THE DISTRIBUTION COST EQUATION FOR FREIGHT: ITS IMPLICATIONS FOR TRANSPORT INFRASTRUCTURE EVALUATION AND MODAL SPLIT

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ABSTRACT: *In this paper a comprehensive distribution cost equation for freight is outlined. It takes account of inventory, insurance and packaging costs, as well as the transportation cost. The three former components generate costs that are proportional to the value of the freight and often result in the traditional transport cost component making a minor contribution to the overall cost of distribution. The implications of this are discussed in the context of the traditional road user cost methods of evaluating the merit of new proposals, and in the context of the public sector's role in providing a balanced system of transport facilities.*

INTRODUCTION

The object of this paper is to offer for discussion and criticism a more rational basis for the economic evaluation of land trunk transport facilities (intercity roads and railways, as transport links between major regional production centres and coastal ports). In doing this, resort is made to some now well-established principles of physical distribution theory and freight forwarding practice. The traditional approach to economic evaluation - which in essence considers only the road system - has been based on the assessment of direct road user costs to provide the benefit stream to set against the investment cost. Although this is admirable for the purpose of determining a works programme for a highway department, say, once it has received a budget allocation, it has many shortcomings when it comes to determining the magnitude of the budget itself and provides no satisfactory basis for comparing the competing claims of road, rail and, in some cases, pipelines.

Before proceeding with the specifics of a cost of distribution of freight model we refer briefly to the regional land-use and transport context, and contrast it with the urban case. In urban situations it is now generally accepted that a transport proposal cannot be properly evaluated in isolation (The Sharpe Report, Transport Planning: The Men for the Job) - either in respect of other appropriate transport modes, the land-use activity pattern or the broader socio-economic environment. Harrison (1974), for instance, describes the analytical methods for measuring the total benefit that captures the total effects of a transport change and summarises three main components:

> "first, user benefit, defined to include benefits accruing directly to industrial users of transport and to firms deriving benefits through the use of transport facilities; second changes in resource use, positive or negative, which takes into account both changes within the transport sector itself and end in the economy as a whole, following changes in the level of total expenditure on transport; third, external effects which include the direct impact of transport use or the provision of transport on the utility of non-transport users" (p.56).

A recent example of this broader appraisal process is the Commission of Inquiry into the Kyeemagh-Chullora Road - a major regional road link between the central industrial area and the western suburbs of Sydney (Hensher, et al, 1983).

In the rural context such interactions are often ignored because their impact is not at first obvious and as a result projects are evaluated independently. The truth of the matter is that they are just as important and become obvious when one considers that freight assumes the dominant role as the medium of land-use and transport interaction rather than the passenger task that establishes the nexus between residential location and employment in urban areas. We shall therefore address the regional transport planning problem in terms of freight traffic.

In this framework the land uses at the origin become generators of rural and agricultural products - coal, ore and other minerals - and the destinations are large consumer populations, ports and other major transport terminals. The units of traffic generation are variously bushells of grain, head of cattle, tonnes of ore, all of which can be converted into dollar equivalents in a much more meaningful way than is possible with passenger traffic. (In stating this we recognise that intercity passenger traffic may have an important complementary role and, in certain cases where tourism is an important land-use activity, passenger traffic does assume a commercial significance.)

The essence of the proposed approach to be considered in the evaluation of regional transport infrastructure is a distribution cost equation. Drawing on and modifying the approach in an unpublished paper by Root and Busch, we explain the components of the distribution cost equation for freight, paying special attention to the inventory component. A simple worked example sheets home the importance of the value of freight and inventory costs in store and in transit. This equation is developed more specifically in terms of a number of significant operational and transport system parameters. Although this approach is well-known to physical distribution managers, its significance in transport planning has been recognised only recently - for example the South-West Areas Transport Study in Perth, Russell (1981) and Mansfield, et al, (1982). A contribution made in this paper is to draw out the implications of this approach for transport system evaluation and to present them for discussion and criticism.

THE DISTRIBUTION COST EQUATION FOR FREIGHT

The distribution cost, C, of moving a unit of freight (usually a tonne) may be represented as the sum of four separate components, viz:

$$C = T + S + I + P$$

where T = the transport cost per unit;
S = the storage or inventory cost;
I = the cost of insurance; and
P = the packaging cost.

Although there is interaction between these components, particularly the last three which are all directly related to the dollar value of the freight, it is instructive at this stage to consider them separately. Hussey (1972), in introducing a comprehensive series of monographs on marketing logistics and distribution planning for the Bradford University Management Centre states that the traditional approach to physical distribution has been to consider only part of it: the transport element. Traditionally, the cost of transport was recognised as a determinant factor on the location of industry, and in the ability of a producer to sell profitably in the various markets available. Whereas the modern view accepts that the transport element is a vital, important part of the physical distribution process, but stresses that it is only a part. A survey of physical distribution costs conducted in 1979-80 found that they varied considerably by the nature of the firms product and varied from 2.1 percent to 33.5 percent of sales revenue while most were in the 10 percent to 15 percent range (Mansfield, et al, 1982, p. 134).

A survey of 27 U.S. corporations sampled by A.T. Kearney and Company found that transport accounts for less than one-third of the total physical distribution costs. "What constitutes the remaining two-thirds or so of the total cost? The answer is: all the other activities that have to be carried out to move the product to the consumer to give it utility of time and place. The total process includes many functions: items such as warehousing; the internal movement of goods within depots; the loading and unloading of lorries; methods of packaging; and - most important - the control of inventories". The above quotation was anticipated by Root and Busch(1), in an unpublished paper nearly two decades ago, and clearly represents the situation.

In our development of the equation the loading and handling costs are included in the transport component. Even so Hussey is right in listing them amongst the other two thirds for the road user cost approach only takes account of the on-the-road costs. However, in attaching a superlative to the control of inventory, Hussey highlights the key concept of the approach we wish to pursue. At this stage, it is apposite to review briefly the meaning of inventory and place it in context.

Inventory

Although the word inventory has long been understood to mean a detailed list of goods, its adaptive meaning in the transport context is a stockpile or stock of goods that generate a number of costs such as safe storage, time cost of its capital value and obsolescence costs. These costs are borne by the owner of the inventory but passed on to the consumer: the owner may be either the consignor or consignee and one or other is deemed to be the owner whilst in the transport 'pipeline'. The inventory costs are clearly proportional both to the value of the stock and the time in storage. It should be noted that the total time in storage comprises the time that the freight is on the warehouse floor plus the time in transit. That the former component - which is usually the dominant one - exists at all is due primarily to the fact that the traditional transport modes execute their task intermittently or in batches (the pipeline is of course the exception). The great growth in recent years of through traffic management and freight forwarding is testimony enough to the importance of keeping valuable freight on the move.

Because of the intermittancy of supply and other strategic considerations a stockpile must of necessity be established at one or at each end of the transport link. This state of affairs is represented in a simple way in Figure 1, which plots stock levels against real time.

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1. A paper presented orally at the Annual Meeting of the Operations Research Society of America, San Francisco (1956) entitled: 'The Application of Operations Research Techniques to a Problem of Development Planning on the Aircraft Industry - a Case Study' by L.E. Root, Vice President, and G.A. Busch, Development Planning Economist, Lockhead Aircraft Corporation, Burbank, California.

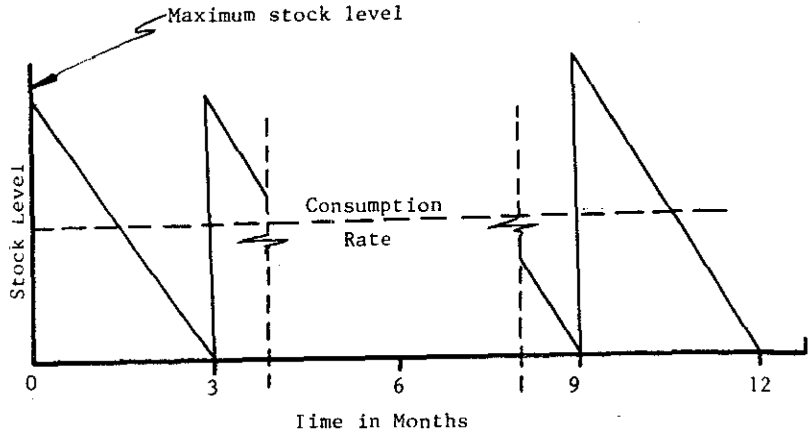


Figure 1: The Inventory Component of Physical Distribution - Stock Levels at Real Time

If the total quantity of goods to be delivered per unit time, say per year, is Q and the number of consignments per year is n, then the inventory cost components are:

$$S_S = \frac{Q}{2n} \cdot C_I$$

and $$S_T = \left(\frac{K_R D}{V}\right) Q \times C_T/8760$$

where S_S = the inventory cost in store;
C_I = the unit cost of warehousing, interest, obsolescence;
S_T = the inventory cost in transit;
C_T = the unit inventory cost in transit;
D = the direct distance betwen origin and destination;
K_R = the route factor; and
V = the average speed.

The route factor to convert direct distance to the actual distance is introduced because it is an important systems parameter that has significant mode and operational implications. More will be said about this later on.

If we now introduce the annual transport cost, T, which may be expressed as:

$$T = R \cdot K_R \cdot D \cdot Q \cdot n$$

where R is the unit rate of transport service, say cents per tonne-kilometre, then the total cost of distribution becomes:

$$C_D = R \cdot K_R \cdot D \cdot Q \cdot n + \frac{Q}{2n} \cdot C_I + \frac{K_R \cdot D}{V} \cdot \frac{Q \cdot C_T}{8760}$$

It can be seen that whilst the inventory cost in store reduces as the frequency of delivery, n, increases the annual transport cost rises with n. There is clearly an optimum value of n, n*, that can be readily found by differentiating C_D with respect to n, giving:

$$n^* = \frac{C_I}{2 . R . K_R . D}$$

Figure 2 indicates the nature of the interaction between the transport and inventory costs.

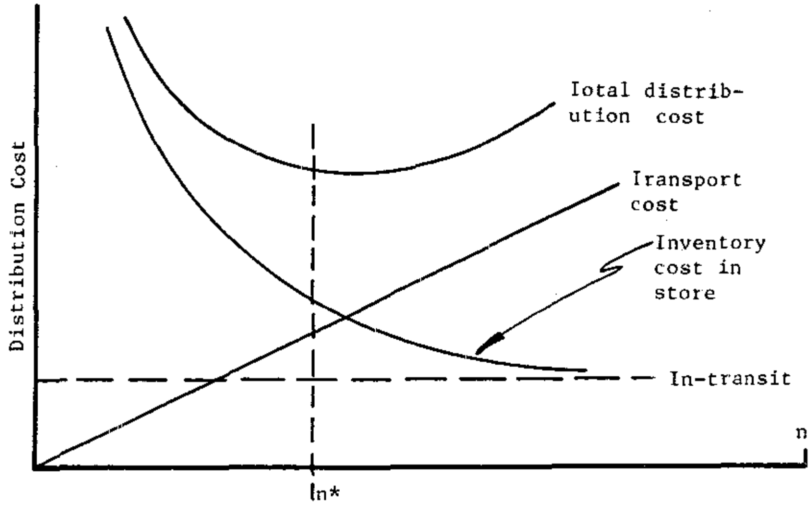


Figure 2: Distribution Cost as a Function of the Frequency of Supply

As formulae become much more meaningful when figures are substituted for the symbols, consider a hypothetical supply problem: suppose there is a demand for a 100 tonnes of paint products per annum by a motor-body works. The supplier is located 75 km away and transport is by road where the route factor is 1.33. The average journey speed is 50 km/hr which includes loading and unloading times. The value of the paint is $10 per kilogram and the unit annual inventory charge is 20 percent of its value per tonne whilst in store and 10 percent of its value per tonne during transit. Compare the inventory cost if the demand is met by: (a) quarterly deliveries; and (b) weekly deliveries, say 50 per year. If the freight rate is 15 cents per tonne-kilometre what would be the optimum delivery schedule?

(a) The inventory cost in store is:

$$S_S = \frac{Q}{2n} . C_I$$

Q = 100 tonnes
n = 4
C_I = 20% of 1 tonne at $10/kg, or $2000 per tonne per annum

Therefore,
S_S = $25,000 per annum.

The inventory cost in transit is:

$$S_I = (K_R \cdot \frac{D}{V}) \cdot \frac{Q}{8760} \cdot C_T$$

$$= 1.33 \times \frac{75}{50} \times 100 \times \frac{1000}{8760}$$

$$= \$23$$

(b) With 50 deliveries per year the cost of inventory in store drops to $2000 per annum and the inventory in transit remains the same.

The optimum delivery schedule may be obtained, viz.

$$n^* = \frac{C_I}{2RK_RD}$$

$$= \frac{2000}{2 \times 0.15 \times 1.33 \times 75}$$

$$= 8.2$$

The total distribution cost would then be:

$$C_D = 0.15 \times 1.33 \times 75 \times 100 \times 8 + \frac{100}{2x8} \times 2000 \times \frac{1.33x75}{50} \times \frac{100x1000}{8760}$$

$$= 11970 + 12500 + 23$$

$$= \$24,493 \text{ per annum}$$

One can make a number of general observations at this stage. With quarterly deliveries the inventory cost component alone is of the order of $25,000 per annum. In this particlar example the inventory in transit is virtually negligible and this points the inherent merit of some form of "continuous" transport medium such as a pipeline that would eliminate altogether the inventory in store. But this requires other conditions to be met and lest we imagine that a pipeline is some kind of panacea let us extend the above example. If a pipeline were in fact used to deliver the 100 tonnes of paint over a year then it can be shown that this would be done by a 10 mm pipeline pumping the paint at 3 metres per minute. However, 75 km of pipe of this diameter would hold 6.5 cubic metres of paint and the value of this would be some $65,000 and the inventory cost in transit at a 10 percent interest rate would generate a charge of about $6,500 per year. Also, for the small transport task in this example the capital cost of the pipeline would make the unit transport cost considerable.

A GENERAL FORMAT FOR THE DISIRIBUTION PROCESS

With the foregoing philosophical backdrop, we can outline a general equation for the distribution process in terms of a number of significant operational and transport-land use system parameters, such as route factor, tare factors, profit/subsidisation factors, and so on. We restate our initial equation, viz:

$$C = T + S + I + P$$

COST OF DISTRIBUTION OF FREIGHT

1. The transport cost, T, for a unit quantity of freight (tonne) may be written:

$$T = D \times K_R \times K_T \times C_T \times K_{p/s} = \$/\text{tonne}$$

where, D = the great circle or airline distance, km;

K_R = the distance route factor (1.xx) - not only is it highly mode specific but it can take account of spatial relationships between terminals and final destinations (or origins);

K_T = the tare factor (1.xx) which accounts for space utilisation of different modes, e.g. the cubic tonne equivalent;

C_T = the true operating cost which should include the fixed cost component; and

$K_{p/s}$ = the profit/subsidisation factor which takes account of concessions or cross subsidisation.

In practice, it is difficult to obtain true operating data, except in the case of highway vehicle operations (Pelensky, et al, 1962, 1968). It is apposite then in many evaluations and analyses to use published freight rates and schedules. The transport cost component can then be rewritten much more simply as:

$$T = d \cdot R \text{ (or } R_T\text{)}$$

where, d = the actual floor to floor distance;
R = the freight rate per tonne-kilometre; and
R_T = the freight cost per tonne-trip.

2. The inventory component, S, may be written

$$S = t \times L_I \times C_I = \$/\text{tonne}$$

where t = the time in transit, days (the floor-to-floor journey time) and equals $D \times K_R$ / V, where V is the speed in km /day;

L_I = the inventory time ratio (days of inventory/day in transit); and

C_I = cost of inventory (warehousing, interest obsolescence): in some circumstances adjustment may be necessary to take account of different rates for inventory in store and in transit, this can be easily enough done by modification of the L_I factor.

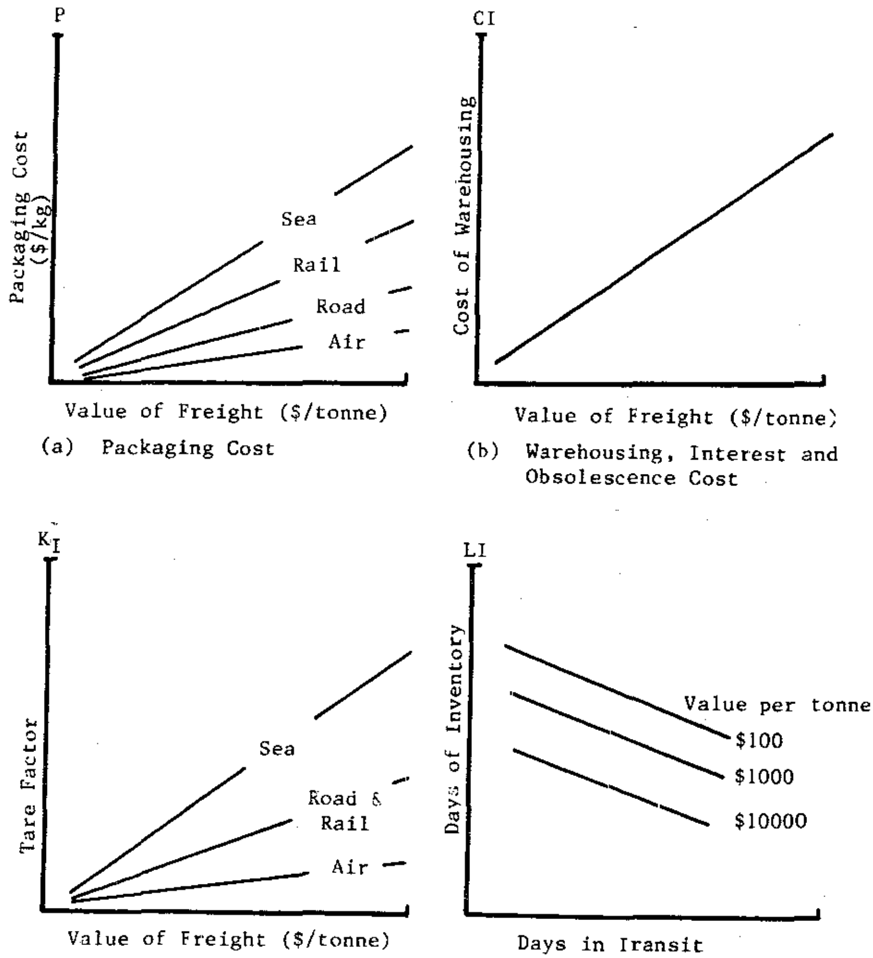
3. The insurance term may be expressed as:

$$I = D \times K_R \times K_T \times C_{IN} = \$/\text{tonne}$$

if the insurance rate, C_{IN}, is quoted on a tonne-kilometre basis. This, of course, is the insurance in transit and represents the extra risk associated with accidents, pilfering, etc; insurance in inventory may also be necessary but is taken into account when obtaining and figure for C_I.

4. Packaging is a most important consideration and may have a dominant effect on modal choice. However, it does defy a simple analytical formulation. Generally, it is proportional to the value of the freight.

The space constraints on this paper do not permit detailed discussion of actual values of the various parameters introduced into the above equation. However a substantial discourse on this aspect has been given by Russell (1981). The general character of the relationship between some of the more novel factors introduced above and the value of the freight are indicated in Figure 3.



(a) Packaging Cost

(b) Warehousing, Interest and Obsolescence Cost

(c) Tare (Cubic-Tonne) Factor

(d) Days of Inventory per Day in Transit

Figure 3: The General Characteristics of Key Factors and Parameters Related to the Transport Mode and the Value of Freight

Having developed and calibrated a comprehensive expression, for the cost of distribution, its application to practical situations requires it to be evaluated for a range of land-use and transport situations: (a) corridor, regional, inter-regional and international geographical land-use systems; (b) various value classes of freight, such as bulk commodities, manufactured products, food, apparrel; (c) different transport modes; (d) distance categories - say, 100, 500, 1000, 10000 km.

DISCUSSION

The essence of the conceptual ideas advanced is that the transport cost represents a part only (sometimes a small part) of the full cost of conveying freight from place to place. The other part of the cost is associated primarily with the value of the freight and the time it is in limbo - either in transit or awaiting consumption. Although the shipper is well enough aware of this and either explicitly or implicitly takes account of it, the highway planner focusses attention almost exclusively on user cost criterion. Whilst this can provide useful guidance for the allocation of priorities for works programmes once a budget has been allocated, it is of little help in determining the size of the budget or its allocation between the competing transport modes.

The road user cost approach, has a heavy dependence on traffic volume and is thus biased in favour of the passenger car user. It is true that commercial vehicles are given passenger car equivalents of 2 or 3 but, this is based on a capacity criterion and no account is taken of the value of the freight being carried. Other complications follow. The benefits arising from the passenger car traffic are due almost entirely to savings in time; operating costs, except where the improvements result in a saving of distance (i.e. a reduction in the route factor) or in road surfaces, usually increase when roads are improved simply because the speed rises (Sharp, 1983, pp. 190-192). Savings in private time are a valid measure of the social benefit of a road but the perceived "dollar and cents" surrogate for time savings is arbitrary and dominating, tending to confuse rather than clarify the true economic issues.

By contrast, the time costs based on the value of the freight are real in the dollar and cent sense: they are also a vital cost of production, especially when considering the competitiveness of exports to world markets. As these considerations are ignored (or at least not formalised) in conventional road user cost analysis, we suggest that the distribution cost equation permits a more realistic basis for the evaluation of benefits from transport infrastructure investments.

Another shortcoming of the road user benefit approach is that it provides no underlying rationale for the apportionment of transport investment amongst the competing modes. The distribution cost function does provide such a basis. Because all the cost components of freight distribution are expressed in real dollar and cent terms, a modal split criterion (c.f. Hodgkin and Starkie, 1976) may be obtained by simply minimising the distribution cost. Figure 4 illustrates a method of doing this for a road/rail situation. The distribuition cost curves are plotted against the value of the freight. In general, the curves cross over with the inherently more expensive transport mode becoming 'cheaper" for the carriage of more valuable freight. Plotted also on the graph is a histogram (here shown as continuous distribution) of the total demand for transport service in tonne-kilometre units. The point where the vertical through the cost curves crossover point meets the demand curve determines the transport task which should be apportioned to each mode. Here it is clear that low value freight (coal, ore, grain) is better handled by rail and manufactured products by road. This method may be extended to include the shipping and air modes.

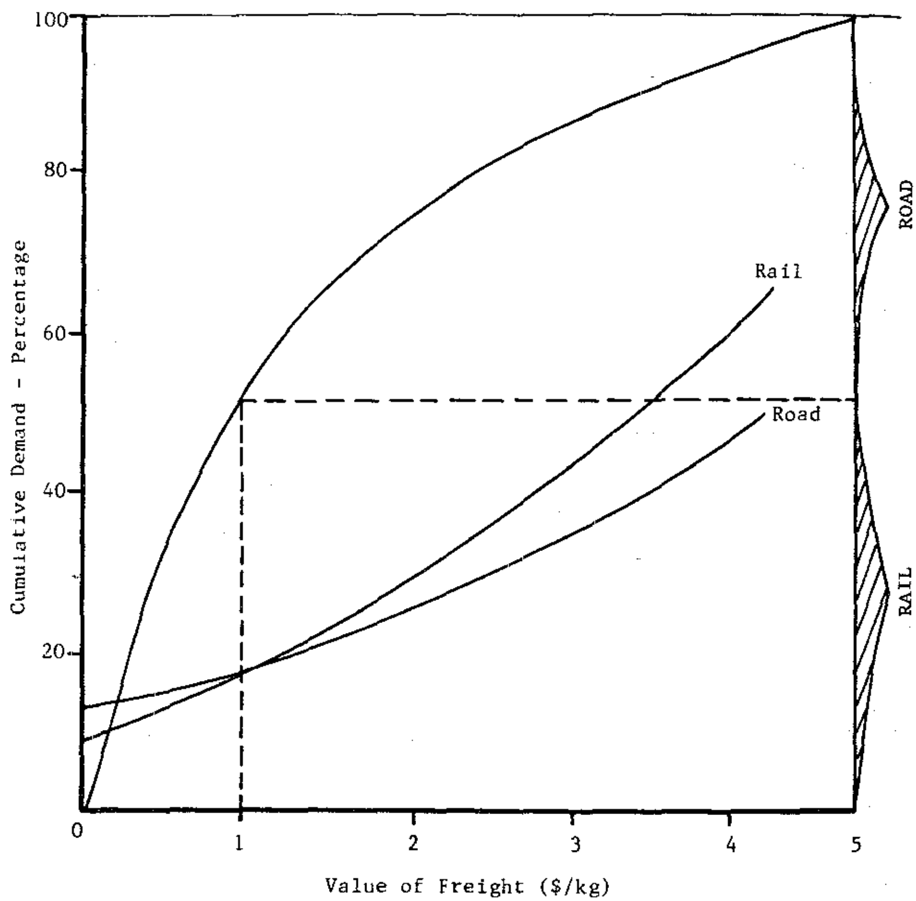


Figure 4: Indicative Distribution Costs by Transport Mode and the Value of Freight - a Rationale for Modal Split

In the day to day operational context, an individual shipper has a simple assignment problem to deal with. For a given product, an existing transport infrastructure and a specified origin and destination, the parameters and coefficients of the distribution cost equation can be evaluated and the shipper chooses the minimum cost alternative. This is analogous to Wardrop's minimum-time principle so widely accepted in individual passenger assignment. Somewhere between the individual shipper and the national or regional infrastructure planner lies the corporation planner who is faced with transport investment decisions, for example, for an OK Tedi or a Mt. Hamersley project. One imagines that in the latter instance just such an approach would have been adopted in deciding to build a railway from the ranges to the coast. Reverting back to the national transport planning task, it would seem that the development of the philosophy along the lines outlined in this paper would permit the establishment of a Commonwealth Transport Bureau that could take the responsibility for the allocation of funds for a balanced development of the nation's sea, rail, road and air transport infrastructure.

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