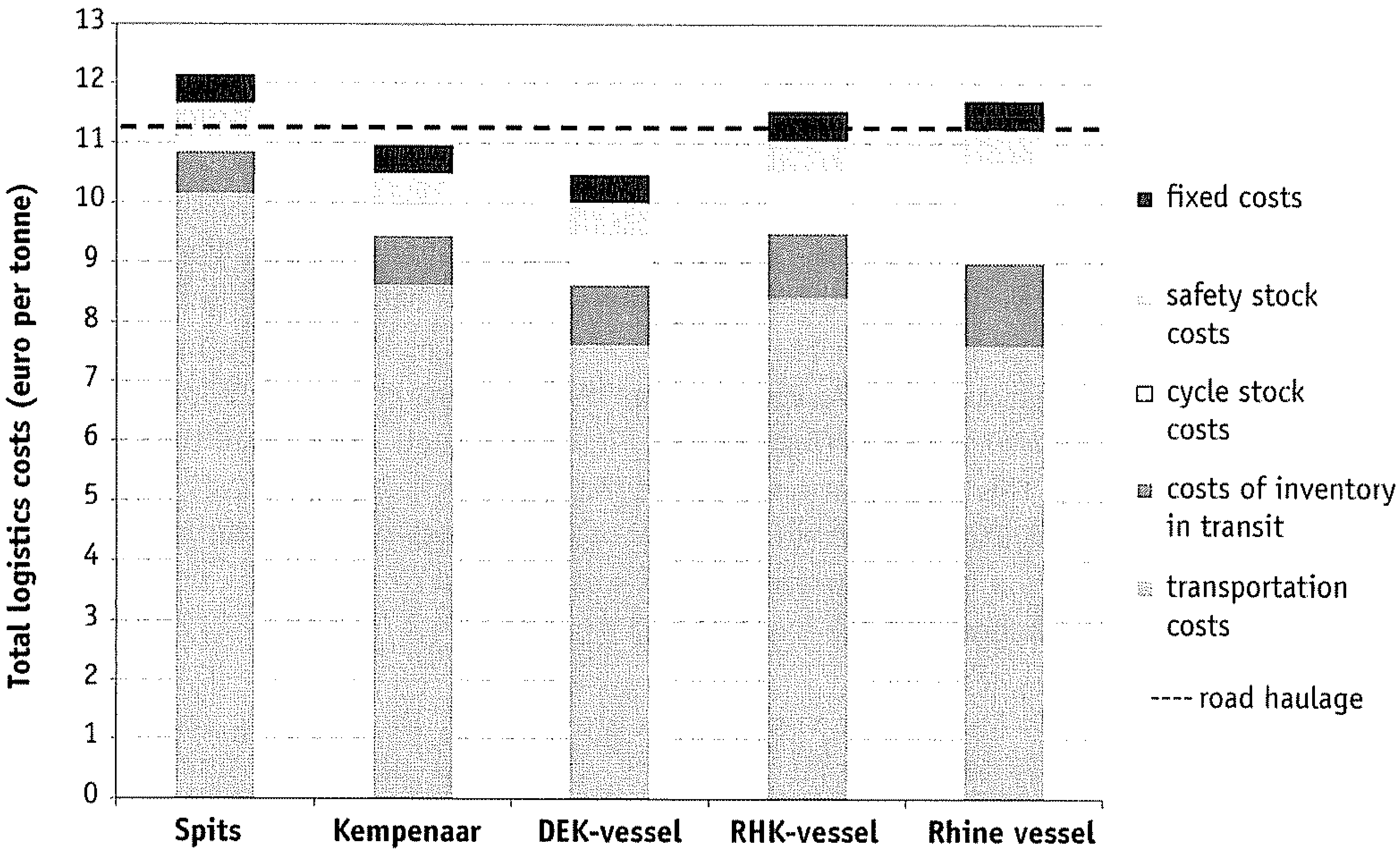
[24] In this specific case study, the loading capacity is 40 tonnes per hour, and the unloading capacity is 80 tonnes per hour. Hence, it takes about half a day to load and unload a *Spits*. Loading and unloading a *Rhine vessel*, on the other hand, would require more than three days.

FIGURE 2. TOTAL LOGISTICS COSTS FOR DIFFERENT VESSEL TYPES



In order to investigate the impact of the Government subsidy on the modal choice decision, we calculated how the total logistics costs of inland navigation would change when the Government would decide to put an end to the "80/20-agreement". We found that, when the company would have to bear the full investment costs for the unloading quay, the fixed costs would increase from 0.47 euro per tonne to 0.89 euro per tonne. As a result, the *Kempenaar* (11.39 euro per tonne) would no longer be cheaper than road haulage (11.26 euro per tonne). Without the subsidy, only the *DEK-vessel* (10.90 euro per tonne) would have a cost advantage over road haulage.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

In this paper, the choice between freight transport modes was analysed from an inventory-theoretic perspective. The analysis was based on the concept of total logistics costs, implying that explicit attention was paid to all costs in the supply chain that are affected by the choice of transport mode.

After an extensive literature review on the inventory-theoretic approach to modal choice in freight transport, a case study was presented to illustrate the concept. A comparison was made between road haulage and inland navigation for the transport of bulk goods. The trade-off between transportation costs and inventory costs was shown: while inland navigation had lower transportation costs than road haulage, its inventory costs were higher. Due to the fact that the goods considered were of relatively high value, the lower transportation costs of inland navigation were more than offset by its higher inventory costs and road haulage turned out to be the cheapest transport mode. However, it was shown that the balance would turn in favour of inland navigation when a smaller vessel type than the current one would be used.

A crucial assumption underlying the total logistics costs model discussed in this paper, was the normal distribution of demand during lead time. Under this assumption, safety stock could easily be calculated as proportionate to the standard deviation of demand during lead time.

However, a number of previous studies have criticised this assumption on the grounds that it can lead to serious errors in safety stock. This is certainly an area for further research. In further publications, we would therefore like to report on the issue of non-normally distributed lead time demand. Yet, the impact of a misspecification of safety stock on total logistics costs should not be overestimated. In the case study the costs of safety stock represent only 1.6% and 4.9% of the total logistics costs for road haulage and inland navigation (for the 1,200-tonne vessel), respectively. Even in the case of high value bulk goods (e.g. a value of 1,000 euro per tonne), the safety stock costs would represent only 2.6% and 6.9% of the total logistics costs for road haulage and inland navigation, respectively. So even if there were a large misspecification of the safety stock, this would not seriously affect the total logistics costs.

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