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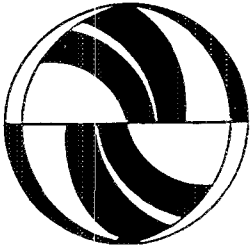**Permalink**
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Adib Kanafani

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Methodology for Mode Selection in Corridor Analysis of Freight Transportation

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1. INTRODUCTION

The purpose of this report is to outline a methodology for the analysis of mode selection in freight transportation. This methodology is intended to partake of transportation corridor analysis, a component of demand analysis that is part of a national transportation process. The methodological framework presented here provides a basis on which specific models and calculation procedures might be developed. It also provides a basis for the development of a data management system suitable for corridor analysis and freight mode selection studies. The scope of the present report is limited to providing a methodological framework and does not include elaboration of specific calculating schemes or computer procedures.

A theoretical framework is adopted from which mode choice models are derived. It is recognized that the theoretical framework is limited concerning the ability of quantitative approaches to completely explain all the factors that affect mode selection. The methodology presented here should be applied only as a guide in planning, and as a first step toward forecasting traffic flows on various modes. More reliable predictions of flows can be obtained only when other nonquantitative considerations are taken into account. The theoretical framework is based on the concept of logistic management, and comprises the assessment of the total costs of transportation and associated activities such as storage and handling. These logistic costs become a basis for allocating commodities to transportation technologies and modes available in a corridor.

The allocation to modes on the basis of the total logistics costs can follow a number of rules, depending on the context within which the allocation is being made. Thus, in a normative systemwide optimization approach that a national government or a very large shipper might adopt, allocation can be done on the basis of cost minimization. Yet if the object is to simulate the behavior of independent shippers, none of which is large enough to affect the transportation supply system, allocation is based on the principle of equilibrium within which the individual cost for each of the shippers is minimized. Normally these two allocation rules will result in different solutions.

The allocation procedures proposed in the methodological framework presented here recognize the stochastic nature of the logistics process and of the decision process of mode selection For this reason, stochastic models of logistics cost, and consequently stochastic models of choice, are proposed as the basis for the application of the methodology

The remainder of this report contains the following sections First, a section is devoted to the introduction of the concepts of logistics management and to the logistics decision process in commodity transportation This is followed by a discussion of the alternatives normally available to the shipper in a transportation corridor, alternatives which include the choice of mode or transportation technology The third section is devoted to elaborating on the components of the logistics cost function In the fourth part the deterministic and the stochastic choice models are described in detail Lastly, a section is devoted to a discussion of the policy context within which the transportation mode choice analysis process fits This section elaborates on the ways in which the methods described here should be used within such a process

2. LOGISTICS FRAMEWORK

The basic principle of the logistics framework for transportation mode choice analysis is that transportation is only one component of a larger, more extensive process that deals with the production and marketing of commodities Transportation of commodities takes place in order either to bring inputs of a production process to the location of production, or to bring finished products to marketing and distribution centers. Thus, transportation is one component of the logistic production planning process, and its analysis should be made within the context of a well-defined production and marketing system

The logistics process concerns decisions regarding important aspects of the production and marketing process. These decisions deal with the selection of production technology, the selection of inputs, the selection of the sources of the inputs and of the destinations of the products, and the selection of levels of production and marketing. The location of the production activity is another important decision in this process and one that has important implications for

transportation requirements It is considered, however, to be such a long-term decision that it is usually assumed to be fixed if the purpose of the analysis is to allocate estimated transport flows to available modes This clearly results in a useful simplification of the analysis

In defining a framework for the methodology of corridor mode choice analysis, some of the logistics decisions will be assumed to be fixed in the sense that decisions are made over terms longer than those of mode selection This simplification is advantageous, and also allows the integration of the mode choice analysis into other corridor studies that form a part of national transportation planning For any given corridor and for any commodity type, it is assumed that the following decisions have been made before proceeding with the mode selection

1   *Locations of Production and Marketing Activities·* As mentioned earlier, these are long-term decisions For the methodology, this implies that the origin and destination of commodity flows are known within the corridor, and only mode choice is to be studied

2   *Quantities to be Shipped·* This again is assumed to result from a more extensive demand analysis than just the choice of mode--it is a part of the overall logistics planning process For the methodology in question here, this decision implies that for each type of commodity, the flow quantities between fixed origins and destinations are given.

It is possible in principle, of course, to integrate one or both of these decisions into a single logistics planning model that would include locational analysis and demand analysis in addition to mode selection The limitation on the scope at this stage is intentionally made in order to respond to a specific analytic component within the National Transportation Plan methodology The incorporation of these decision analyses could be conceived and performed at a subsequent stage without difficulty.

The logistics decisions remaining in the mode selection methodology that is presented here are discussed in more detail in the following chapter Naturally, since the logistics process is broader than simply the choice of mode, the methodology provided here will reflect that extended range

Logistics Decision-Making Unit

Before proceeding with the detailed specification of the logistics choice process and its modeling, it is useful to clearly define the decision-making unit involved. In general, transportation decisions are made by a variety of participants in the production and marketing process The decision to ship a particular commodity can be made by the producer as part of a marketing plan, or by the consumer as part of an input acquisition plan The decisions regarding the specific operation of the transportation system are usually made by the carrier, and occasionally influenced by regulatory institutions Such decisions are considered as a part of the supply process. and not of the logistics decision process

In developing the methodology for mode selection we shall adopt the perspective of the shipper The shipper is the decision-maker who determines the various logistics choices involved in a commodity transportation activity The *shipper* is a generic term and could, in fact, refer to a producer who is shipping outputs to a marketplace, or a receiver who is ordering shipments from the production point It could also refer to a single entity that is both a producer and a consumer in the sense of being directly involved in the marketing of the products in the marketplace The shipper could also be a corridor level planning agency (or development corporation) which makes decisions regarding the deployment of commodities within the region The adoption of the shipper as the decision-making unit is not to imply that the selection of modes will always be made with the shipper's perspective and objectives in mind This adoption is rather a behavioral assumption stemming from the role of the shipper in logistics decision-making The decisions made by a shipper will significantly affect the total generalized costs of transportation, and hence will influence the selection of transportation options, regardless of what objectives are used to guide this selection Indeed, as we shall discuss in a later chapter, there exist planning situations where the shipper perspective is not an appropriate one for mode selection, but where an overall system objective guides the choice

3. LOGISTICS CHOICES IN COMMODITY TRANSPORTATION

As mentioned earlier, the scope of the methodology developed here is limited to the following scenario A corridor is given with a fixed set of economic and geographical characteristics Within this corridor locational and production technology decisions have been made, resulting in a given demand flow in each of a set of commodity types In order to carry out this transportation activity, a shipper or shippers have to make a number of logistics decisions defining the manner by which the commodities are shipped and the technologies are used.

The following are the important choices that must be made by the users of the commodity transportation system

1   *Mode.* As different modes will in general offer different levels of service and result in different costs for commodity transportation, the firm will in general choose among available modes in an effort to minimize the total generalized cost of transportation

2   *Shipment Size* The firm has a choice of shipment size associated with any given total quantity of commodity shipped More frequent shipments result in smaller shipment size and vice versa. The size of shipment is an important factor in logistics decisions, affecting the levels of inventory that must be kept on hand in order to meet the needs for the commodity during the time between shipments Shipment size will also affect the choice of mode

3   *Frequency of Shipments:* Closely related to the choice of shipment size, this choice will depend on the handling costs involved in making orders, and will also affect inventory levels

4   *Re-order Point:* This is the firm's choice of the point at which to plan the arrival of a shipment in relation to the point at which available inventories are expected to run out Usually as a safety measure re-order points occur sooner than stock-out points, how much sooner will of course depend on inventory costs.

To illustrate the interaction between the choices of shipment size and frequency of shipments, consider the following situation a firm requires a total of T tons of a certain commodity per year The firm has a choice of frequency of orders and shipment size Let the handling cost per order be h, and the frequency of shipments be f, so that average shipment size is $S = T/f$ The warehousing cost per ton and per unit time is w Figure 1 shows the levels of inventory that have to be maintained by the firm for a given value of f or S It can be seen from the figure that the average inventory level, not including any safety stocks for emergencies, is given by

$$\iota = \frac{1}{2} S = \frac{T}{2f} \tag{1}$$

The total warehousing cost is then given by

$$W = w\iota = \frac{w}{2} S = \frac{wT}{2f} \tag{2}$$

The firm has a choice between infrequent large shipments, which would raise the total warehousing costs, or frequent small shipments which would raise the handling costs The optimal combination of shipment size and frequency can be derived by minimizing the sum of these two costs, which we shall refer to as logistics costs L

$$L = \frac{wT}{2f} + hf \tag{3}$$

where, as defined before, h is the handling cost per shipment and W is the unit cost of warehousing The optimal frequency of shipments can be found from

$$\frac{\partial L}{\partial f} = 0 \tag{4}$$

and combining Eqs. (3) and (4) yields the optimal frequency and shipment size.

$$f^* = \sqrt{wT/2h} \tag{5}$$

and

$$S^* \equiv \sqrt{\frac{2hT}{w}} \tag{6}$$

for which the total logistic cost is given by

$$L^* = \frac{wT}{2f^*} + h \tag{7}$$

$$= \sqrt{2hwT}$$

This model represents only the trade-off between warehousing costs and handling costs Other considerations can influence the choice of shipment size (and hence frequency), and transport rates and mode levels of service. It should be clear that the appropriate size of shipment is not independent of the mode considered It is also interesting to note that a given shipment size S will result in a given logistics cost L Hence the use of shipment size as a factor in a transport demand function such as the Friedlaender and Spady model described in the previous section is a proxy for logistics costs. Whether the demand has a positive or negative elasticity with respect to shipment size will depend on the relative values of w and h This elasticity will normally be negative except when the handling cost per shipment is unusually high

This simple example can also be used to illustrate the firm's choice of strategy for re-ordering as an aid in dealing with uncertainties either in the transportation system performance or in the use rate of the commodity Figure 1 shows the evolution of inventory levels when every shipment of size S = T/f arrives precisely on time, that is, at precisely the point in time when stocks on hand run out. It also depicts a situation in which the rate at which the commodity is used up is precisely S tons per time period between shipments 1/f, i.e., precisely T tons per year If for some reason the commodity is used up at a faster rate, such as due to an unexpected upsurge in the demand for the firm's output, then the inventory will run out before a shipment arrives Both of these events--the delayed arrival of a shipment and the early depletion of inventory--will result in what is called a stock-out, at potentially high opportunity costs to the firm In order to avoid stock-out, the firm will usually maintain a safety stock by adjusting the re-order schedule and the scheduled arrival times of shipments in such a way as to limit the risk of stock-out to a certain level.
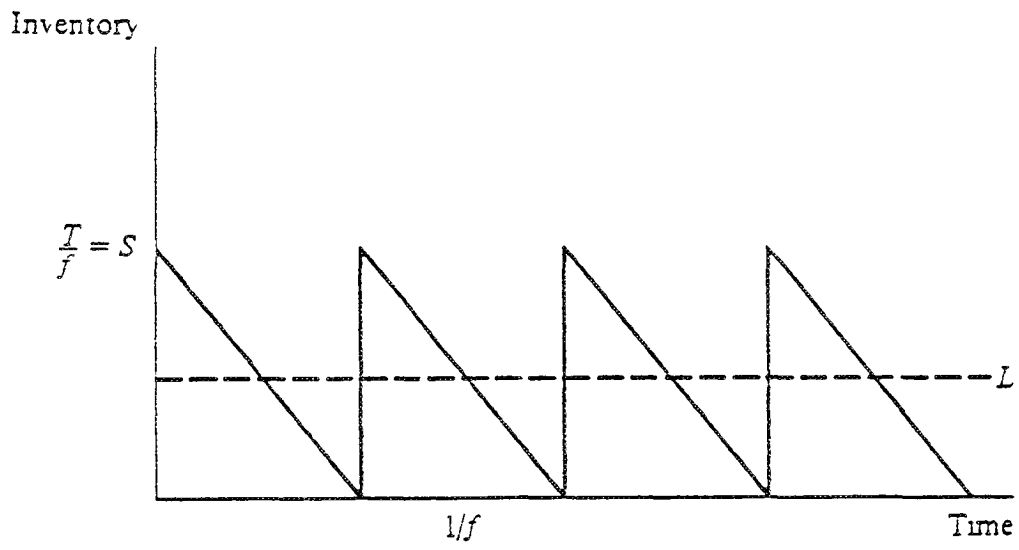
Fig. 1 Inventory History with Regular Shipment Arrivals

Figure 2 illustrates how a delay of shipment arrival can result in stock-out and how the firm can avoid that by having shipments scheduled to arrive earlier. In the figure a shipment arrival delay from b to b' can cause a stock-out as indicated by the cross-hatched area. In order to avoid a stock-out, the shipment can be scheduled to arrive earlier, at b", resulting in a maximum expected inventory level S' and a safety stock of S_1 which could be used up if the shipment is delayed and arrives at time b rather than b". Clearly, the maintenance of a safety stock will increase inventory costs. Hence the selection of the appropriate level of that stock would depend on the warehousing cost, stock-out costs, uncertainties about the transportation system, and estimates of the demand for the firm's output. For some commodities it is possible to keep safety stocks to a minimum if a fast mode of transport, such as air, can be used for quick response to emergencies and imminent stock-outs. Safety stocks are usually made proportional to the sum of the time between shipments $\frac{1}{f}$ and the travel time. One method is the following simple rule for determining safety stock S_1

$$S_1 = K \sqrt{[(1/f)+f]T} \qquad (8)$$

where the proportionality factor K would depend on the unreliability of the transport systems measures, e.g., by the standard deviation of the travel time, or the unreliability of the estimate of the firm's rate of use of the commodity, also as measured by the standard deviation of that estimate.

With so many choices involved in any transportation activity, and given the possible range available for each, it can easily be imagined that the number of options rapidly becomes intractable. Therefore, it is necessary in any model choice application to limit these alternatives by defining a domain of choice for any given corridor and commodity type. This can be done by defining the appropriate mode-shipment size combinations. Clearly, there are modes that are not suitable for very small shipments, and others that are suitable only for small shipments. For example, it is only feasible for a shipper to operate its own trucks if there are shipments to fill the trucks for a reasonable frequency of trips. If not, it is reasonable to expect that the
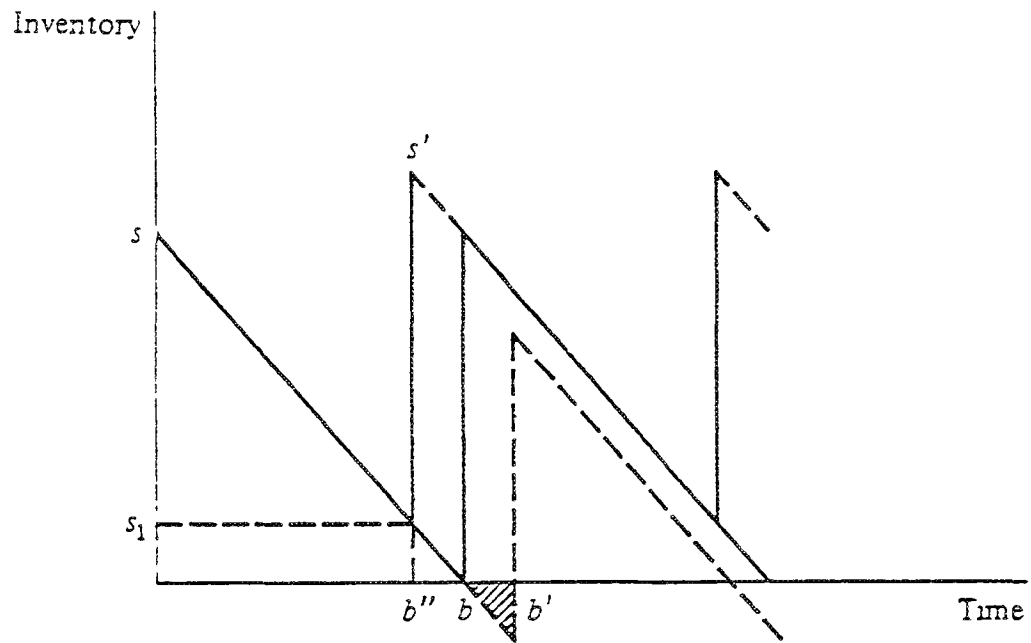
Fig. 2 Inventory History with Irregular Shipment Arrivals

shipper is better off purchasing transportation from a carrier in less-than-truck-load (LTL) units. Similarly, certain commodities will not lend themselves to air transportation because of their density and packaging characteristics. Hence one should define for each corridor and commodity type the "choice set" representing the alternatives available to the shipper for the purposes of applying a choice model. Note that the definition of choices needs only to concern the combination of mode and shipment size. The frequency of shipments and re-order point decisions are made independently on the basis of the relative costs of inventory and handling, as described earlier. A typical layout for a definition of a choice set is given in the table below. There are 22 alternatives identified with four modes (rail, private truck, common carrier trucks, and air) and with different shipment-size groupings for each.

It is, of course, possible to expand or contract this type of choice set depending on the suitability of the commodity, available technology for classification, and availability of data.

Analysis of Choice

Having identified the relevant options in a particular mode selection situation, the next step is to identify the important determinants of choice and to assess their values for each of the alternatives on hand. This is followed by the application of some rule to select the appropriate alternative on the basis of these determinants. This choice analysis process can then be summarized as follows.

a. Identify the relevant alternatives in the corridor,

b. Quantify the determinants of choice for each alternative,

c. Apply a choice rule to select one alternative

To illustrate this process with a simplified example, suppose that in the choice among alternatives the only determinant is the travel time. Step b in this case would be to compute the total travel time for each of the alternatives identified in Step a. This is followed by the application of a decision rule for the choice of alternative. For example, if the rule is to minimize travel time, then the choice would be the alternative that has the lowest overall travel

TABLE 1

A Sample Mode Choice Set for Commodity Transportation

1 - RAIL/freight forwarder, minimum charge

2 - RAIL/freight forwarder, small shipment

3 - RAIL/freight forwarder, large shipment

4 - RAIL/trailer on flat car, one trailer

5 - RAIL/trailer on flat car, two trailer

6 - RAIL/carload, small shipment

7 - RAIL/carload, large shipment

8 - RAIL/multiple carload

9 - Common Carrier TRUCK/less-than-truckload, minimum charge

10 - Common Carrier TRUCK/full truck load, small shipment

11 - Common Carrier TRUCK/full truck load, large shipment

12 - Private TRUCK/less-than-truckload

13 - Private TRUCK/full truck load single truck

14 - Private TRUCK/full truck multiple trucks

15 - AIR/individual shipment, minimum charge

16 - AIR/individual shipment

17 - AIR/container, small shipment

18 - AIR/container, medium shipment

19 - AIR/container, large shipment

20 - AIR/charter, small shipment

21 - AIR/charter, medium shipment

22 - AIR/charter, large shipment

time If, on the other hand, the rule is to achieve equilibrium among alternatives, then the flows will be assigned to the various alternatives in such a way that travel times are equal on all of them Different decision rules are relevant for different policy analysis situations, this will be discussed in a later chapter of this report

The determinants of choice that can be quantified for the purposes of this analysis are going to be defined as components of one single overall measure referred to as the "total logistics cost" It is believed that, at this level of quantification, the total transportation cost is the single most important determinant of mode selection, provided that cost is defined in a sufficiently broad sense to include all aspects Departures from logistics cost as the determinant of selection are, of course, common in reality This should not, however, preclude the cost-based analysis from providing the first cut at the rationalization of the mode selection in corridor analysis This issue is discussed later in this report. We will first present a discussion and model of total logistics costs

4. LOGISTICS TRANSPORTATION COST

In this chapter we discuss the total logistics costs as defined in the previous chapter These costs will constitute the total costs involved in the transportation of commodities between origins and destinations and with all the activities associated with this transportation, such as storage and inventory control, insurance, and emergency shipping and handling The challenge in modeling mode choice in commodity transportation lies in understanding and quantifying the factors that make up the total cost of transportation These costs depend primarily on three factors. 1) the transportation technology used, 2) the logistics of shipment scheduling and sizing, and 3) the commodity characteristics These three factors are not independent; it is easy to see that the cost of using a particular technology depends, among other things, on the size and the frequency of shipments as well as on the type of commodity being carried.

The following are the components of the total cost of commodity transportation

1   *Shipping Cost* This is the rate charged by the carrier per unit of the commodity, and is usually dependent on the shipment size and on the length of haul. The shipping rate charged by a carrier will often include many of the components of commodity transportation, other than simply the cost of operating the carrier's system These components will include insurance, handling costs, sometimes packaging costs, and often a provision for reimbursement for delays in transit that might cause the receiver to incur stock-out costs The shipping cost will depend predominantly on the mode of transportation used Handling costs as well as packaging costs will also depend primarily on the mode used Packaging costs will often be influenced by the costs of loss or damage that may be caused by poor packaging.

2   *Time Cost* The travel time components contribute to commodity transport cost in two ways First is the potential loss of value of the commodity due to its limited shelf life either because of perishability, as in the case of fruits and vegetables, or because of its time value, as with newspapers and fashion clothes. Second is the cost of the tied-up capital represented by the value of the shipment while it is in transit. For high valued commodities, or for very large shipments, this can add up to a significant cost component.

3   *Warehousing Cost:* This cost usually depends on the type of commodity stored, and also depends on the overall general level of inventory As discussed in the previous section, the deterministic level of inventory, not including safety stock, will depend on the frequency and size of shipments

The warehousing, or inventory cost, will also include the cost of the capital tied up in the inventory This will usually encourage shippers or receivers of high value commodities to maintain minimum inventory levels and to depend on emergency, fast transportation, such as private truck or air, in order to avoid stock-outs

4   *Ordering Cost per Shipment* This cost usually depends on the mode used and on the nature of the process by which the carrier in question operates Frequent long-term orders from the same supplier will understandably result in lower ordering costs than when the supplier choice is constantly changed Emergency orders will also tend to cost more

5   *Unreliability Costs* These costs are reflected in two ways First, in response to unreliability in the logistics process, higher safety stock levels must be kept, resulting in higher warehousing costs Second, frequent emergency orders and disruptions in the receiver's or the shipper's inventory control system, or even production and marketing processes, will all result in higher costs

Cost Model

In order to account for these costs it is suggested that a cost model be constructed and calibrated for use in the mode selection model discussed later in the analysis This cost model will contain variables that describe the various cost components mentioned above Simplifications are made with a view toward reducing, or at least limiting, the data requirements for building such a model.

In the cost model, the total logistics cost for transporting will be written as an additive function as follows

$$C(T) = \text{Transport Charges} + \text{Value of Time in Transit} + \text{Inventory Cost} + \text{Stock-Out Cost}$$

where $C(T)$ is the total cost of transportation of T tons of a commodity in a given corridor. Taking each of these components in detail, we have

$$\text{Transportation Charges} = r\,T$$

where r is the unit transportation rate (tariff), and T is the total quantity shipped. We have assumed here, for simplification, that the tariff will include all the insurance, packaging, and handling charges associated with the shipment. If this is not the case for a particular situation,

then r should be modified to include these components to the extent that data about them are

available

Value of Time in Transit = Loss of Commodity Value + Value of Capital Tied Up

$$= utd(t)T + utkT$$

where u is the unit value of the commodity

d(t) is a function that describes percentage deterioration in value of commodity as a function of time For example, if at $t=5$ days 50% of the commodity will be lost to deterioration or loss of time value, then d(t) is 0.5

t is the total travel time, including all terminal times

k is the cost of capital, or the interest rate on the capital value of the commodity while it is tied up in transit

It is important to note here that u should represent the unit value of the commodity as perceived by the shipper In other words it is the price of the commodity at the destination, since it is this value that will be lost if the commodity is lost

Inventory Cost = Cost of Storage + Value of Capital Tied Up in Storage

$$= \sqrt{2hwt} + hT/2w$$

where, as defined earlier

h is the handling cost per shipment

w is the warehousing cost per unit time, and per unit of commodity

k is the total cost of capital over the period of time in question.

Note that the first component of this cost is the inventory cost as determined by equation (7) in the previous chapter The second component measures the value of the capital tied up in inventory Using equations (5), (6), and (7) it can be seen that the average inventory level, or the average of the quantity stored at any point in time, is hT/2w When multiplying this by uk, the cost of the capital tied up is yielded

Stock-out Cost = Cost of a Stock-out x Expected Number of Stock-outs

s x E(n)

where S is the cost of a stock-out this is to be calculated on the basis of the commodity and the corridor in question For example, if the alternative during a stock-out is an emergency order by air of the minimum shipment size, then that could be used as a cost of stock-out during the analysis period (for example during one year) This is to be assessed exogenously for every corridor and technology

If we combine all these components into a single cost function, we obtain the following

$$C(T) = r T + ut\, d(t) + utk\, T + \sqrt{2hwT} + uk \times hT/2w + s\, E(n) \quad (9)$$

The various components of this function will have to be assessed and accumulated in order to perform the mode selection analysis Care should be exercised in doing this to maintain consistency in units and definitions of terms

Units and Variables of Cost Model

In order to maintain consistency in units and dimensions for the various components of the cost model, the following is a definition of each of the variables

T is the total quantity in tons that will be shipped during a period of analysis such as a year. Tons per year.

c(T) is the total transportation cost for transporting the T tons It is measured in Bs per year.

r is the transportation charge per unit for the corridor in question. It is measured in Bs per ton

u is the value of the commodity True market value per unit, measured in Bs per ton

t is the total travel time from origin to destination. This should include the terminal times and times for access and egress from a line haul mode such as a railhead. It is measured in the same units used for T Thus, if T refers to tons per year, the travel time t is measured in years (or fractions of years).

d(t) is the fraction of commodity that will be lost during a time period t It is a dimensionless fraction

k   is a capital carrying cost It is analogous to the interest rate It should be measured in percentage points, referring to the same time period used for T Thus, in this case, it is the annual interest rate

h   is the handling cost for shipment orders It is a one-time cost for a shipment Here it is assumed to be independent of shipment size Thus it is measured simply in Bs per shipment

w   is the warehousing cost The cost of storing one unit of commodity for one unit of time, it is measured in Bs per ton per year.

s   is the stock-out cost This is calculated by determining the alternative form of shipment for emergencies, which will occur when a regular shipment is delayed The alternative shipment cost for minimum shipment size is recommended as a measure for this variable It is measured in Bs per shipment

E(n) is a number that reflects the reliability of a proposed technology It is to be exogenously estimated, preferably using qualitative judgment rather than complex quantitative analysis It is the number of times per year shipments are expected to be delayed or canceled

The cost model thus defined should be constructed for each of the alternatives identified as relevant choices in the corridor and for the commodity in question Once this is done, it is possible to proceed to a mode choice model, where some rational rule of choice will be applied. The mode choice model is described next.

5. MODE CHOICE MODELS

The purpose of a mode choice model is to estimate the selection of mode alternative on the basis of a predetermined decision rule The decision rule takes into account the measures of performance of each alternative, such as the total cost, and applies to it a selection rule that represents the policy objectives behind the analysis. In this case, the measure of performance is the total generalized logistics transportation cost $C(T)$ as defined in the previous chapter In any given situation, a corridor is given and a commodity flow for a particular commodity type is known A set of alternative technologies is identified and the values of $C(T)$ are estimated for each. The mode choice model will then be used to assign or allocate the commodities to the alternatives according to some rule.

There are two fundamentally different approaches to mode allocation that can be applied in corridor analysis. The first is an optimization approach and always attempts to allocate commodities to transportation system facilities in such a way as to minimize the total transportation costs. The other is the equilibrium approach which attempts to simulate market behavior where every shipper allocates commodities to modes according to individual cost minimization objectives. In general, these two result in different allocations at the corridor level, the selection of which model to apply is a matter of analysis policy and should be consistent with the way other analyses are done in National Transportation Planning.

Optimization Model

This mode is simply a scheme to allocate each bundle of commodities to the alternative that has the lowest value of C(T). When the commodities of transportation are independent of the flow quantities, T, the solution is a relatively trivial solution referred to as the all-or-nothing assignment. This, of course, is an unrealistic condition and it is rarely a good model of transportation.

When, on the other hand, total transportation cost on any alternative is not independent of its traffic flow, then a more complicated model would be necessary to implement the optimization process. In the simplest and most common form, it is usual to assume that the transportation cost functions are linear in the sense that average costs are constant and independent of traffic flow. In this case, the allocation of commodity flows to the alternative is done by a linear programming model with the objective function of minimizing total system cost. Since the total traffic on any alternative mode system is composed of the sum of traffic of the different commodities assigned to that mode, a modification of the conventional linear programming formulation is necessary in order to allow a realistic calculation of transportation costs.

Let there be I alternatives ($i = 1,2,...,I$) and J commodities ($j = 1,2,...,J$). Let T_{ij} be the flow of commodity j on mode i, and C_{ij} be the average transportation cost per unit of flow of commodity j on mode i. With C_{ij} assumed constant, we can obtain a simple linear programming formulation for the allocation of flows to modes.

$$minimize \quad \sum_i \sum_j C_{ij} \; T_{ij}$$

$$subject \; to \quad \sum_i T_{ij} \; = \; T_j$$

$T_{ij} \geqslant 0$ where T_j is the given corridor demand for commodity j transportation When the average transportation cost C_{ij} is not fixed but dependent on the total flow T_i on an alternative technology i, then the program is modified to read

$$minimize \quad \sum_i \sum_j C_{ij} \; T_i \; T_{ij}$$

$$subject \; to \quad \sum_i T_{ij} \; = \; T_j$$

$$\sum_i T_{ij} \; = \; T_j$$

$$T_{ij} \geqslant 0$$

and $C_{ij} \; T_i \; = \; f_i(T_i)$ which implies that the cost-flow relationship for a mode i, $f_i(T_i)$, is to be determined and proven a priori.

Linear programming solutions for mode allocation have been used commonly in practice. In some corridor analyses they may be appropriate models of traffic estimation, but that depends very much on the policy context within which they are applied This issue is discussed later on in the report.

Equilibrium Model

The equilibrium model of mode selection departs from the assumption of optimization and applies a different selection rule In the optimization model the assumption is that mode selection occurs according to a global rule that the total system cost is to be minimized, and that the rule is implementable in the real situation This means that some central authority is in a position to allocate flows to modes in order to optimize the total system in the corridor. The equilibrium model, on the other hand, takes the position that no such global rule is implementable, and that each shipper, or group of shippers, attempts to optimize its own

transportation system, which is only a subsystem of the total Equilibrium is achieved in the

total system, when no shippers, or groups of shippers, can improve their condition by shifting

the allocation of flows among modes This occurs when the average costs on all mode alterna-

tives are equal in the whole system

In the situation where average costs are fixed and independent of flow, the solutions of

both the optimization and the equilibrium models are identical they both result in the trivial

case where all flows are assigned to the mode with the lowest average transportation cost for

each commodity type In the more realistic situation where average costs are dependent on

traffic flow, the equilibrium model assumes a more complicated form The model will, in this

case, assign flows to modes until the equilibrium criterion is achieved, namely until all modes

have equal average costs Depending on the nature of the cost-flow relationship used, an

appropriate algorithm is usually designed to perform this allocation This is similar to the appli-

cation of equilibrium analysis in traffic assignment The most commonly used algorithm is the

so-called incremental assignment algorithm in which traffic flows are assigned gradually to the

system alternatives A simple flow chart explains this method

a   Calculate the zero-flow costs on all alternatives C_{ij} (O)

b   Assign a proportion (e.g., 10 percent) of the flows to the minimum alternative for
     each commodity

c.   Recalculate the costs on the alternative subsystems with the flows assigned in step b

d.   Assign the next increment (e.g , additional 10 percent) to the minimum cost alterna-
      tive for each commodity using the recomputed costs.

e.   Repeat steps b and d until all flows are assigned.

Note that the equilibrium allocation method will result in a distribution of commodities

among alternatives The solution is not an all-or-nothing solution, for each commodity type,

different proportions are transported on each of the mode alternatives available in the corridor

The above algorithm should be easily programmable on a computer system and should be rela-

tively straightforward to implement. The important thing is to have on hand average cost

functions for each alternative and community, $C_{ij}(T_i)$, in order to permit the computation of step c

Stochastic Model of Choice

In the two previous models it is an implied assumption that the cost functions are well known and understood by the shipping decision makers, whether individual shippers or a central authority It is possible to relax this assumption and to postulate that the cost functions are perceived differently by different users, or on different occasions when the shipping decision is being made Alternatively, it is impossible to postulate that the allocation rules are applied nearly consistently all the time, but not always perfectly consistently These postulates result in formulating the allocation model in a stochastic way The most common method is to assume that the cost functions themselves C_{ij} (T_{ij}) are random functions made of the deterministic component that is measured according to the analysis described earlier, and a stochastic random component representing the variability in the manner by which measured costs are perceived, or are used in a selection rule

$$SC_{ij} \ (T_{ij}) \ C_{ij} \ (T_{ij}) \ + \ e_{ij}$$

where

    SC   refers to a stochastic cost

    e_{ij} refers to a random variable with some distributional characteristics

The assumption of the stochastic allocation method is that $SC_{ij}(T_{ij})$ rather than $C_{ij}(T_{ij})$ is the criterion for allocation of flows to mode alternatives. Depending on the distributional assumptions made for the stochastic components of the cost function, specific formulations of the choice model result. The simplest and most common method is the logit method which results in the following allocation rule·

$$P_{ij} \ = \ \frac{e^{V(ij)}}{\sum_i e^{V(ij)}} \tag{13}$$

where

P_{ij} is the proportion of all flows of commodity j that are allocated to mode alternative i,

$V(ij)$ is a choice function related directly to the cost function developed in the earlier sections In this application it is appropriate to use the deterministic component of the cost function for the model In other words $V(ij) = C_{ij} (T_{ij})$

This model results from assuming that the stochastic components e_{ij} are all independent and identically distributed random variables with a Gmbell distribution It has the advantages of simplicity and ease of calculation

In stochastic modeling of choice, it is common to assume linear cost functions, i e , constant average costs C_{ij} In the model of equation it is then appropriate to use the deterministic average cost as the $V(\ )$ choice function, with the result that

$$P_{ij} = \frac{e^{C_{ij}}}{\sum_i e^{C_{ij}}} \tag{14}$$

The logit model results from making some simplifying assumptions regarding the distributional characteristics of the e_{ij} terms Most importantly they are assumed independent of the choices This implies that the randomness in the perception of mode attributes are independent among modes If it is desirable to change this assumption because mode alternatives are known to have similar characteristics, and attributes that might vary simultaneously, then it is possible to modify the choice model and replace the logit formulation by a probit formulation where the random terms are assumed to have a multivariate normal distribution with correlations between mode alternatives This normally results in a complication of the model used in the procedures used for its application It is suggested that at the corridor level the simpler logit model be applied for mode selection. Computer routines are simple for the logit model Some already are available although it might be desirable to develop one specifically for use in the corridor analysis of the National Transportation Plan

Note that stochastic modeling is an equilibrium formulation. The assumption is that each shipper, or group of shippers, is attempting to minimize costs, but that the costs are perceived in a random fashion, hence there is a distribution of flows among modes.

6. CORRIDOR MODE SELECTION PROCESS

This section is devoted to the discussion of the process within which the models suggested in the report are to be applied. As mentioned earlier, mode selection, whether it be in a corridor context, or in an urban transportation context, is a process that extends well beyond the economic comparison of costs, regardless of how well and how inclusively these costs are defined It is a planning and management process, and as such has economic, as well as political, social, and practical aspects

As mentioned earlier in this report, the mode selection methodology proposed for use in the National Transportation Plan consists of a number of major steps Once the cost functions for each alternative are defined according to the logistics cost principle discussed earlier, the specific model of choice to be used will depend on the rule that is to guide the selection of technologies Two possible rules are available, and the choice between them should be a matter of policy determined on a corridor-by-corridor basis The first is the normative rule in which the allocation of commodities to modes is guided by the objective of minimizing total corridor transportation costs As we saw earlier, this rule requires the application of a liner programming formulation The other rule that can be used is the equilibrium rule in which the mode selection is a prediction of the behavior of individual or small groups of shippers No attempt is made in this case to optimize over the whole corridor system. The equilibrium model, which can be implemented with a gradual assignment algorithm, becomes a prediction of shipper behavior in the absence of central control over the whole freight transportation system in the corridor Therefore, the choice between these two approaches is a matter of policy if central control exists in the corridor in question, and for the commodity in question, then the optimization model is to be preferred, but if such a control does not occur then the predictive model of equilibrium is more suitable. The use of the predictive model does not rob planners or policymakers of the opportunity to exercise some normative control in the planning of the transportation system Indeed, one can still influence the choice of mode as predicted by an equilibrium model by limiting the range of options available, or by influencing some aspect of the

level of service of some technology For example, if for reasons apart from logistics and cost considerations, a particular mode is to be "favored" in the allocation of flows of some commodity, then the levels of service of that mode can be influenced to achieve the result The influences placed on the attributes should in this case reflect the types of policies that are envisioned in order to encourage the use of that particular mode For example, if the government wishes to use tax incentives to encourage the use of a particular form of transportation, then this can be reflected by reducing the transport charges for that mode in the choice model

Stochastic versus Deterministic Models

The user of a mode selection methodology has the choice between the deterministic and the stochastic models presented in the previous chapters Optimization models with stochastic components are rather complex and intractable Their use in practice has been limited to specialized applications In this case, it is recommended that if an optimization approach is adopted, then a deterministic model such as the one presented in this report should be used Indeed, the idea behind the optimization model is that there is a central authority that exercises control over the allocation of commodities to technologies of transportation on the basis of cost and other considerations In such a case the opportunities for random behavior are limited, and the deterministic model is appropriate On the other hand, if the market equilibrium approach is adopted, then in simulating shipper behavior there are strong arguments in favor of the stochastic postulations Hence, one would then opt for the stochastic choice model If the opportunity is available for "calibrating" the choice models on the basis of data from the various corridors included in the National Transportation Plan, then the opportunity will exist for adapting the choice model to reflect the specific aspects of the shipper behavior in those corridors This can be done by allowing the choice model to have parameter values that can be determined on the basis of the calibration process. If, on the other hand, calibration is not realistic, then the model without specific randomness parameters can be used The parameters of the model will in such a situation be determined by comparison with other models applied in similar situations.

It would therefore be imperative to determine at an early stage in the further developments of the model the extent to which available origin-destination flow data can be put to use in calibrating specific parameter values for application in the National Transportation Plan

Limitations to Mode Choice Modeling

The models used in mode choice analysis are seen as tools that form a part of an overall planning process In corridor analysis, this process includes, in addition to such models, analyses of technology options for development and evaluation of investment strategies and implementation programs As such, there are limitations to the extent to which the mode choice methodology presented here can be used to obtain a definitive answer to the technology choice question In addition to the economic and operational considerations included in the model presented here, there are numerous intangible, or unquantifiable, considerations that enter into this process As discussed earlier in this chapter, the opportunity exists through exogenous control of model variables to introduce some policy considerations favoring one modal aspect or another, but such opportunities are limited at best, and could lead to arbitrary modifications of models It is essential that the user of a methodology such as this one recognize the limitations of the quantitative analysis The proper place of the models presented here is within an overall corridor analysis process that includes technical and economic analyses as well as evaluation procedures.

The important unquantifiable aspects of corridor mode selection include the developmental effects, social and political, of the modes implemented, as well as the secondary impacts that might result from the operation of these transportation technologies in the corridors in question Defense considerations and environmental impacts are also important criteria for the evaluation of transportation technologies Such an evaluation should occur at a much broader level than that of the choice of mode for commodity shipments in a corridor Other methodologies are available for accomplishing some of this analysis In particular, multicriteria evaluation procedures can be used to evaluate some of the unquantifiable impacts and to assign priority to technology choices