TOTAL LOGISTICS COST AND QUALITY ATTRIBUTES OF FREIGHT TRANSPORTATION

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Abstract

The organisation of a firm’s transport is approached from a total logistic cost point of view that includes the full chain of transport operations from the shipping firm to the consignee. Thus, this paper analyses not only the full transport costs (transport and handling), but also the ordering and administrative costs, as well as the various costs of inventory (in-transit, cycle and safety). The relationship between these elements and the quality attributes of transport means is analysed. These are identified as the frequency of service, transport time, reliability, the carrier’s flexibility of response, and the absence of damages and losses. The total logistic cost of a transport flow is minimized with respect to these attributes and the shipment size. The optimal conditions allow to derive a set of marginal value relationships between the cost of transport and the above quality attributes. They provide a framework of interpretation for an analysis of the role played by quality attributes in the decision of a transport means choice.

Keywords: Freight transport; Logistic costs; Service quality
Topic Area: B3 Logistics, Freight and Fleet Management

1. Introduction[1]

The general organisation of a firm’s transport must be approached from a business logistics point of view, which analyses “ the movement, storage and related activities between the place of origin where the company obtains its raw materials, and the place where its products are required for consumption by its customers (Blauwens *et al.*, 2002). In some cases, this may lead to an analysis of the production process of the shipping firm or of the consignee. Actually, the total logistics approach is in principle concerned with the whole chain of productive activities including transport. While acknowledging this very comprehensive view, the present paper must nevertheless limit somewhat its scope to an analysis of transport operations as they may directly influence some elements of the firms’ costs structure and determine the choice of a mode or means of transport. Actually, we only analyse this problem at the level of a specific freight transport flow between an origin and a destination. Thus, beyond the usual freight transportation and handling costs, this paper focuses on the impacts of transport operations on the ordering and administrative costs, and on the costs of the different types of inventory stocks related to a specific freight flow.

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[1] This paper is one preliminary output of a research led by a Belgian consortium directed by M.Beuthe (Catholic University of Mons), H.Meersman and E.Van de Voorde (University of Antwerp), M. Mouchart (Catholic University of Louvain), and F.Witlox (University of Ghent). We thank the Belgian Federal Office for Scientific, Technical and Cultural Affairs (OSTC) for the financial support it granted to this project.

This wider scope of analysis necessarily leads to an investigation of the role played by the qualitative attributes of transport services: their frequency, time of transport, reliability, flexibility of response by the carrier, and absence of damages. These attributes certainly matter for the transport manager as they affect the transport chain and the management of inventory stocks. Hence, it is important to analyse the role they play in the choice of a means of transport.

On the basis of the literature on transport total logistic cost, the paper first formulates a set of analytical cost functions of the shipment size of a freight flow, its total volume, and the above quality attributes. In a second section, a minimization of the total logistic cost provides a set of optimal conditions that allow the derivation of marginal value relations for the qualitative attributes, and provide a theoretical interpretation framework for their implicit values. The last section discusses estimation strategies which could be applied to the data of a transport managers survey on transports' quality of service that a consortium of Belgian universities is about to complete. Using a UTA type of multi-criteria analysis, it also presents a few illustrative examples of estimates of the quality attributes importance in the decision process.

2. The logistic costs

a) Transportation costs: These are the charges paid to the carrier or incurred by the shipping firm if it uses its own vehicles and personnel. Transport costs are function of the mode used, the volume of the flow and the size of the shipments. The rates that are paid are function of the market organisation. While, road and inland waterway transport rates are likely to be close to cost, because of the competitive structure of these modes, railway rates are better controlled by the railways which can discriminate among their clients according to their location and what transport alternatives they may have. Focussing on the relationship between cost, on the one hand, and shipment size and volume, on the other hand, we can write the transport unit cost function (cost or rate according to the situation) as: $R = R(q, Q, Z)$, where q is the shipment size, Q the total of shipments over a year, and Z is the vector of transport mode (or means) characteristics, i.e. its reliability (G), safety (S), time of transport (T), frequency (D), and flexibility (F).

b) Freight handling costs: The costs of loading, unloading, and transhipments can be sizable. They may play an important role for the choice of a transport solution, when comparing direct road transport to waterway or railway transports, which often involve some trucking in inter-modal or multi-modal solutions. The total handling cost for a particular transport solution can written as $h(Z, q). Q$, since it varies with the transport characteristics and shipment size.

c) Ordering cost: The cost of order processing and administration can be taken as proportional to the number of orders. Hence it can be written as: $a(Z).Q/q$, in case it varies with the transport characteristics.

d) Inventory costs: These costs are composed of several elements, mainly, the cost of the cycle stock, the one of the in-transit inventory, and the cost of the safety stock (Baumol and Vinod, 1970). Seasonal demand and speculation may also justify some stocking of goods, but they will not be considered here as we want to focus on elements that play a role in a relatively stable economic environment.

1° Cycle stock : With the exception of Just-in-Time delivery systems, most companies order goods in a quantity that satisfies their needs for a certain period. Hence, stocks are bound to exist with a cyclical pattern, since they build up at the consignments arrival and diminish progressively until the arrival time of the next consignment. In case the stock of a particular good is consumed at an even pace, the level of its stock will have take the shape of a series of rectangular triangle next to each other, and its average level will be equal to half the size of one consignment. Hence, the cycle stock cost is $Ic = ½.w.q$, where w is the yearly inventory cost per unit. The inventory cost takes into account the unit value of the good, the rate of interest on the capital embedded in the stock, and all the other costs associated with the stock operations (insurance, warehousing, etc.). It is obvious that the smaller the size of the consignment q, the smaller is the cycle stock cost for the consignee.

2° In-transit inventory: Goods are also in inventory during transportation, and there is a similar cost attached to that inventory on wheels. This cost again depends on the consignments' value, the rate of interest and insurance cost, the total volume shipped, and the duration of transport. For a particular transport solution, it can be written as $It = v. T. Q$, where v is the inventory cost per unit of time and T is the average transport duration (in fractions of a year).

3° Safety stock: Even though we assume a rather stable economic environment, there remains some uncertainty linked to the irregular level of demand from day to day and possible delivery delays of the goods. Hence, it is necessary to keep some additional stock beyond what is normally needed to meet the average rate of stock consumption. Besides the marketing policy adopted by the consignee, the safety stock level is mainly a function of the transport mode characteristics Z. Like the cost of cycle stock, the cost of the safety stock depends on the value of the good, the rate of interest and insurance. It depends also on the Z characteristics of the transport, i.e. reliability, safety, frequency, flexibility and time of transport.

This cost can be estimated as $Is = w \,.\, k \,.\, \sigma(q, Z)$, where

$\sigma = (L(Z).\sigma_q^2 + q^2.\sigma_L^2)^{1/2}$ is the standard deviation of demand during lead time L, assuming that demand and lead time are independent of each other (Fetter and Dalleck, 1961; Ballou, 1999)[2];

σ_q^2 is the variance of demand;

σ_L^2 is the variance of lead time;

$L(Z)$ is the average lead time in 1/m fractions of year, a function of Z; it is counted from the moment an order is placed until its delivery and includes transportation time;

q, the consignment size, is also the average demand for a 1/m fraction of year ($qm=Q$);

k is a parameter depending on the probability of running out of stock that a firm is ready to accept;

w is the yearly inventory cost, as above.

The variance of demand is outside the control of the firm, whereas the lead time and its variance depends upon Z. Hence, the writing of the standard deviation as a function of q and Z. We can postulate that σ and the safety stock increases with the lead time L, and decreases with increasing reliability, safety, flexibility and frequency of transport service.

The parameter k is a measure of the willingness to accept a stock-out. It is a somewhat subjective parameter that must be decided by each firm and depends on the type of good and adopted marketing strategy. In a specific firm logistic analysis, it can be chosen on the basis of a reasonable assumption, or estimation, of the probability distributions of demand and lead time. Assuming a normal distribution, k is then the critical value at which the area under the standard normal curve at the right of k equals the accepted risk of running out of

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[2] Under the hypothesis that the lead time is distributed according to a Poisson distribution, σ can be estimated as $\sigma = ((1/m + t)\ q.m)^{1/2}$ (Hadley and Whitin, 1963; Baumol and Vinod, 1970)), where $(1/m + t)\ q.m$ is an estimate of the unsatisfied demand that may accumulate during the period $(1/m + t)$ of maximum lead time, $1/m$ being the time between two shipments, i.e. the delay, additional to the transport time t, when an order is just missing a shipment. Different assumptions lead to other specifications of σ, which are reviewed in Vernimmen and Witlox (2001).

stock. For instance, k = 2.33 for a 1% risk of running out of stock, and k = 1.64 for a 5% risk.

The parameters v and w depend on the money value of the goods. Hence, they vary from one firm to another, like the standard deviation σ, which depends on the demand and lead time variances.

Note that only the cycle and safety costs of the consignee are considered in this analysis since it is focused on a particular flow of goods towards one consignee. The management of the overall stock by the producer of a good would require an altogether more global analysis. In the present context, it is supposed to be a given, which may constraint the transport solution. Also, it is assumed that essentially all impacts of a particular transport flow on the consignee's production cost are taken into account through the various inventory costs, and particularly through the parameters k and σ of the safety stock function . It follows that the total logistic cost, for the period during which the total flow is Q, can be written as the sum:

$$C = R(q, Q, Z).Q + h(Z, q).\ Q + a(Z).\ Q/q + \tfrac{1}{2}\, w.\ q + v.\ T.\ Q + w.\ k.\ \sigma(q, Z), \text{ or} \qquad (1)$$

$$C(q, Q, Z) = E(q, Q, Z) + I(q, Q, Z),$$

where, $E(q, Q, Z) = R(q, Q, Z).Q + h(Z, q).\ Q$, and

$$I(q, Q, Z) = a(Z).\ Q/q + \tfrac{1}{2}\, w.\ q + v.\ T.\ Q + w.\ k.\ \sigma(q, Z).$$

In this formulation, the function $E(q, Q, Z)$ corresponds to what could be called the external part of the logistic cost determined by the transport supply side, i.e. the carrier, even in the case where the transport operation is not outsourced. In contrast, the function $I(q, Q, Z)$ corresponds to the internal logistic cost of the shipper and/or consignee[3].

As an example, Table 1, drawn from a firm's case-study by Vernimmen and Witlox (2001), gives the values taken by some of the variables and parameters in equation (1).

Table 1: Example of logistic costs

	Road haulage	**Inland navigation**
R (€ / tonne)	10.91	8.43
w (€ / tonne)	93	93
t (days)	0.19	4.48
v (€ / tonne/day)	0.26	0.26
q (tonnes)	25	1200
$k.\ \sigma$ (tonnes)	250	1214
Transport cost/ tonne	10.91	8.43
In-transit inventory cost/ tonne	0.05	1.14
Cycle stock cost / tonne	0.02	1.01
Safety stock cost / tonne	0.18	0.89
Additional fixed cost / tonne[1]	0.09	0.45
Total logistics cost / tonne	11.25	11.92

Source: Vernimmen and Witlox (2001).

[1] Costs that do not vary with the stock level (unloading quay and equipment, warehouse insurance).

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[3] For lack of a better terminology. Indeed part of the handling cost may include an internal component, like the loading/unloading operation at origin or destination.

3. Optimal conditions for minimum transport logistic cost

Assuming continuous functions, the first order conditions for a minimum of the total total logistic cost $C(q, Q, Z)$, given a total flow Q, are

$$\partial C/\partial q = Q.\partial R/\partial q - a.Q.q^{-2} + Q.\partial h/\partial q + ½\, w + w.\, k.\, \partial \sigma/\partial q = 0, \quad (2)$$

$$\partial C/\partial Z_i = Q.\partial R/\partial Z_i + Q.\partial h/\partial Z_i + Q.q^{-1}.\partial a/\partial Z_i + w.\, k.\, \partial \sigma/\partial Z_i = 0, \text{ for } Z_i \neq T, \quad (3)$$

$$\partial C/\partial T = Q.\partial R/\partial T + Q.\partial h/\partial T + Q.q^{-1}.\partial a/\partial T + v.\, Q + w.\, k.\, \partial \sigma/\partial T = 0. \quad (4)$$

We can assume here that the second order conditions also are satisfied.

From equation (2), the optimal "economic order quantity" q^* can be deduced:

$$q^* = [\, a.\, Q.\, (Q.\partial R/\partial q + Q.\partial h/\partial q + ½\, w + w.\, k.\, \partial\sigma/\partial q)^{-1}\,]^{1/2}, \quad (5)$$

which is similar to the usual expressions found in the literature (Blumenfeld, 2001), even though it is adapted to the current context.

From equations (3) and (4), the marginal value of the transport characteristics can be shown as:

$$\partial R/\partial Z_i + \partial h/\partial Z_i = -(\, q^{-1}.\partial a/\partial Z_i + w.\, k.\, Q^{-1}.\partial \sigma/\partial Z_i\,), \quad \text{for } Z_i \neq T, \quad (6)$$

$$\partial R/\partial T + \partial h/\partial T = -(q^{-1}.\partial a/\partial T. + v + w.\, k.\, Q^{-1}.\partial \sigma/\partial T)\,. \quad (7)$$

Indeed, (6) and (7) equate a characteristic's marginal cost paid by the shipper to its internal marginal cost. For a characteristic like reliability, for example, equation (6) shows that its internal value is linked to its impacts on the ordering cost and safety stock, whereas equation (7) shows that the value of transport time also depends on its impact on the in-transit inventory.

It is worth pointing out that the conditions of logistic optimality, equations (2) to (3), suppose that the variables are continuous. For a given choice of a transport mode, that may approximately be the case, since several levels of service are indeed proposed by carriers. However, there are strong discontinuities from one mode to another, so that carriers may not be able to supply the desirable levels of some transport services. To give obvious examples, the transport time of each mode can only vary within a limited range for technical and structural reasons, and available vehicles' carrying capacity may not be appropriate to transport a given optimal shipment size q. It follows that the choice of a transport solution is constrained by the set of available alternatives, hence, that there is no guarantee that a shipper (or consignee) can reach a solution that strictly would satisfy the optimal logistic conditions. Actually, in most cases, the analysis of a best logistic solution, including the choice of a mode, has to focus on the valuation of the total logistic cost function and the comparison of values it takes for a discrete set of available solutions. For doing so in a rigorous analysis at the firm's level, all the logistic cost components for each solution should be estimated by the firms, in particular v, w, k, L, and the two variances σ_q^2 and $\sigma_L^{\,2}$.

In Section 1, a number of qualitative attributes of transport service have been identified, which determine to a large extent the total transport logistic costs. They are the reliability (G), safety (S), flexibility (F), time of transport (T) and frequency of service(D). They obviously play an important role in the choice of a transport solution, and particularly in the choice of a mode. From the definition of total logistic cost and the discussion above, it is clear that the willingness to pay for a quality level of transport service depends on its impact on the internal logistic cost $I(q, Q, Z)$. Thus, rather than trying to estimate each of the parameters in (1), an alternative approach is to analyse directly the relative importance for the shipper of the "external cost" E in comparison with the relative importance of each qualitative factor in the "internal logistic cost".

Assuming again continuity for expository convenience, we can presume that the ordering cost is not likely to vary with the reliability, safety and time attributes, so that this specific cost can be written as $a(F, D).\ Q.\ q^{-1}$. From the right-hand-side of equations (6) and (7), it follows then that :

$$\begin{aligned}
\partial I/\partial G\ .\ Q^{-1} &= w.\ k.\ Q^{-1}.\ \partial\sigma/\partial G\ ,\\
\partial I/\partial S\ .\ Q^{-1} &= w.\ k.\ Q^{-1}.\ \partial\sigma/\partial S,\\
\partial I/\partial T\ .\ Q^{-1} &= v + w.\ k.Q^{-1}.\ \partial\sigma/\partial T,\\
\partial I/\partial F\ .\ Q^{-1} &= q^{-1}\ .\partial a/\partial F + w.\ k.\ Q^{-1}.\partial\sigma/\partial F,\\
\partial I/\partial D\ .Q^{-1} &= q^{-1}.\ \partial a/\partial D + w.\ k.Q^{-1}.\ \partial\sigma/\partial D.
\end{aligned} \tag{9}$$

These equations provide a theoretical interpretation of the firms' willingness to pay per unit for an attribute (small) variation around a given transport solution. They suggest that the safety stock factor could play a more important role in the transport choice decision than the other attributes. Note that all the derivatives in (8), except the one with respect to T, should take a negative value, because ordering cost could only decrease with an improved carrier's flexibility and higher frequency, while the standard deviation should also decrease with more favourable levels of quality attributes.

Other assumptions about the inclusion/exclusion of qualitative attributes in the various functions could very well be made that would simplify this set of equations (8), but, like the above assumption, they should be the object of empirical verification whenever possible.

4. Research in progress: Estimation methodology

As suggested above, a technical analysis of specific cases could provide estimation of the parameters of the logistic functions, at least for these cases. This is an effort we pursue at the present time.

Beyond this approach, there are essentially two ways to estimate the value of these partial derivatives or their discrete equivalents. Firstly, we can observe the chosen transport solutions and analyse directly their relationship with the cost of transport and its reliability, flexibility, safety, time and frequency of service. This can be done through various techniques of regression analysis, like multinomial logit and probit analyses that estimate linear decision functions, the coefficients of which can be used to value transport attributes in money equivalent. This type of analysis is usually performed at the aggregate level of a sample of firms. With a consortium of Belgian universities (Universities of Antwerp, Gent, Mons and Louvain-La-Neuve), we are currently completing a survey of Belgian transport managers that should provide enough information to perform such analyses.

Another approach, at the level of individual firm, can be considered if enough information about the firm's preferences is provided by interviews organised along the line of Stated Preference methodology. Actually, the survey mentioned above is organised around a Stated Preference questionnaire that proposes hypothetical transport solutions the transport manager must rank according to his/her preferences. This information can then be used as an input in a variety of regression models, but it can also be analysed with techniques of multi-criteria decision analysis. This approach at the individual firm level should prove itself particularly useful if it is also applied in the context of case studies, so that comparison could be made between values obtained from technical analyses and those obtained from surveys and econometric estimations. However interesting, such a comparative work could turn out to be rather difficult, since both revealed and stated preference analyses could include additional subjective factors that may influence transport decisions; moreover, stated preferences can only relate to intentions rather than to real decisions.

This is still a research in progress, and we cannot as yet propose any comparison between the different methods. However, borrowing from a previous paper (Beuthe et al., 2003), we can provide some results obtained from a UTA multi-criteria analysis applied to stated preference data of a sample of firms. They indicate that, after the most important direct cost of transportation (i.e. the external cost), it is the reliability and, in some cases the time, that appear relevant for the transport manager. Reliability certainly must be the factor that influences the most the level of the safety stock.

In our on-going survey, 25 hypothetical transport solutions are proposed to transport managers who must rank them according to their preferences. The transport alternatives are defined by the levels of six transport attributes: Frequency of service, Time of transport, Reliability, Flexibility, Absence of damages, and Cost. Both Time and Cost includes all the loading and unloading operations. The level of attributes in the different alternatives is defined in percentage with respect to the present situation. The design of the transport alternatives is such that it makes up an orthogonal matrix.

The UTA multi-criteria model evaluates an additive “utility” function of the attributes on the basis of rank ordered preferences among alternatives. It is set as a goal programming model, which estimates for each criteria a set of partial utility values that allow the derivation of piecewise non-linear functions made of successive linear segments. In the present case, the task was performed with the MUSTARD software (Scannella, 2001, Scannella and Beuthe, 2001 and 2002).

The first line of the following Table gives the average weights computed over the 98 firms that we have already interviewed. They clearly show that transport cost is the most important factor, followed by reliability but with a much lower weight. The Table also gives the individual results of nine firms chosen from different industrial sectors. Again the importance of the cost appears quite clearly, as it is the main factor in seven out of nine cases. Reliability comes next but often receives a small weight. The other factors take some importance in a few cases according to the particular circumstances of transport; otherwise, they receive small weights. For instance, transport time is important for the textile firm and the producer of electronics, which ship over rather long distances. For these two firms, as well as for the pharmaceutical firm, cost appears less important and the weights are more equally distributed. Reliability is the first factor for the pharmaceutical firm, which also gives a high weight to an absence of losses. This last factor also has some importance for one of the steel making firm that ships by waterway. It is worth underlining though that these results do not mean that the non-cost quality attributes taken together do not play an important role in decision making. Indeed, together they weight about as much as the cost. This question certainly deserves additional probing.

These results and comments are just descriptive of a few particular situations. Nevertheless, they indicate that there is much heterogeneity in the results. This could be expected as these firms are very different with respect to their products and spatial situation. A rigorous analysis of possible explanatory factors can only be performed on a sample or groups of firms and with the help of appropriate econometric techniques. This will be done when the survey is completed.

Table of Relative Weights of Attributes

Firms	**Freq.**	**Time**	**Reliab.**	**Flex.**	**Loss**	**Cost**	**Σ errors**	**Kendall**
5. Average weights 94 firms	**.069**	**.068**	**.170**	**.065**	**.097**	**.532**	**-**	**-**
Steel, multimodal 991 km, 240 hours C:.038, S: 350	**.008**	**.029**	**.115**	**.042**	**.084**	**.722**	**.009**	**.978**
Steel, waterway 404 km, 55 hours, C:.017, S: 900	**.003**	**.008**	**.001**	**.004**	**.327**	**.658**	**.345**	**.947**
Textile, multimodal, 2104 km, 120 hours, C:.11, S: 15	**.081**	**.267**	**.145**	**.060**	**.146**	**.301**	**.163**	**.933**
Electronic, road 800 km, 48 hours, C: .12, S: 23	**.174**	**.360**	**.139**	**.069**	**.043**	**.215**	**.225**	**.962**
Chemical, Rail 1200 km, 48 hours, C: .002, S: 28	**.003**	**0**	**.001**	**.004**	**.001**	**.983**	**.011**	**.909**
Cement, road 123 km, 3 hours, C: .25, S: 31.5	**.001**	**.001**	**.011**	**.002**	**0**	**.985**	**..021**	**.945**
Packing, road 500 km, 10 hours, C: .16, S: 12	**.003**	**0**	**.092**	**.002**	**.001**	**.902**	**.011**	**.978**
Pharmaceutical, road 240 km, 24 hours, C: .96, S: .1	**.076**	**.045**	**.358**	**.127**	**.187**	**.207**	**.409**	**.930**
Building mat., waterway 155 km, 48 hours C: .025, S: 1000	**0**	**0**	**.167**	**0**	**0**	**.833**	**0**	**1**

Note: C is the Euro cost per tonne/km; S is the shipment size in tonne.

Source: Beuthe et al., 2003.

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