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ALTERNATIVE SCENARIOS FOR FEDERAL TRANSPORTATION POLICY

VOLUME IV

NETWORK MODELS FOR TRANSPORTATION POLICY ANALYSIS

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

MASTER

FIRST YEAR FINAL REPORT

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16. Abstract

The research evaluates the economic effects of existing and prospective federal policies governing intercity and international freight and passenger transportation enterprises in the economy of the United States. The analysis encompasses all modes of transportation, including rail, motor, water, air and intermodal coordinative institutions, and focuses upon the impact of alternative regulatory policies. However, other federal policies including subsidy, taxation, procurement, government ownership and investment, special programs for particular transportation industry problems and impacts of general national policies on transportation will be included when relevant.

Economic evaluation includes the study of efficient resource allocation and distributional effects of alternative policies together with consideration of both partial and general equilibrium effects. The research is interdisciplinary in scope, drawing upon engineering, economics, statistics, law and administration.

There are four volumes included in this report:

Volume I - Summary of First Year Report
Volume II - Policy Review and Scenario Development
Volume III - An Integrated Policy Model for the Transportation Industries
Volume IV - Network Models for Transportation Policy Analysis

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METRIC CONVERSION FACTORS

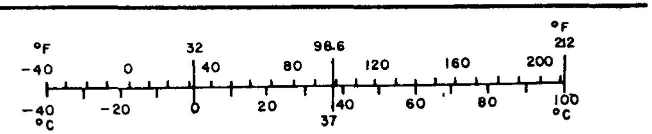
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. Introduction

This report describes our work in developing methods of economic analysis for common carrier transportation firms operating over a network of transportation markets. We feel that the network models described here are essential to a complete and valid understanding of the behavior of such firms. An explicit modeling of the fundamental relationships is particularly important when examining scenarios proposed for economic regulation of transportation.

The classical theory of the firm is not adequate. As we hope to show, transportation service always occurs with a mismatch of average demand to capacity. This ratio is called load factor and it introduces a new degree of freedom in the classical problem of matching supply, demand, costs, and prices in a market. Secondly, once a transportation company offers one service in one city pair, all other types of service in this or any adjacent city pair are offered at joint costs.

We shall briefly explain why it is necessary to perform economic analysis at the network level for common carrier transportation firms. Then, the network models will be described in an evolutionary manner. Finally, the last two chapters provide an overview of some preliminary results in applying these models to the study of various policy issues in the economic regulation of domestic intercity air passenger transportation.

II. Transportation Economics at the Network Level

There are three levels of analysis for transportation systems: an aggregate system level, an individual market level, and a network level. In our view, it is essential to a valid understanding of transportation economics that we work at the network level for common carrier systems.

At the system level, the transportation firm is studied in terms of aggregate measures of input and output over some time period. The analyst is forced to assume as output a homogeneous quantity called a ton-mile, or seat-mile. This hypothetical 'good' is produced in an ill defined abstract market. The consumption of input factors in the form of labor, fuel, and transportation facilities is expressed in terms of annual system expenditures, and then unit costs of output expressed in terms of dollars per ton-mile or cents per seat-mile.

At this level of aggregation, facts essential to understanding the economics of a transportation firm are masked. It is fundamentally incorrect to assume that buyers are purchasing a good called a ton-mile or seat-mile in bulk lots in a market perhaps national in scope. A market in transportation is defined by the origin and destination for trips. The buyers in each market purchase services which are not substitutable in other markets. Furthermore within one market, trips have a widely varying service quality in the form of trip time, frequency, reliability, comfort, safety, etc. These facts must be accounted for in studying the economics of transportation. Unfortunately they are often ignored.

A more reasonable level of analysis is the market level where output is taken to be the provision of transportation services between a pair of geographic regions with some recognition of the quality of these services. We can now define a demand function specifically for this market as a function of price and service quality. The quantity of demand is measured in terms of passengers or shipments or tonage by commodity over some time period.

The quantity of supply, however, is measured in different terms. It is measured in terms of vehicle departures, or seat departures, or available capacity in terms of space or weight over the same time period. On the average, only a fraction of the supply quantity is sold. The ratio of demand to supply may be called "Load Factor." "Load Factor" is a two edged sword. It is an index of the quality of service in that low (average) load factors mean most of the peaks of demand are accomodated. It is also an index of technical efficiency since high load factors provide consumption goods (market trips) more cheaply.

Load factor is not controlled by the firm independent of demand behavior. This adds a degree of freedom to the process of seller competition. Consider the usual case of a market with perfect competition. The price per unit of demand (per trip) will be equated to marginal cost per unit of supply (per capacity) divided by load factor -

i.e. $p = MC/_{LF}$

Since LF is indeterminate, there is no unique static market equilibrium for such a hypothetical transportation market. If price is higher, load factor will be lower, and vice versa. If a high cost operator can achieve a high load factor he may remain in the market. An offering of more service to the market is not automatically sold at a given load factor. The suppliers must compete in obtaining a good load factor as well as compete in price. Their behavior in competing for load factor may be undesirable and may further contribute to unstable market conditions. A determinate solution can exist in the cases of oligopoly or monopoly market structures, but we will not discuss these matters here. This level of analysis is still not adequate for a complete understanding when transportation firms are operating over a network of markets.

If transportation firms confined their supply to a single market, then it would be possible to determine the average and marginal costs per unit of supply. However, when they operate services along a route, they offer services jointly to a small set of markets, and it becomes impossible to determine the marginal cost of supply to an individual market. The firm now makes supply decissions about dispatching a vehicle along the route and will know the cost of each such dispatch. There is now an arbitrary decision about pricing the service in each market along the route. There may be other dimensions of arbitrary costing if more than one class of service is jointly offered or more than one segment of demand exists. The different transportation goods are split not only by geographical market but also by quality. But the important point is that we cannot determine the marginal costs for transportation service in an individual market of a network.

Where before we could postulate an optimal profit seeking behavior for the firm in a single market, now we must postulate profit seeking behavior over the network of markets. If we examine an individual market, the behavior of a firm may seem non-optimal. Firm behavior in a market depends upon geographically adjacent market operations.

If we now propose to examine the competitive behavior of transportation firms which operate in a given market but which have dissimilar networks, we cannot expect to understand their behavior in this particular market without simultaneously understanding their behavior in the adjacent markets. A high activity adjacent network gives a carrier the power to reroute vehicles with empty space through the given market at a very low marginal or incremental costs, and provides that carrier with unusual market power over a local carrier. This holds true even if the local carrier were to enjoy lower average costs. Thus, there is a discretionary routing power associated with an increased scale of network [activity which a large network] activity which a large network carrier may elect to use against any competitors in any given (local) market.

Economic efficiency demands that this empty space be filled at low marginal costs, but this may be regarded as unfair or predatory competitive practice since the large carrier has the power to use it in an aribitrary fashion in selected markets at any given time. This makes it difficult for new carriers to enter the industry unless they instantly provide a large quantity supply over a strong network of markets. The only advantage the new carrier may have is lower labor costs, since the larger carrier may have used the efficiencies arising from large network routing powers to reward operating and management personnel with higher wages.

To determine whether a carrier is practicing predation, we need to determine his marginal costs of supplying the market. This can only be determined if we know the demands in the remaining markets of his network and his various routing options and their costs. Notice that as demand levels change over time, so will these marginal costs so that his competitive position and behavior in the market may be time varying. There is little chance for a competitive equilibrium in markets when the carrier networks only partially overlap and where their marginal costs depend upon time varying demand in related markets.

It should be clear for all these reasons that it is necessary to analyze the economics of a common carrier transporatation firm at the network level. We shall now develop a set of network models for the transportation firm which use standard tools in mathematical programming to describe the interactions of supply and demand over a network.

III. Modeling the Transportation Firm

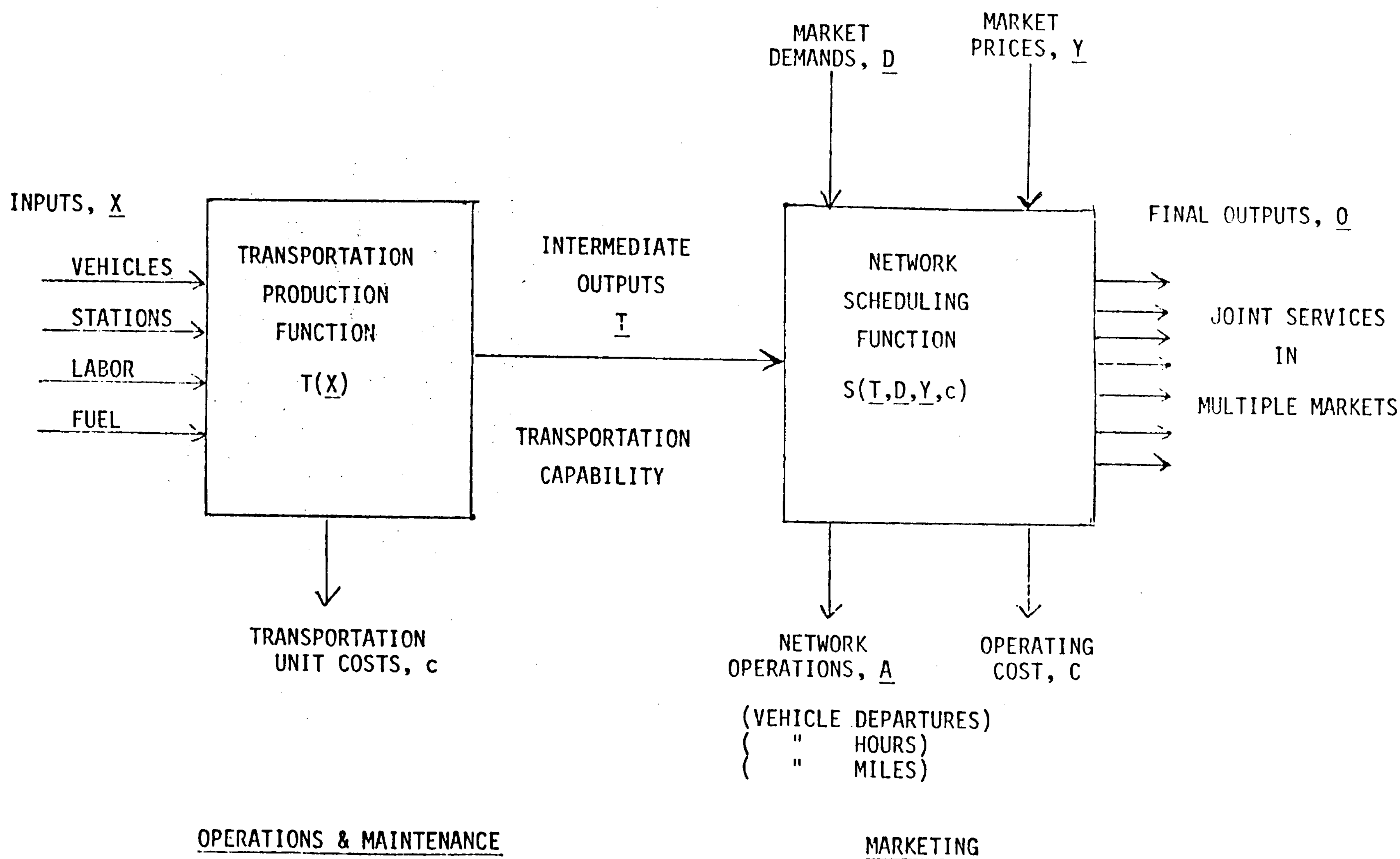
III.1 The Two Stage Supply Process for Transportation

A schematic diagram for the supply processes in transportation is given by Figure III-1. It is a two stage process. First, inputs of vehicles, stations, labor, and fuel are used in a transportation production function to create a transportation capability as an intermediate output. This output is measured in vehicle available hours or miles, or available capacity ton-mile capability.

Secondly, this transportation capability is input to another supply process called a transportation scheduling function. This function also accepts inputs from the demand side of markets, and attempts to provide the most efficient use of the given transportation capability; its output is the provision of joint transportation services in the multiple markets of its network. This is the final output - a set of services consumed by shippers and passengers in each market. Its quantity is measured as service frequency and volume (in terms of available seats, tons, or space) in each market. To produce these outputs, the scheduling function will prescribe a set of activities or operations for vehicles and stations over the whole system. These activities are not outputs.

In our work we shall study the costs of producing transportation capability in an empirical fashion looking at the available cost data from industry sources. For airline studies, we can isolate the costs of operating particular aircraft in terms of hourly costs for labor, fuel, and ownership, and the costs of operating stations in terms of costs per passenger boarded or ton loaded and costs per vehicle departure. These empirical cost studies give us evidence about the transportation production function across airlines

Figure III-1 THE TRANSPORTATION PRODUCTION PROCESS ON A NETWORK



of varying size and through the years.

We shall study the transportation scheduling function in a quite different manner. Here we construct a detailed model of the decision making process for the firm in finding an optimal equilibrium between supply and demand over the markets of an operating network subject to a variety of constraints on operations, operating authority, available transportation capability, market conditions, etc. The basic decision of the firm is made in terms of vehicle-frequency-routing; i.e. select the frequency of departures for each type of vehicle along a routing. We assume a knowledge of demand as a function of price and quality of service (in terms of non-stop, through, or connecting service, frequency of service, on-time performance, space availability, etc.) for each market. We shall assume various competitive scenarios in these markets, and that the firm will be profit seeking over the complete system of markets.

III.2 Modeling the Cost of Network Operations

The operating costs for transportation vehicles may be related to operating hours, miles, or capacity miles. The input factors are operating and maintenance labor, operating fuel, and capital in the form of vehicle ownership. Generally, there are costs associated with the arrival and departure of a trip, and then costs proportional to trip distance or trip time. Thus, we can usually calculate the vehicle operating costs for a trip, or trip segment. (In our scheduling model these are called a route or route segment.)

These trip costs increase with vehicle size, but at a rate less than the size increase. Thus, there are decreasing trip costs per unit of capacity as vehicle capacity is increased. This is true of all forms of transportation, so that we say there is an economy of scale where scale refers to vehicle size. A larger vehicle consumes relatively less labor and fuel inputs. Its acquisition price is determined by the market for vehicles where aircraft efficient in labor and fuel may be priced higher relative to those less efficient.

The operating costs for station operations may be related to passengers boarded or tons loaded. Here, we often see economies of scale at a station as it increases its scale of operations and makes more efficient use of necessary facilities; but then as the scale of operations continues to increase, the effects of complexity and congestion may cause unit loading costs to increase. Notice that these costs are incurred at the station level and must be jointly shared among the several markets using that station.

There are also system overhead costs which are not directly variable with vehicle or station operations, but which in the longer run are proportional to system operating costs. We shall treat these costs as fixed costs and the operating costs as variable costs. Our scheduling models maximize the surplus of revenues over variable costs, and thus may be said to maximize contribution to overhead. System fixed costs must be subtracted to get an operating income.

This structure of costs applies to all forms of transportation and is widely used by management and planning personnel for each firm. Such data is available in the public domain only for air transportation where an extensive data base exists from airline reports to the CAB under a uniform system of accounts. No equivalent system exists for trucking, rail, or barge operations at the ICC, and the cooperation of firm managements would be required in obtaining equivalent data. It is, however, this information upon which they make decisions and would be required to understand their behavior. Our initial case studies are restricted to air transportation due to the availability of vehicle trip and station loading cost data.

III.3 Transportation Network Models - Fixed Demand

Now we shall describe an initial model for the transportation scheduling function for a firm operating on a network. We will present a gradual development of models of increasing complexity from this primitive beginning, defining our notation as the models are presented.

The problem posed here is to find the set of vehicle/route/frequency decisions which carry a fixed demand in all markets of the network and which minimizes the operating cost. There are four sets of input data:

1) Market Data - D_m is the average demand quantity in market m for some period such as an average day of a month or season. A market m is defined by a pair of stations serving their respective regions or cities.

2) Routing Data - R is a large set of routes, r, which can be followed by vehicles in moving over the network. R_m is the subset of routes which serves market m, and we assume there will always be more than one route for every market. The routes may be non-stop or multi-stop trips for the vehicles. (Later we will consider routes for passengers or shipments which use portions of vehicle routes to form a "connecting" service.)

3) Vehicle Data - U_v is the available transportation capability for vehicle type v over the time period (such as an average day). We know the operating costs for each vehicle type along each route r, C_{vr}. This includes arrival and departure costs (such as port fees and vehicle servicing and

refuelling charges) for each step along the route.

4) Station Data - we may wish to bound the number of vehicle departures at a station. We denote FL_{vk} as the lower limit on departures per day by vehicle type v at station k, and FL_k as the lower limit for all types. These limits would ensure a reasonable level of service at the city, or ensure a reasonable utilization of the station. We denote FU_{vk} an an upper limit on departures/day by type v, and FU_k as an upper limit on all types/day at station k. These limits ensure operations within station capacities.

We also know the operating costs for loading and unloading a unit of demand in the market, C_m. We can limit the volume of demand at a station to be less than a value denoted by DU_k, or represent a set of loading costs which increase as the volume of demand at a station increases.

We can now state this initial model in terms of the following mathematical program:

a) Minimize Operating Cost:

$$\text{Minimize COST} = \sum_v \sum_r C_{vr} \cdot F_{vr} + \sum_m C_m \cdot D_m$$

where F_{vr} is the decision variable - the frequency of service by vehicle v on route r. Since there may be a large number of routes, many of these F_{vr} values will be zero. More than one vehicle type may be sent along a route. On the other hand, some vehicles may not be capable of using certain routes. Since all demand will be served in this first model, the second term in the COST function is constant.

We must minimize cost while insisting that certain relationships exist. These supply four major sets of constraint equations for the mathematical program:

b) Market Demand must be served:

$$\sum_{r \in R_m} D_{mr} = D_m$$ for all market, m where D_{mr} is a variable

describing the portion of market demand service via route r which belongs to R_m.

c) Vehicle Capacity must not be exceeded:

$$\sum_{m \in M_{\ell r}} D_{mr} \leq \sum_{v} F_{vr} \cdot S_v$$ for all links, ℓ where $M_{\ell r}$ is the

set of markets which traverse link ℓ of route r; where S_v is the effective capacity of vehicle v expressed in seats or tons. These constraints ensure that sufficient capacity exists on the average to handle the demand flowing over each link of each route. The capacity values S_v must account for some <u>maximum</u> allowable <u>load factor</u> which relates the true physical capacity offered to the peaking over time of the market demands. Thus we do not set the load factor, just its upper bound. Even this limit is not necessary. Instead of a single value of effective capacity as modeled here, we could include a cost of operating at higher load factors to account for inconvenience or delay to shipments or passengers, or as lost revenue to the firm as demand decreases due to these factors.

d) Station Capacity must not be exceeded:

$$FL_k \leq \sum_{r \in R_k} \sum_{v} F_{vr} \leq FU_k$$ for all stations, k where R_k

is the set of routes which use station k. The double summation counts all vehicle departures at the station over the period which is being constrained here to lie between upper and lower bounds. Again, if there are increasing delay costs due to station congestion, they can be included in the model rather than an absolute upper capacity on station activity.

Similar relationships may be stated in terms of demand volume at the station. For example,

$$D_k = \sum_{m \in M_k} D_m \leq DU_k$$ for any station k where M_k is the set of markets using station k.

e) Vehicle Availability is not exceeded:

$$\sum_r F_{vr} \cdot U_{vr} \leq U_v$$ for all vehicle types, v where U_{vr} is the vehicle use associated with route r (e.g. the total flight hours for aircraft v to fly route r) and U_v is the daily fleet usage available for vehicle type v.

In summary, this initial model will find a set of decision variables, F_{vr}, which minimize the total operating cost to transport a fixed set of market demand, D_m, while not exceeding vehicle capacity, S_v, station capacity, FU_k, or vehicle availability, U_v. The vehicle type, the routing, and the frequency of service on the routing are all simultaneously selected to accomplish this. The resulting service in a market may consist of a variety of routings, by aircraft of different types, and varying frequencies of non-stop and multi-stop service. In general, the answer in a market may not be the simple application of the vehicle with least cost per unit of capacity for non-stop service in the market.

III.4 Transportation Network Models with Demand-Price Relationships

In the basic model of Section III.3, the objective was to minimize the costs of providing required transportation services. Since the demands D_m were fixed, there was no need to include revenue in the objective function. If we now fix the price P_m for a unit of transport service in market m, and allow as much demand to be carried as desired up to the limit of D_m, then the objective function becomes a profit maximization:

$$\text{Maximize PROFIT} = \sum_m Y_m \cdot D_m - (\sum_v \sum_r C_{vr} \cdot F_{vr} + \sum_m C_m \cdot D_m)$$

where Y_m is the net yield per unit of demand in market m, and the market demand constraints 1) become an inequality;

$$\text{1a)} \quad \sum_{r \in R_m} D_{mr} \leq D_m \quad \text{for all m.}$$

But we may go much further than this. If we know the complete Demand-Price curve, we may include D_m and Y_m as variables to be optimally determined by the model. To do this, we need the Demand-Price relationship and the Revenue-Price relationship.

We can introduce the Demand-Price relationship in the form of a piece-wise linear curve as shown in Figure III-2.* As long as the curve has the convex shape shown, we can state the market demand as follows:

$$D_m = D_m^\circ + \sum_i d_m^i \cdot y_m^i$$

*Our apolgies to economists who are accustomed to seeing this curve with the axes reversed. Our sensibilities require that the independent variable, P_m be placed on the horizontal axis.

Figure III-2 Demand - Price Relationship

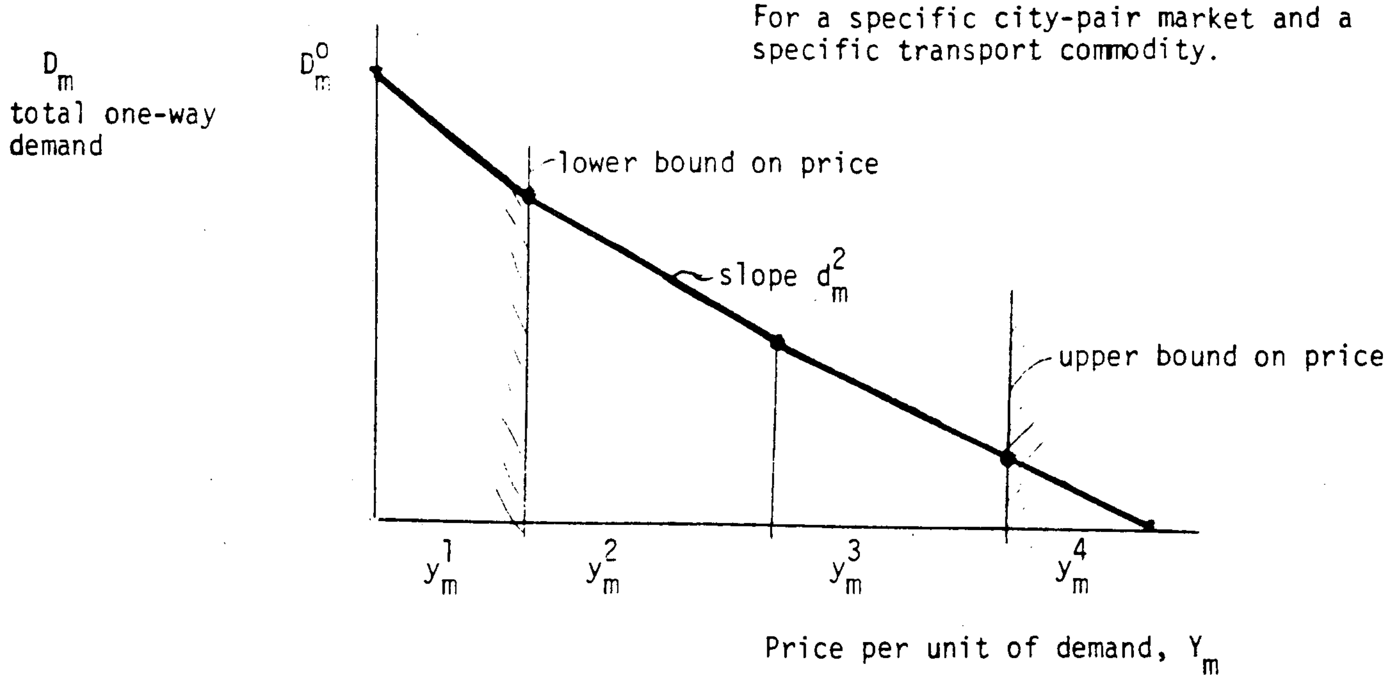
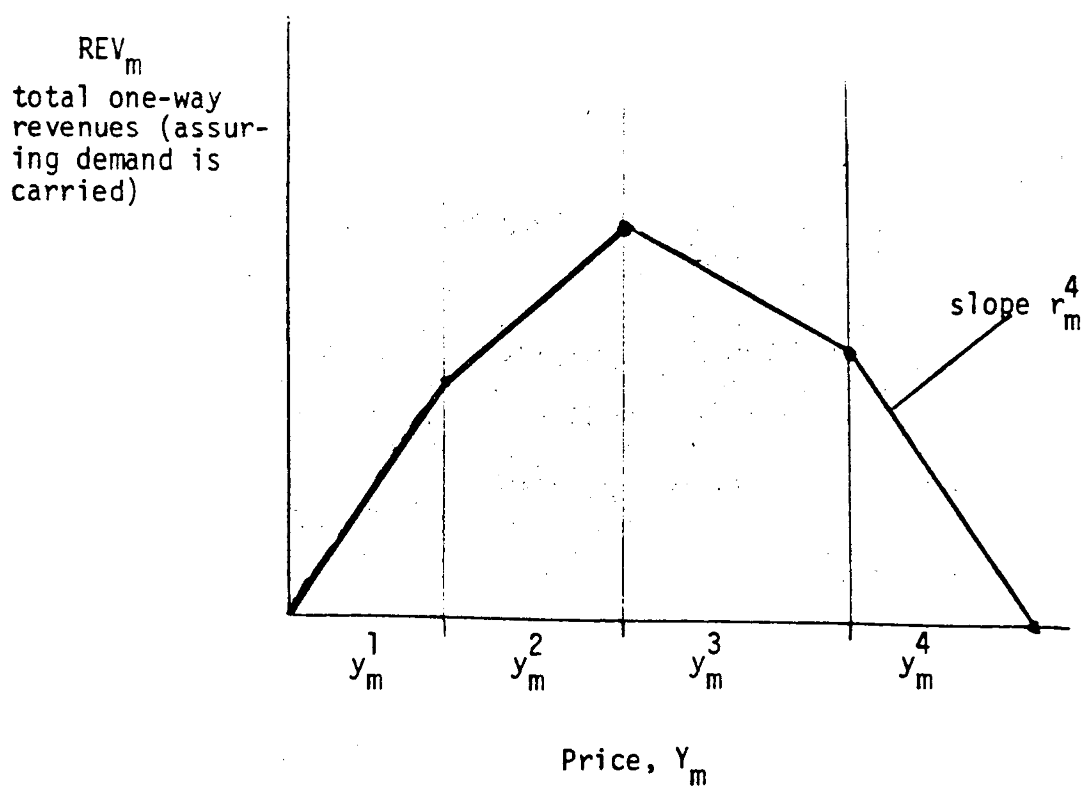


Figure III-3 Revenue - Price Relationship



where y_m^i are bounded components of the unit price Y_m,

$$\text{i.e.} \quad Y_m = \sum_i y_m^i$$

and d_m^i is the slope of the segment of the demand curve. Notice that there is a finite demand at zero price and finite price for zero demand.

There is a corresponding Revenue-Price relationship, as shown in Figure III-3. Again the curve is convex, and using the same price components we can state the market revenue as follows:

$$REV_m = \sum_i r_m^i \cdot y_m^i$$

where r_m^i is the slope of the segment of the revenue curve.

The slope of r_m^i are positive at first, causing revenue to increase rapidly to a maximum. This corresponds to an inelastic portion of the demand curve. Then the slope becomes negative, causing revenue to decrease corresponding to an elastic portion of the demand curve. We assume that this is a general representation of revenue and demand for the firm operating in an oligopolistic market. We now need to produce much better information on market demand than has been available in the past. Knowledge of current traffic and prices, and an estimate of the point elasticities is not sufficient. We want the complete demand curve facing the firm.

If these market demand curves are known, the model is now free to choose vehicles, routings, and prices such as to maximize its profit (or perhaps more correctly, its operating income), subject to any operating constraints. By lowering prices, the firm can fill any empty capacity on a route. By raising prices, it can reduce demand to ensure that it has sufficient capacity to carry the demand. If we add upper and lower bounds on price variables to the model, we are effectively bounding the levels of demand which can or must be carried in the market. (See Figure III-2.)

In freight transportation, it is possible that we have a variety of goods each of which has its own demand-price relationship. The total demand and revenue would be the sum and the model would choose an optimal set of prices for each commodity in the transportation market. Notice that these prices would vary by market, and would depend upon the network geometry and the routes used by vehicles within the network.

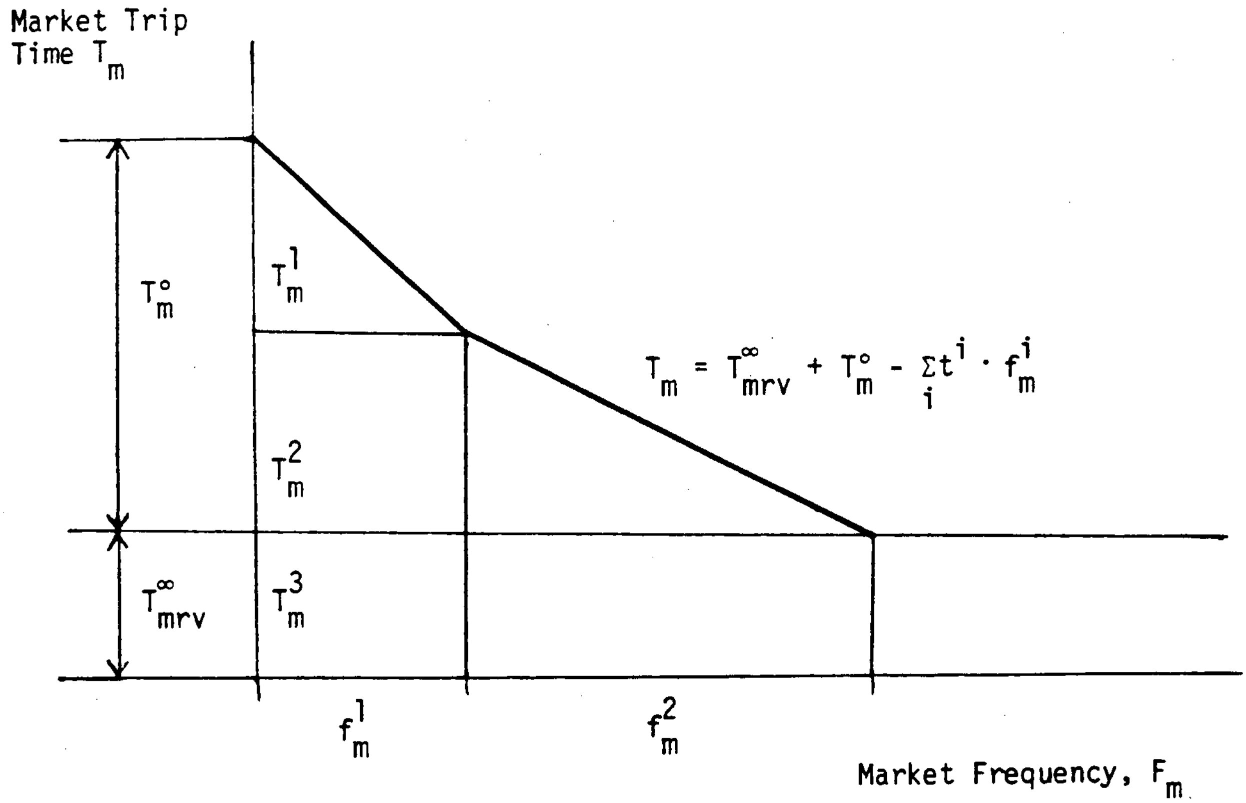
The Demand-Price relationships described in this section assume that the quality of transportation service is being held constant. Quality of service is a multidimensional vector with components of trip time, trip reliability, trip comfort and trip convenience (actually, subcomponents exist in each of these categories). In the next section, we shall introduce Demand-Trip Time relationships or, more specifically, Demand-Frequency of Service relationships for each market while holding prices fixed.

III.5 Transportation Network Models with Demand-Trip Time Relationships

In this section, market demand will be expressed as a function of quality of service supplied in the dimensions of total trip time and frequency of service. We shall temporarily hold prices fixed, but revenues will depend upon the demand actually generated by the quality of services supplied. The models are profit maximizing and seek an equilibrium between demand, quantity of supply, and quality of supply in all the markets of the network under various operating or regulatory policies or constraints.

The relationship between trip time, T_m and market frequency of service, F_m is shown in Figure III-4. As before, we model the functions as piecewise

Figure III-4 Market Trip Time as a Function of Market Frequency



linear curves. Trip time is expressed as the sum of two components, T^{∞}_{mvr} and T^{f}_{m}.

$$T_m = T^{\infty}_{mvr} + T^{f}_{m}$$

where T^{∞}_{mvr} = the vehicle travel time as a function of vehicle type and routing used (at infinite frequency of service).

T^{f}_{m} = a value for "schedule delay," or wait time for service between trips. As frequency of service increases, the schedule delay is reduced in a piecewise linear fashion.

$$T^{f}_{m} = T^{\circ}_{m} - \sum_{i} t^{i} \cdot f^{i}_{m}$$

where T°_{m} = a maximum value for schedule delay

t^{i} = slope of schedule delay reduction with frequency over segment i

f^{i}_{m} = are bounded components of the frequency of service in market m.

The frequency of service in market m, F_m, is a weighted sum of the frequencies of services by vehicle types and routes;

$$F_m = \sum_{r \varepsilon R_m} \omega_{mr} \cdot \sum_{v} F_{vr} = \sum_{r \varepsilon R_m} \omega_{mr} \cdot F_r$$

where F_r = frequency of service on route r by all aircraft types

ω_{mr} = weighting values (unity for non-stop service, and fractional values for multi-stop services inversely proportional to the longer travel times)

For the piecewise segmentation of frequency, the following must hold:

$$F_m = \sum_{i} f^{i}_{m}$$

Notice that the cost of any value of F_m is not unique. It depends upon the set of F_{vr} variables used to achieve F_m.

The functional relationship between market demand D_m and trip time T_m is shown in Figure III-5. A corresponding piecewise segmentation of this curve is constructed so that

$$T_m = \sum_j T_j$$

Now, as frequency of service is increased through segments f_m^1, f_m^2, etc. the total trip time is reduced from a maximum value along segments T_m^1, T_m^2, etc. Notice that the time segments are indexed by j along the direction of decreasing trip time. The market demand, D_m can now be expressed in terms of T_m.

$$D_m = D_m^\infty - a_m \cdot T_m$$

where D_m^∞ = demand level at infinite frequency of service

a_m = slope of the demand curve with trip time for market m.

It may be advantageous to express the relationship between demand and frequency directly as shown in Figure III-6. This "Traffic-Frequency" curve is often used in airline/passenger transportation models. Notice that demand rises quickly as frequency is initially increased, but eventually saturates so that further frequency increases do not stimulate demand. The curve in Figure III-6 is entirely equivalent to the curves of Figures III-4 and III-5. There are advantages in using the more complex set of relationships which allow us to incorporate faster or slower vehicle travel times and to handle the "connecting demand" as described in the next section.

Figure III-5 Market Demand as a Function of Market Trip Time

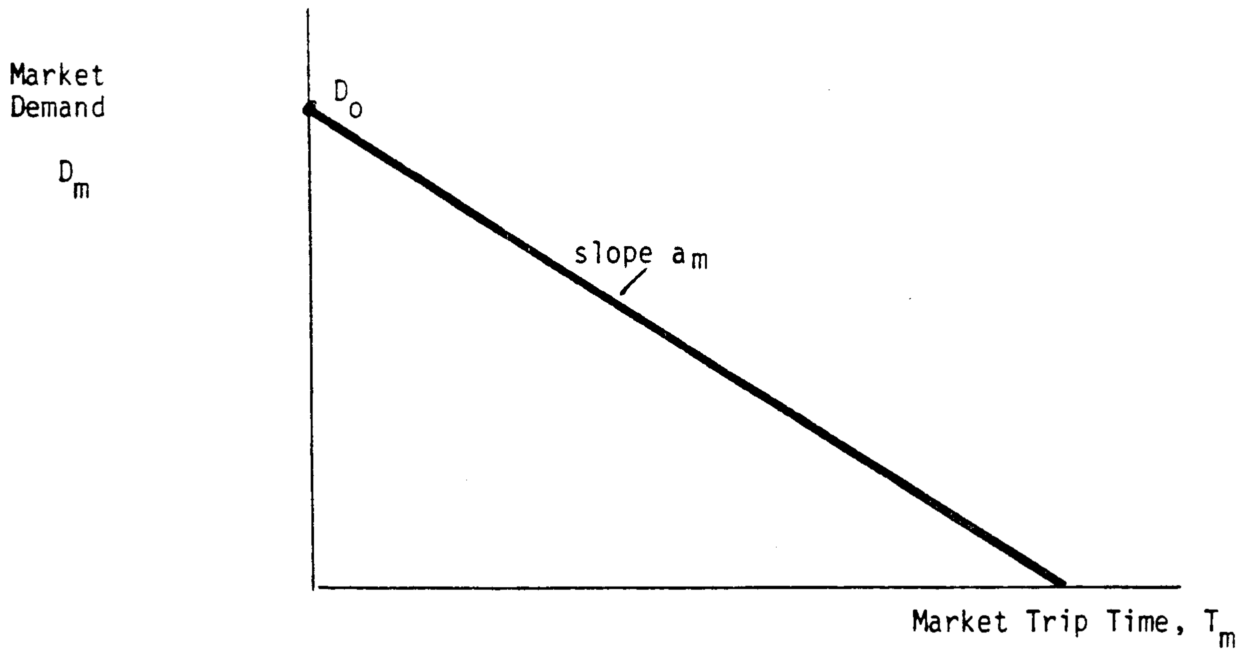
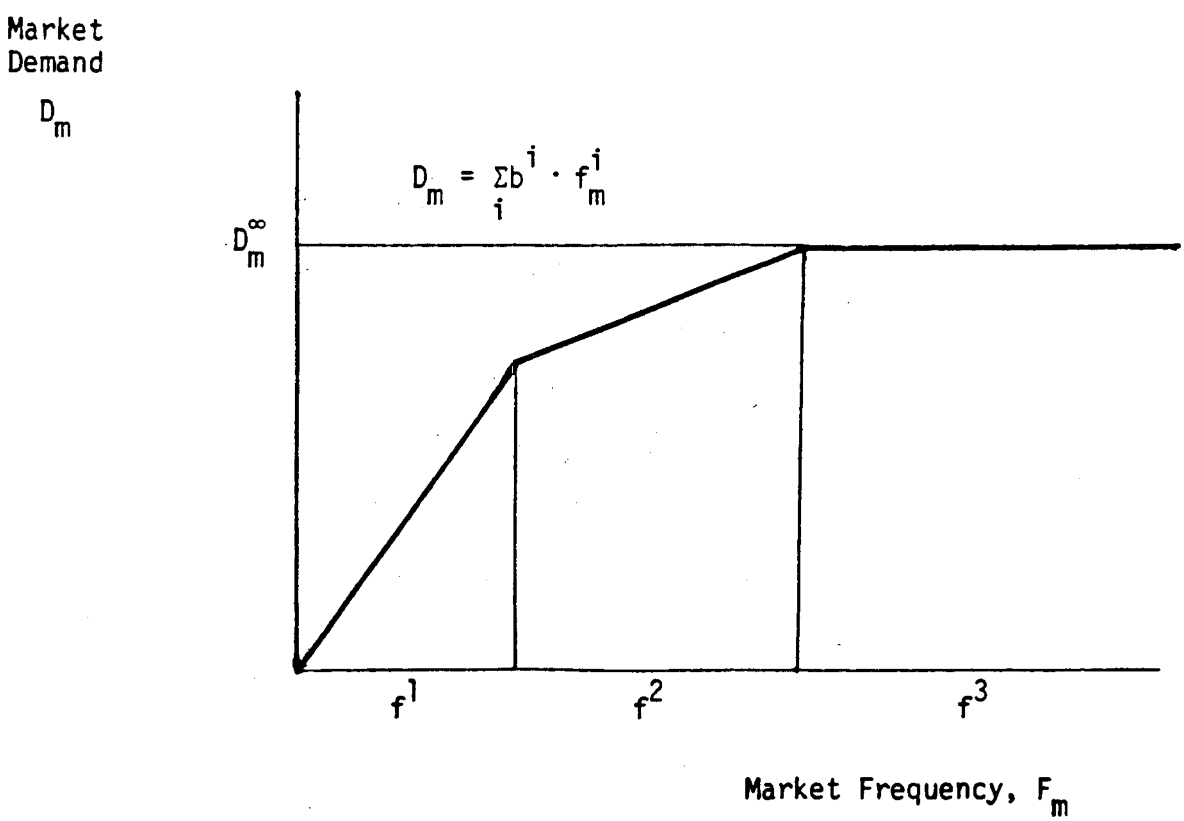


Figure III-6 Market Demand-Frequency Relationship



If these market demand functions of trip time and frequency are known, the model will select vehicle types, routings, and frequencies such as to maximize its profit, subject to the operating constraints. By using a smaller size vehicle, with higher unit costs, the firm can increase its frequency of service in the market, thereby increasing its share of market demand, revenue, and profitability. By using multi-stop routings, it can increase its load size on any segment at any given frequency, thereby allowing the use of larger vehicles with lower unit costs. These trip time and frequency effects are particularly important in the transportation of business passengers. Once again, it is clear that the answer in terms of vehicle type, size, frequency and routing in a given market depends strongly upon market demand and supply in adjacent markets of the network.

III.6 Transportation Network Models with Connecting Traffic Paths

To this point, only single vehicle, "through" service has been offered to any market. In this section, we expand the model to allow an optimal selection of either "through" or "connecting" services. This is vitally important in modeling both freight and passenger transportation systems, particularly in lower density markets where the "economies of load size" are stronger. Here, vehicles can be loaded with further demands which disembark at stations along the route in order to transfer onto another vehicle route.

We define a set, P_m, of connecting traffic paths, p, available to the market m. These paths are made up of portions of existing vehicle routes, r, and specify intermediate connecting points. Now the demand in a given market may follow a route r or a path p, so that we redefine local market demand as:

$$D_m = \sum_{r \varepsilon R_m} D_{mr} + \sum_{p \varepsilon P_m} D_{mp}$$

where D_{mp} is that portion of D_m which elects to follow the connecting path, p.

But now the "traffic" in this market consists of the above "local" demand, plus the "connecting" demand which is being routed through this market. If we define M_p to be the set of "connecting" markets for a path, p as defined by the connecting points, then the "connecting" traffic in market m

$$DC_m = \sum_{m \varepsilon M_p} \sum_{p} D_{np}$$

where D_{np} is the demand from market n which follows path, p. Thus, the total traffic is the sum of the local and connecting traffic and must be routed as above;

$$D_m + DC_m = \sum_{r \varepsilon R_m} D_{mr} + \sum_{p \varepsilon P_m} D_{mp}$$

As before, the demand assigned to a route, D_{mr}, is subject to capacity constraints to ensure that traffic loads on any link are less than the vehicle capacity supplied. On the other hand, this demand can be assigned to a path, D_{mp}, whence it will appear as connecting demands in other markets and their routes.

There will be costs associated with handling connecting traffic. Since we have specifically identified this connecting traffic by the variables, D_{mp}, it is simple to include connecting costs. As well, we can sum the D_{mp} values to obtain the total connecting traffic for each station;

$$DC_k = \sum_{m \varepsilon M_k} \sum_{m \varepsilon M_p} \sum_p D_{np}$$

This traffic can be added to the station capacity constraints, or become part of the constraints which compute station congestion costs as station traffic increases. We denote the costs of handling a connecting unit of demand at station k by C_k.

The local market demand P_m may still be expressed as a function of market price Y_m, assuming the price independent of the route or path used.

Alternatively the connecting demand D_{mp} may respond to the trip time in a manner analogous to the direct demand-time relationships given in section III.5. In this case the trip time is the sum of the trip times on the two segments making up the connecting path. The sum of direct and connecting demand must also be subjected to a limit, D_m, so that the market is not doubly stimulated by both services:

$$D_m \geq \sum_p D_{mp} + \sum_r D_{mr}$$

As with direct demands we find ourselves unable to include in our mathematics a model in which both price and travel time change simultaneously. We must again rely upon the disaggregated formulation.

III.7 Transportation Network Models - Summary

A complete statement of the network model is given in Figure III-7. While these mathematical relationships may seem complex, they are straight forward to implement and solve using current mathematical programming computer codes. The model becomes a computer tool where given the required input information on network routings, operating costs, market demands, capacities of vehicles and stations, we can quickly and easily obtain an optimal pattern of service for the firm. We are now in a position to study the profit maximizing behavior of a transportation firm operating over a network of markets under a variety of possible regulatory policies.

In the present studies, we will be exercising these models on the domestic airline industry, both at the level of the individual firm, and the level of a competitive industry. Today's interest in economic regulation of the domestic airline industry assures us of an interested audience. For airline studies, there is an adequate data base on market demand and market share functions, and on vehicle and station operating costs to provide model inputs for which we have some degree of confidence.

The next two chapters describe some initial applications of these models to current policy issues in the economic regulation of domestic airline transportation. They are preliminary in nature, and only an overview is given here. Further reports on these studies will be issued later.

Figure III-7 <u>The Complete Network Model</u>

1) Objective Function - maximize profit (operating income)

$$\text{Maximize PROFIT} = \sum_m REV_m - \left(\sum_v \sum_r C_{vr} \cdot F_{vr} + \sum_m C_m \cdot D_m + \sum_k C_k \cdot DC_k\right)$$

2) Demand Relationships

a) Market Demand may be served on a route path

$$D_m + \sum_{m \varepsilon M_p} \sum_p D_{np} = \sum_{r \varepsilon R_m} D_{mr} + \sum_{p \varepsilon P_m} D_{mp} \qquad \text{for markets, m}$$

b) Market Demand can be a function of market price

$$D_m = D_m^{\circ} + \sum_i d_m^i \cdot y_m^i \qquad \text{for all markets, m}$$

$$REV_m = \sum_i r_m^i \cdot y_m^i$$

c) Market Demand can be a function of trip time

$$D_m = D_m^{\infty} - a_m \cdot T_m$$

In this case revenues are calculated at fixed price

$$REV_m = \sum_m Y_m D_m$$

d) Trip time depends on total market frequency

$$T_m = T_m^{\circ} - \sum_i t_i^i f_m^i$$

where total frequency F_m is

$$F_m = \sum_i f_m^i = \sum_{r \varepsilon R_m} \omega_{mr} \sum_v F_{vr}$$

e) There are other related demand constraints not shown here.

Figure III-7 continued

3) Supply Relationships

a) Vehicle Capacity must not be exceeded

$$\sum_{v} S_v \cdot F_{vr} \geq \sum_{m \varepsilon M_{\ell r}} D_{mr} \qquad \text{for all links of any route } (\ell, r)$$

b) Station Capacity must not be exceeded

i) for vehicles

$$FL_k \leq \sum_{r \varepsilon R_k} \sum_{v} F_{vr} \leq FU_k \qquad \text{for any station k}$$

ii) for demand units

$$D_k + DC_k = \sum_{m \varepsilon M_k} (D_m + \sum_{m \varepsilon M_p} \sum_{p} D_{np}) \leq DU_k$$

c) Vehicle Availability must not be exceeded

$$\sum_{r} F_{vr} \cdot U_{vr} \leq U_v \qquad \text{for all markets, v}$$

IV. Airline Policy Analysis at the Industry Level- A Preview

IV.1 Introduction

In these studies we attempt to analyze network effects within the context of the domestic air transportation industry. We choose this arena for three reasons:

(1) Passenger air transportation consumes a large number of dollars for small amounts of traffic movement. Thus it is important.

(2) Contemporary econometric models of industry behavior have failed to demonstrate either joint costs or economies of scale although both are to be suspected.

(3) Data exists on historical costs, demand, and levels of service for air transportation.

The task we have set is this: given a network of major city pair markets, given the demand function in these markets, given the costs of the vehicles available for use, and given the routes over which they may be used, can we predict this industry's behavior in terms of scheduling services among the cities? Do we find indications of significant changes in that behavior under alternative forms of operation?

In this chapter we explore these questions using the largest markets for air travel in the U.S. as our test case.

IV.2 Airline Operating Costs

This section discusses the simplified costing methods used to provide inputs to the network model. We are fortunate in that operating costs and associated operating activity measures are reported by the airlines each year. From this we deduce the costs per vehicle hour, boarding, etc. Airline operating costs were divided into five categories each of which is treated separately below.

a) Aircraft Operating Costs

Aircraft operating costs comprise about 60 percent of airline expenses. The manufacturing industry designs and sells transport aircraft on the basis of operating cost/block hour formulae which reflect on intrinsic physical relationships of speed, structural, and propulsion efficiencies. These formulae[2] suggest that transport aircraft costs/block hour should be linear with capacity for aircraft of identical design range and speed, seating density, and technical advancement. Where an aircraft falls short of this performance frontier, its purchase price on the used aircraft market is reduced until the operating costs fall into line. Reported airline operating costs, shown in table IV-1, agree with this linear prediction. Figure IV-1 compares the aircraft types in service in 1973, making corrections for seating density and cruise speed, but not for different design ranges. The resulting straight line has been used to represent aircraft operating costs in these industry studies.

Thus a review of aircraft operating costs suggests that within the range of capacities indicated in Figure IV-1, the costs are linearly dependent on vehicle capacity. To a first order, aircraft costs are not dependent on firm or fleet size.[3]

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[2] See Simpson (1972)

[3] See, in addition, Douglas and Miller (1974) and Air Transport Association (1967).

Table IV.1 Aircraft Operating Costs

Aircraft Type	DOC[1]	Seats[2]	Speed[3]	Capital Cost[4]	$/Mi[5]
4 engine Wide Body	$1288	389	534	$900	$4.10
4 engine Narrow Body	705	146	520	195	1.73
3 engine Wide Body	903	275	518	600	2.90
3 engine Narrow Body	550	110	505	180	1.45
2 engine Narrow Body	431	84	465	105	1.15
4 engine Turbojet	724	122	504	30	1.50
	$/block hour		mph	$/block hr	

(1) Reported domestic industry average direct operating costs less depreciation and rentals. 1973 data. See CAB, Aircraft Operating Cost and Performance Report, Vol. IX (1975).

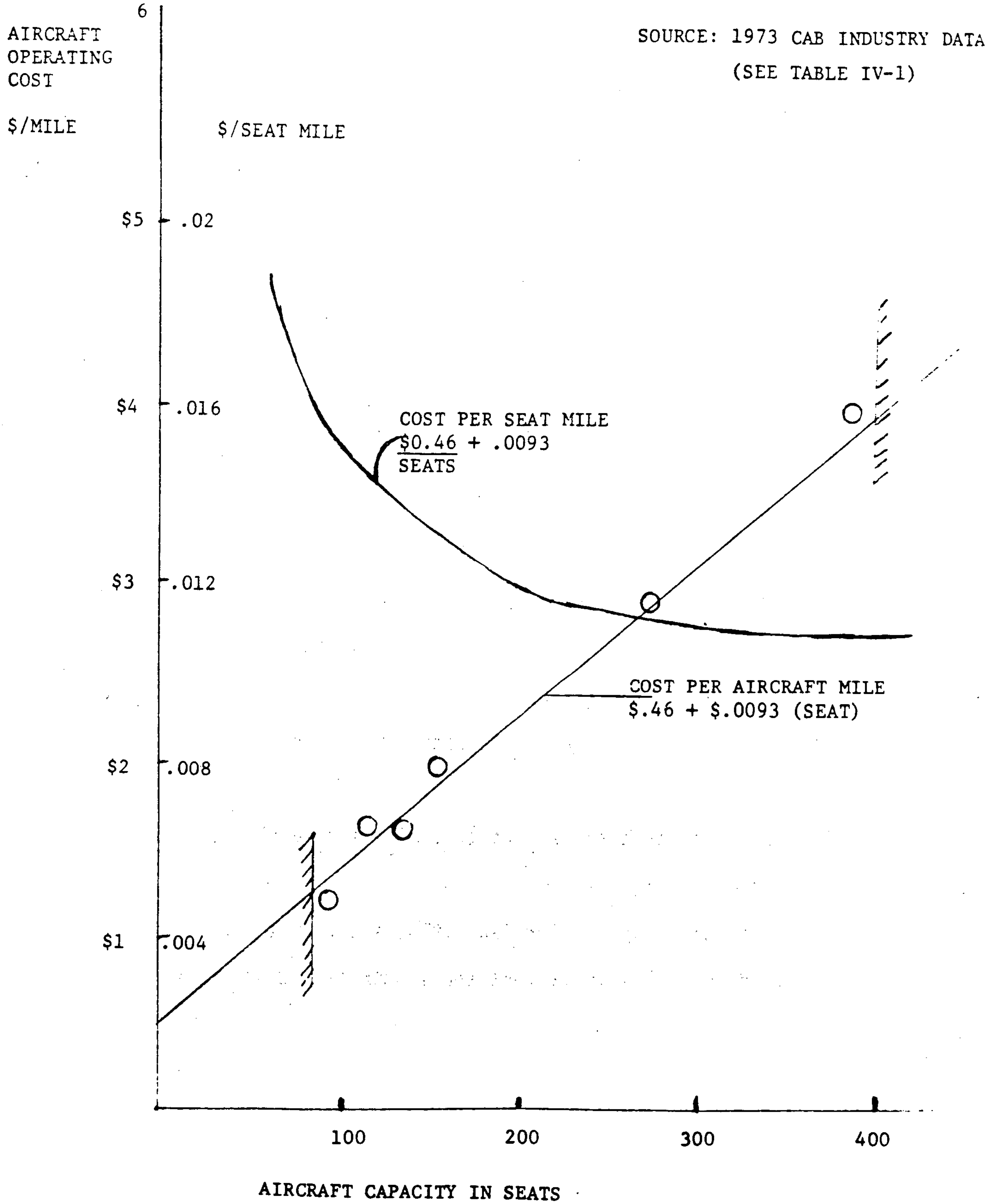
(2) Based on average payload in domestic operations, with 7.5 seats per ton.

(3) Cruise speed based on regression analysis of airline time tables. See Sercer (1973).

(4) Based on market prices for Jan. 1973, see Swan (1976). Depreciation is based on a 15 year 4% mortgage in constant dollars and 3000 block hours per year.

(5) Cost in cruise. According to block time regression, Sercer (1975), a departure consumes roughly the same time as 100 miles of cruise.

FIGURE IV-1: AIRCRAFT OPERATING COSTS



For the purpose of these studies we will allow the airline to use aircraft with capacities from 80 to 400 seats and costs falling along the line in Figure IV-1.

b) Passenger Service Costs

Flight Attendants are required on aircraft for safety reason: The number required is proportional to the passenger load. Attendants are paid by the duty hour so that their total costs should be directly proportional to passenger hours. Unfortunately, only revenue passenger miles are reported . We can compute the average cost of passenger service as $.0073 per revenue passenger mile in 1973.[4] This agrees with the results of prior regression analyses for passenger service costs when the figures are restated in 1973 dollars.[5] However, a correction can be made for duty time on the ground, reducing the cost per passenger mile and adding a cost per boarding. The new estimate of passenger service costs is $.005 per revenue passenger mile + $2.00 per passenger boarding. This agrees with figures obtained by regression by Swan (1976). This formula produces the correct total at average trip lengths, and is reasonable at both transcontinental and short haul trip lengths.

c) Traffic Servicing Costs

The costs of aircraft ground handling and of passenger boarding and baggage handling are reported under this account. Previous regression analyses have failed to indicate the logical dependence of this costs of number of aircraft departures and passenger boardings.[6] Longer trips correlate with heavier baggage loads, longer gate occupancy times, and greater fueling and cleaning efforts for the aircraft departure. Therefore, some correlation of this cost with

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[5] See Simpson and Taneja (1967).

[6] See, for example, Simpson and Taneja (1967) and Douglas Aircraft Company (1975).

revenue passenger miles is not unreasonable. But a lack of any dependence of boardings and departures is suspect. A regression analysis of domestic trunk airlines' annual expenditures in this category for the years 1970-1974 was made using 1973 dollars.[7] Annual passenger boardings, aircraft departures, and revenue passenger miles (RPM) were the independent variables. Because of collinearity among the variables, the inclusion of boardings and departures increased the standard error of the prediction of total expenses. Nonetheless, the coefficients produced were of the right sign and of reasonable magnitudes. The resulting cost prediction was \$3.20/boarding + \$59/departure + \$0.008/RPM.

d) Promotion and Sales Costs

A travel agent fee of 7 percent of the ticket price represents much of the cost reported in this category. Advertising, reservation costs, and the cost of credit cards and bad cheques are also largely proportional to sales. The industry average for this cost is 12 percent of revenues. Previous regresions approximate this simple rule for the ticket prices current at that time.[8]

e) General and Administrative

Overhead costs average 5.5 percent of all costs other than deprecation for this industry. Regression analysis of industry data[9] detects no economies of firm size and supports this figure.

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[7] See Swan (1976)

[8] See Simpson and Taneja (1967) and Douglas Aircraft Company (1975).

[9] Douglas Aircraft Company(1975).

f) Summary

The association of airline expenditure with intermediate outputs such as block hours, departures, passenger miles, and boardings is possible and over current ranges of airline scale these costs appear reasonably constant.

It is important to remember we have not determined the cost function for transportation services. We have merely established the costs of the intermediate transportation capabilities which are inputs to the transportation scheduling process.

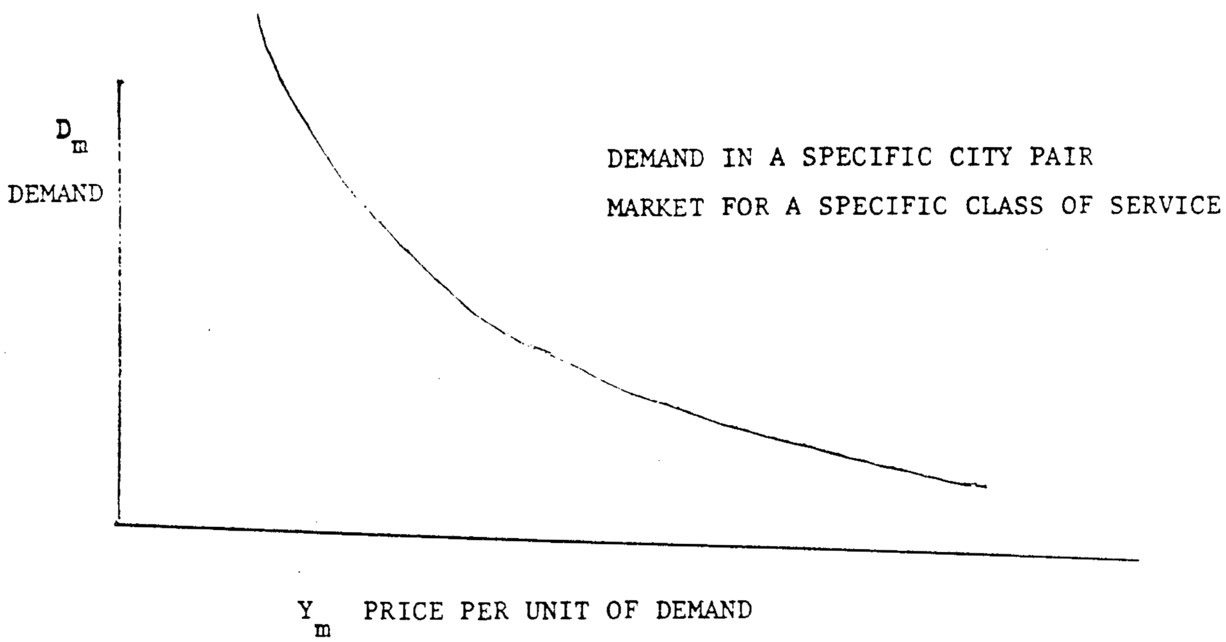
IV.3 Demand in Airline Markets

This section discusses the second major input to network modelling, the demand functions. The modelling of demand involves over half of the formal mathematics of the model because the variation of demand with the convenience and price of the service offered by the firm is the essential behavior to be captured.

Demand in a city pair market responds to price and to travel time. Demand also responds to load factor, level of comfort, and the price and travel time in other markets. But for the moment we simply assume that each city pair demand depends on its own price and travel time.

The total travel demand is divided into business demand and pleasure demand. The business demand travels at fixed fare, but its volume varies with the level of service in terms of travel time or frequency in each market. Pleasure demand varies with the fare level and does not respond to frequency of service. We assume the airline can distinguish pleasure demand from business demand and charge the pleasure demand a different fare. The fare for pleasure demand is determined on a market by market basis as part of the network decisions made by the firm

FIGURE IV-2: DEMAND-PRICE RELATIONSHIP



a) Demand-Price Relationship (The "Pleasure" Market)

Figure IV-2 illustrates a downward sloping curve which, at least over its central region, is supposed to describe the pleasure demand-price relationship of a single city pair market. The managements of transportation firms face one such curve for each market they serve. For the purposes of our development it does ot matter whether the curve represents competition with another airline, with other travel modes, or with the consumer's dollar for other goods. Usually a combination of these factors determines the market price elasticity.

Such a curve is constructed for each market from a knowledge of current price and demand combined with an estimate of the demand elasticity of the market. In the absence of knowledge about the curvature, a straight line demand curve is taken as a good approximation of the complete curve. The shape is derived from the estimate of price elasticity:

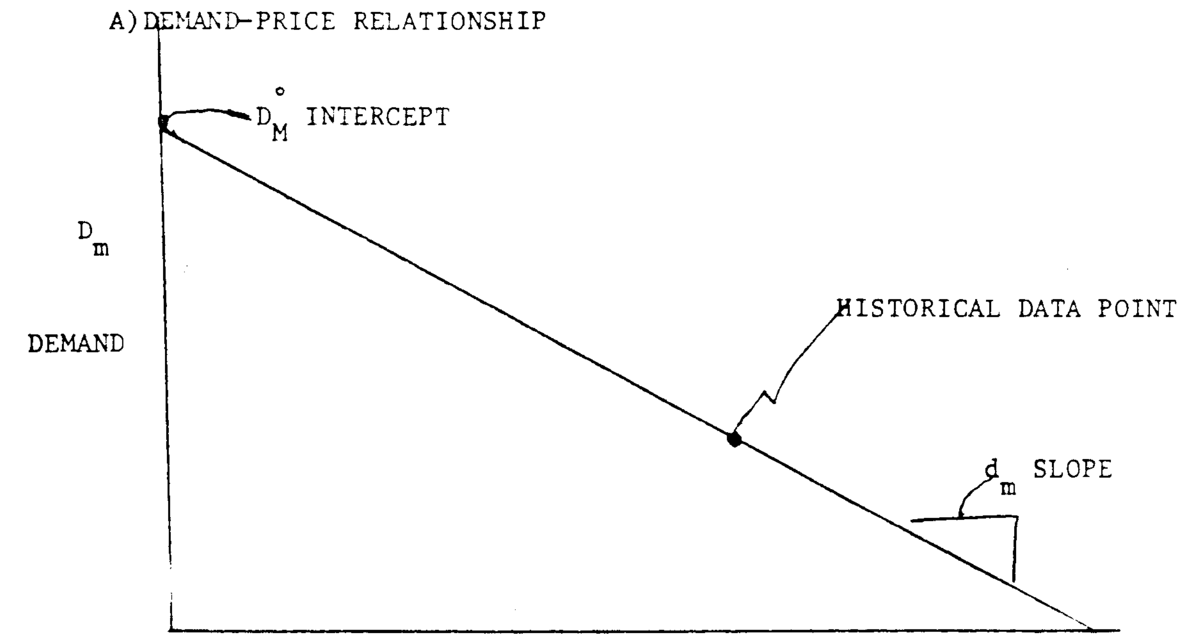
$$D_m = D^\circ_m + d_m \cdot Y_m$$

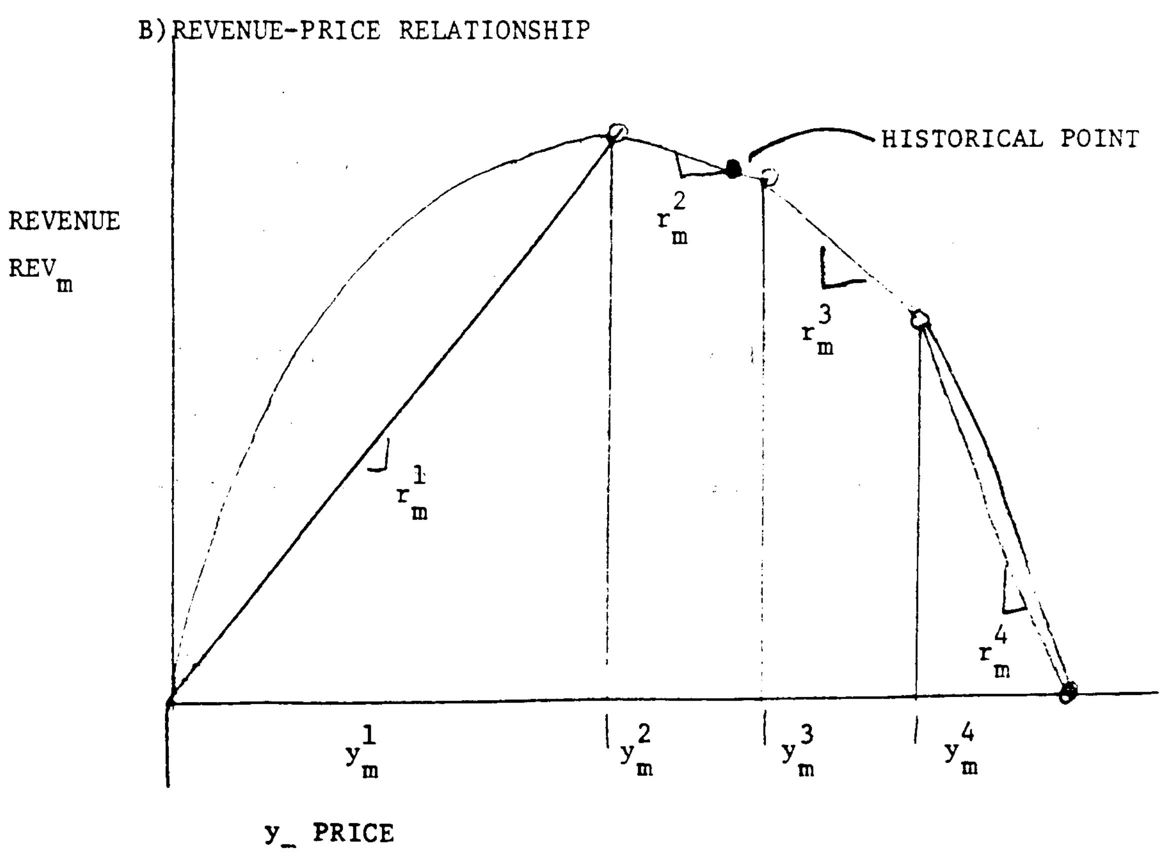
Figure IV-3(A) illustrates that D°_m is the demand at zero fare and d_m the negative slope of the demand-price curve. Y_m is the price for market m. For this demand curve the revenue curve is a parabola. Figure IV-3(B) approximates this shape by a series of line segments.

In Figure IV-3(B) we have broken the price Y_m into a series of bounded sub-segments y^1_m, y^2_m , y^3_m , and y^4_m . Each segment has a slope measured in revenue dollars change per price dollar change. This gives us a revenue equation for each market which is

$$REV_m = r^1_m \quad y^1_m + r^2_m \quad y^2_m + r^3_m \quad y^3_m + r^4_m \quad y^4_m$$

FIGURE IV-3: DEMAND AND PRICE-REVENUE RELATIONSHIPS





If it had the ability to discriminate with respect to price between business and pleasure travellers, an airline would face two such demand-price curves in each market. We are going to model this situation. The curve illustrated in Figure IV-3 might well be appropriate for the pleasure passenger. The price elasticity at the historical fare is near -2.0. From the historical point, the airline would lower its prices to increase its revenues from this market. For the other half of the market, the business traveller, a price elasticity of -0.5 would be more appropriate. This produces the demand-price curve and the revenue price curve of Figure IV-4.

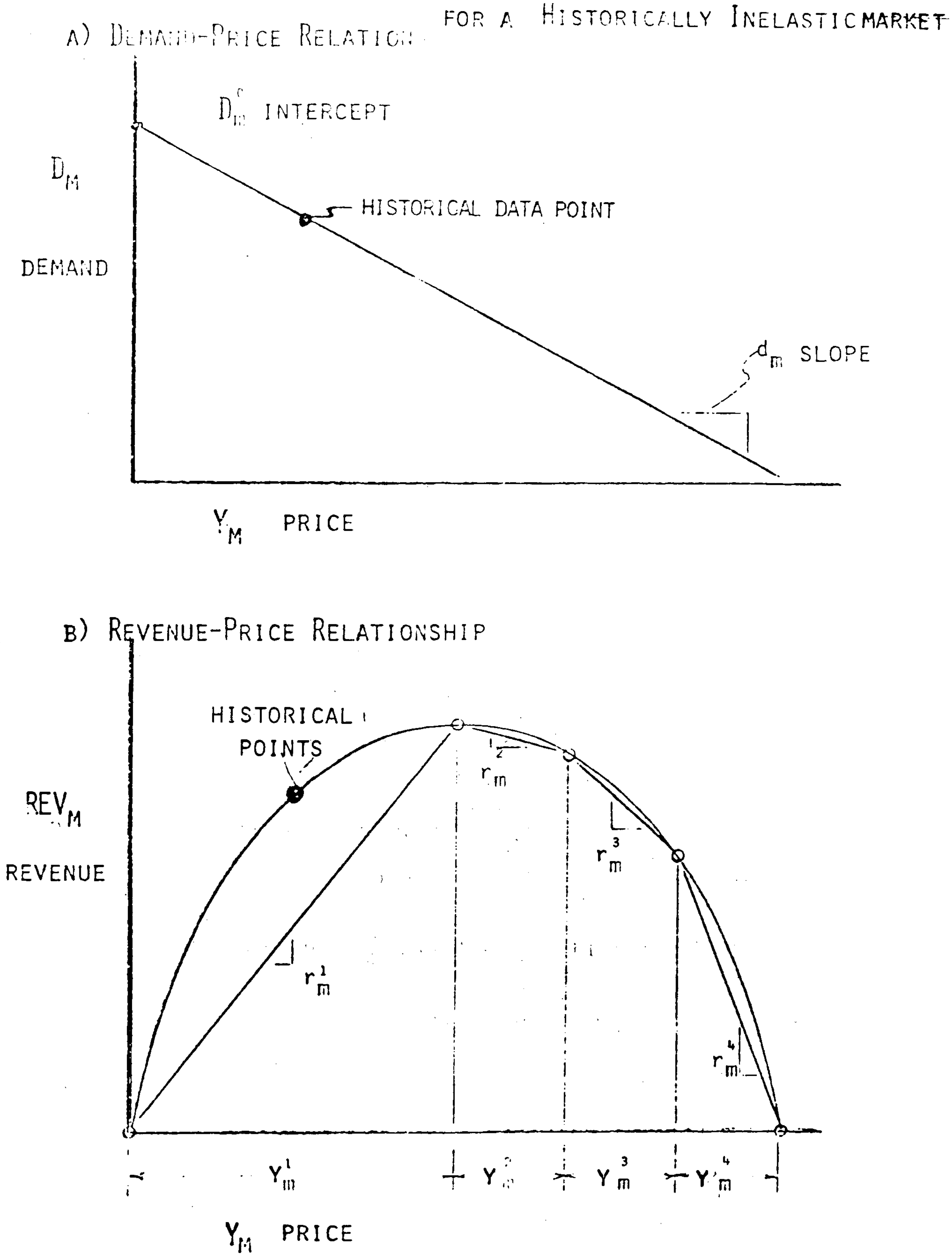
In Figure IV-4(B) the historical price is below the maximum revenue price. In our model a profit seeking airline would raise its price at least to this maximum revenue point. If in real life an ailrine has failed to raise prices to this point, it is possible to argue that regulation is constraining the airline's pricing behavior.

This is indeed what is done. Airline regulation does limit fare increases. In practice the Civil Aeronautics Board (CAB)sets maximum fares. With fixed fares applying to what we have called the business segment of the airline market, the airlines must consider the next most important influence on business, travel demand, - travel time.

b) Demand-Time Relationship (The Business Market)

In this section we model the situation facing an airline which is constrained to charge a fixed fare for its service. It can compete with other airlines and other goods for the consumer's dollar, but the competition can only be in the level of service. An important aspect of this level of service is the time, and the perceived total travel time is influenced by the schedule's delay.

FIGURE IV-4 PRICE-DEMAND AND PRICE-REVENUE RELATIONSHIPS FOR A HISTORICALLY INELASTIC MARKET



This delay rests primarily on the number of aircraft departures, that is the frequency of service. This is the dependence we wish to model.

In the absence of any other information we may assume demand at fixed fares fall off with increasing travel time as illustrated in Figure IV-5(A) Once again we have a linear relationship:

$$D_m = D_m^{\circ} + a_m T_m \quad \text{for each market } m.$$

The travel time T_m multiplied by the negative slope a_m dilutes the demand from its maximum value D_m°.

In this case we are fortunate that we may use a linear demand curve. A curve concave upward cannot be put into our linear program. This was not the case for the price-demand curve in the previous section, although there are limitations set by the convexity of the revenue curve.

Since all airline operate at nearly the same speed, most changes in total travel time come from changes in schedule delay. Schedule delay ,is the average amount of time wasted because flights do not leave when the demand is ready. A practical estimate of this number is $4/F_m$, where F_m is the nonstop daily frequency of service in the city pair market or its equivalent.[11]

Figure IV-5(B) illustrates this relationship between market frequency of service F_m and total travel time T_m:

$$T_m = T_m^{\circ} + t_m^1 f_m^1 + t_m^2 f_m^2 + t_m^3 f_m^3$$

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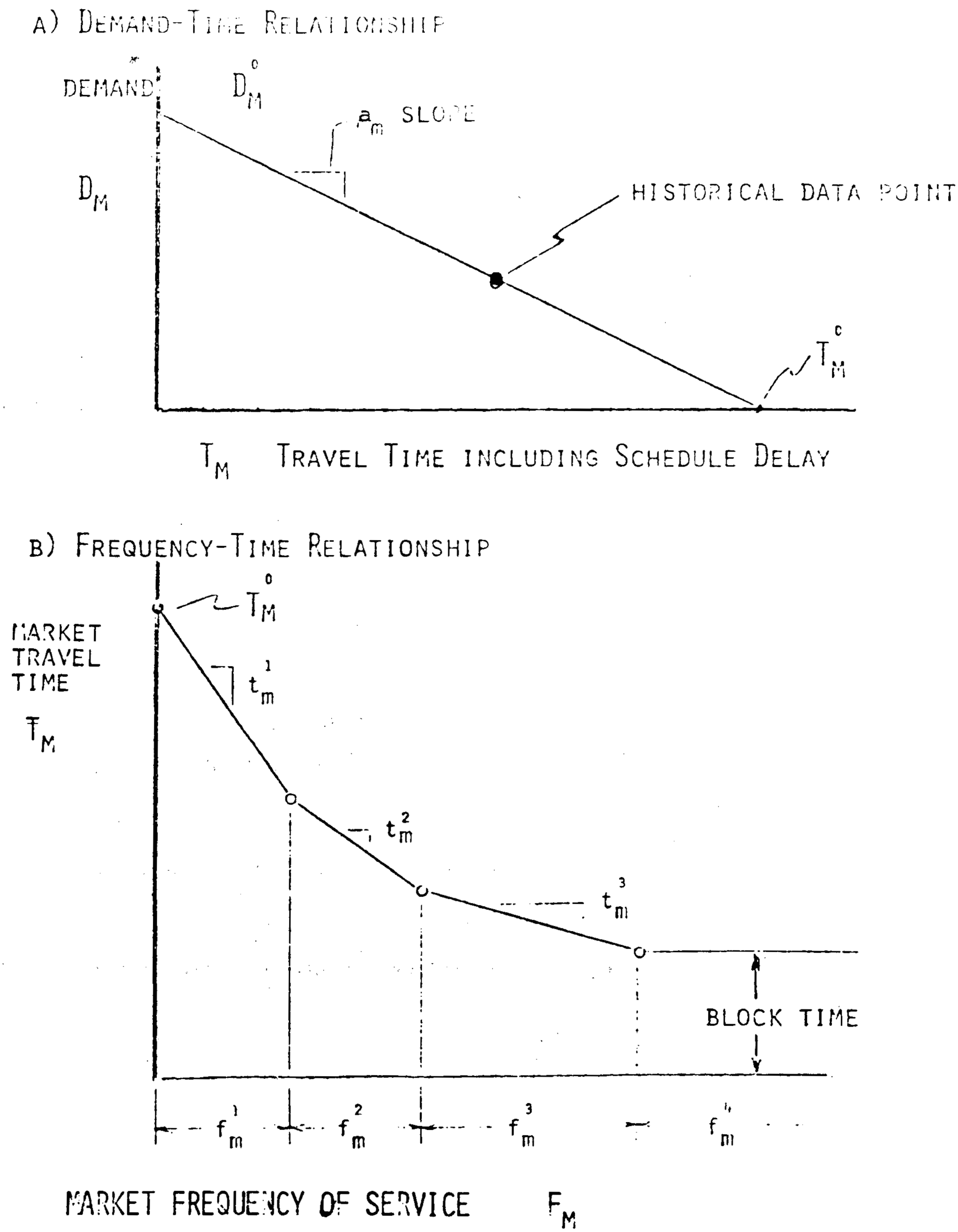
11 See Simpson and Neuve-Eglise (1968) and Swan (1973).

FIGURE IV-5
DEMAND-TRAVEL TIME RELATIONSHIP
FOR A CITY PAIR MARKET



The total frequency of service F_m has been divided into bounded segments f_m^1, f_m^2, f_m^3 and segment f_m^4. This frequency must also be noted as the sum of the frequencies of each aircraft route F_{vr} covering that market:

$$F_m = \sum_{r \varepsilon R_m} \sum_{v} F_{rr}$$

c) Airline, Market Competition in Demand Modelling

The network scheduling process for an individual airline or the total industry is modelled the same way whether the markets are competitive or not, i.e. the mathematical formulae are the same. What changes are the shapes of the demand curves for each market as perceived by the firm or industry. In order to describe the shape of the industry demand curve in an oligopolistic market it is necessary to make some assumptions about the behavior of the competing airines.

In this work, for the fare-sensitive pleasure travellers the assumption was that the monopolistic demand curve could be used. Since we are modelling the sum of the behavior of several airlines over a network, this assumption implied all airlines agreed to charge the fare which maximized total industry profits. We intend to relax these assumptions not by altering the demand curve but by changes in the objective function; but this is work for a later date.

For the frequency-sensitive business travellers a specific form of competitive scheduling behavior was assumed. From observations of competitive markets we learn that a certain amount of head to head scheduling of flights occurs between competing airlines.[12] This has the effect of "diluting" the observed industry frequency of service since some services are without value in reducing schedule delay. A useful approximation of the amount of dilution was found to be

$$V_m = [(1/MS_{max} - 1.)/2) + 1.0]^{-1}$$

---

12 See Swan (1976).

This formula implies that the airline with the largest market share (MS) does schedule reasonably, but half the flights added by other competitors are head to head departures. The function is numerically similar to

$$V_m = 1/\sqrt{MS}_{max}.$$

which is easier to think of.

The factor V_m may be interpreted as the average number of aircraft departures per scheduled departure time. The factor V_m dilutes the values of service in the equation which relates the frequency on each route $F_{vr.}$ to the service in each market F_m :

$$F_m = V_m \sum_{r \varepsilon R_n} W_{mr} F_r$$

These adjustments are speculative.[13] They currently represent only the best available guess at the true correction factors. This is unfortunate because these adjustments have a significant influence on the shape of the time-frequency curve and thus the market demand for the industry level models. Furthermore it is through manipulation of the index of head to head scheduling that we represent the situation facing a market. We must remember the quality of our inputs when the time comes to discuss the validity of our outputs.

d) Calibrating the Demand Models

At the start of this effort it was hoped that survey data provided by United Airlines on demand by trip purpose and fare by market would be available

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13 Research nearly compete on this point has confirmed the relationship with compelling statistical evidence. See Dennis Mathaisel at M.I.T. FTL.

to obtain the fractions of business and pleasure travellers in each city pair. While this data is still anticipated , the present work was guided by system averages which were immediately available.

Thus it was concluded that for 58 percent of the passengers in each market the purpose of the trip was business oriented. The remaining 42 percent of the passengers were classified as pleasure passengers. The business passengers were classified as frequency sensitive with time elasticity - 2.1. Pleasure passengers were time sensitive. This produced an overall market time elasticity of -1.25, which recent studies of US domestic market have predicted .[14]

The pleasure passengers were classified as purely fare sensitive with fare elasticity -2.0, a reasonable guess. For the purpose of historical calibration the ratio of business fare to pleasure fare was 1.164.[15] Overall yield (ratio of total revenues to tourist fares) was 92 percent.

1974 annual passenger flows were taken from CAB, Origin-Destination Survey of Airline Passenger Traffic, Vol. VII-4 (1975). The corresponding historical fares and frequencies were taken from the Official Airline Guide (May , 1974).

Thus with historical fare, passengers, and frequencies in each market, and with systemwide rules for determining elasticity and market splits between business and pleasure, it was possible ato create a frequency sensitive demand and a fare sensitive demand for each market.

IV. 4 The Network Modelled

The scenario we wish to create is this: we want to consider all 91 city pairs among the 14 largest centers for air travel. The cities involved are

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14 See Eriksen, Scalea, Taneja (1976).

15 This is based on systemwide data from United Airlines.

listed in Table IV-2. As discussed above, we will consider two markets in each city pair: one, called business travellers, is sensitive to frequency of service at fixed fares. The other, called pleasure travellers, is sensitive to fare. We calibrate our efforts against fares, frequencies, and passengers experienced in 1974.

By choosing the densest markets in the US we emphasize the jointness of simultaneous carriage of the business and pleasure markets and deemphasize the joint costs associated with spatially interconnected markets along a route. This occurs because most services offered currently in these markets are nonstop. Also, the larger markets have the greatest competition, so this aspect is also important.

We model the combined behavior of all the airlines involved in these markets. To do this we assume competition with respect to frequency of service. That is, each airline knows a change in its frequency of service will probably bring forth a proportional change on the part of its competitors.

We approach this top end of the airline market as much because of its importance in terms of total dollars as its interest for a technical study.

IV.5 Preliminary Conclusions and Results

A total of seven preliminary runs have been made using the model and data described above. These exercises are not intended to be definitive, but merely to provoke discussion and lay the groundwork for a more thorough set of runs this year. It is useful to present preliminary results with the model description and assumptions in order to provoke comments.

In the section below the runs are compared by topics.

a) Current Airline Discounting Appears Near the Industry Profit Optimum

For this study, two linear programming solutions to the network problem of the 91 city pairs were run. In the first the fare for pleasure travellers was fixed at the historical value, which was near 90 percent of the business yield. In the second the industry was allowed to set fares in the pleasure markets in order to maximize the joint profits. In both cases the industry could vary the frequency in each market to change the level of service for the business demand.

The results for the fare varying situation were very close to those with the pleasure fare fixed. A modest increase (5 percent) in the fare occurred in most markets. This produced a modest decrease in travel. But the differences were within the inaccuracies of the assumptions.

The conclusions to be reached are two: first, existing discount fare schemes appear to be reasonably near profit optimums for the pleasure markets; and secondly, among the major city pair markets, there are few markets where marginal passenger costs are either so high or so low as to produce a large deviation from the norm. What this means is that the maximum vehicle size was seldom too small, and there were few low load factor services flown in the network considered.

The conclusion that discount fares are near profit optimums in the pleasure market rests on two key assumptions. The first is that fare elasticity in that market is near -2, and the second is that load factors of 65 percent are reasonable for discount travel. It is possible to imagine air travel penetration into lower cost, lower quality of service markets. A full charter style operation would have somewhat lower costs, higher load factors still, and very possibly would deal in a demand market of different elasticity.

b) Joint Costs and Network Effects are Significant

The network considered included all 91 city pairs possible among the 13 largest hubs in the country. As a consequence all 91 city pairs involved significant amounts of passenger traffic. In fact, 94 percent of the passengers travelled nonstop, compared to about 2/3 nationwide. Nevertheless the combining of services onto multistop flights was a significant part of the industries' behavior.

Eight out of 91 business markets were not served in the model at anything like the actual levels-- all because of network effects. Two were neglected because of the lack of additonal traffic which in real life feeds from points outside the postulated network. Three were neglected because the routing historically used was inadvertently left out of the route options (although other seemingly useful multistop routes were available). And three more were neglected because the multistop services dominating those markets involved cities not in the list of 13.

Furthermore when only nonstop services were allowed in each market, a total of 16 more city pair markets were served at very low (or zero) levels compared to both actual practice and the full network of routes. This is especially noteworthy since we are dealing with a list of fairly large markets.

With only nonstop routings available, the profit optimum for pleasure fares was no longer below the business yield, but rather pleasure fares were generally at the existing business yields. Both airline profits and total passenger use[16] fell by 20 percent.

c) Monopoly Services Cost Less and Carry More

Competition in this model was reflected in the amount of head to head scheduling of departures which occurs in each market. As discussed in the section

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16 A weighted sum of business and pleasure miles and boardings.

on demand modelling the index of competitive scheduling was conservatively chosen. Nevertheless elimination of this wasteful scheduling allowed a more convenient schedule to be constructed with equal or fewer flights. Larger aircraft could be used at savings in cost. The result was a 14 percent increase in profits, a 9 percent increase in business travel, and a minor scattering of raises in pleasure fares.

We must recall that the assumed competitive scheduling behavior was that airlines expected their additional flight services to be matched by their competitors to the same degree as the existing services were matched. Also, business fares were regulated in both the competitive and non-competitive cases.

d) Economies of Scale are Significant

Two cases of monopoly services at regulated business fares were compared. In the first demands were as expected for 1974, the normal case. In the second all demand curves were increased in demand by 20 percent. There was a resulting increase in travel and in costs. We used an index of travel use which was a weigted sum of business and pleasure boardings and miles. This index grew faster than the increase in cost. The ratio of the percentage changes was .94, implying a cost increase of below 19 percent for a travel increase of above 20 percent.

The observation that marginal costs are 6 percent below average costs applies only for this high density network. Previous work by Swan (1976) suggests lower relative marginal costs for networks of low density service.

e) Summary of Results

Presenting the output of a network study is difficult because total activity figures may not reveal the detailed behavior. Nonetheless a list of measured outputs is provided in Table IV-3 . Some of the measures selected may have significance.

IV.6 Future Work

Work is underway at present to extend this modelling process to a low density network characterized by feeder services and connecting passengers. Once the connecting aspect of network analyses has been sucessfully tackled for the air transport case, the model will be employed to study ground mode problems.

The scenario for connecting passenger studies has been chosen as the area between St. Louis and Chicago comprising the towns of Springfield, Peoria, Champaign, an Decatur, Illinois. At present this region receives some direct services to Washington and New York.

IV.7 Glossary

Competition

Competition between carriers is included only by the considerations of head to head scheduling of departures. This reduces the effective level of service at the reported total industry frequency. We assume a constant degree of this overlap. It also implies that each airline schedules with the knowledge that the competitors will respond with proportional changes in service.

Connecting Passenger

The model employed does not consider passengers connecting by getting off one flight and onto another. Fortunately the large markets considered are not served by connecting service.

Demand Curves

This model employs demand curves which are straight lines. The normal (constant elasticity) demand formula used for regressions employs demand curves which are straight lines in logarithms. This produces curves which lend themselves to regression analysis, but which have incorrect behavior near the axes. Except for this limiting behavior, there would seem to be no reason to prefer one shape over another. Economic tradition favors straight lines for illustrative cases and constant elasticity for numerical ones. Because the numerical cases come second, there may be a tendency to consider the curved shape more sophisticated.

Demand Elasticity

Demand elasticity is taken to determine the slope of the demand curve at the historical point. Since no knowledge of the curvature exists, it is assumed to be zero in real space (that is space not transformed by logarithms).

Depreciation

Airline depreciation figures are computed differently for reports to (1) the CAB, (2) the IRS, and (3) the SEC. For the purposes of this study depreciation figures were replaced by an estimated lease cost corresponding to a 15-year 4 percent mortgage on the market price of the aircraft, (4 percent is the constant dollar cost of capital and may be high).

Profits

The model employed maximizes contribution to fixed overheads. Any fixed costs must be covered before profits are accumulated. Investment in aircraft is covered under operating (nonfixed) costs including a normal costs of capital. Airline firms probably have small fixed costs.

Firm vs. Industry

For this work the firm is an airline. However, because we are modelling the behavior of several firms together, we may be said to model the industry in total. Cost figures for aircraft block hours are treated as constant under assumptions of free market availability of aircraft, labor, and fuel. From an industry viewpoint these assumptions may be vitiated unless there is a substantial world market for these commodities or alternative domestic uses. Fortunately these conditions do obtain.

Load Factor

Load factor is the ratio of passenger miles to seat miles. One aspect of the quality of a service is the probability of being able to get a seat on the most convenient flight—the higher the load factor, the lower the probability. Load factor should be determined on the basis of the marginal cost of a seat and the value of that seat in creating higher availability.

The probability of a seat unavailability displays a sharp increasing rise at load factors in the 60 percent range. The nature of our network model at present requires that the maximum permissible load factor be set externally without the benefit of the tradeoff of cost and value mentioned in the preceding paragraph. Therefore we chose to set the maximum permissible load factor for business just below the congestion point, at 54 percent and just above the congestion point, at 65 percent for pleasure travel.

Long Run Costs

Airlines have no very long run costs. Investments in aircraft normally can be undone by sales in a used aircraft worldwide market within 6 months to a year.

Price Discrimination

This effort assumes that it is possible to discriminate between fare sensitive-frequency insensitive demands and frequency sensitive-fare insensitive demands by changing the conditions of service offered. Since the services purchased are different, there is no legal price discrimination amongst travellers.

Utilization

Utilization is the number of block hours of aircraft use per year. The two important influences are stage length and scheduling practice. Schedules designed to service demand in the evening and in the midday slump can increase utilization by 10 percent, see Fromme and Swan (1976). However, for our purposes a utlization of 3000 hours a year was assumed, without adjustment for stage length or of off peak pleasure level. This amounted to a neglect of a 1 percent change in operating costs.

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V. Airline Policy Analysis at the Firm Level - a Preview

V.1 Introduction

In order to apply the network models in a scenario closer to the real world, we selected a particular trunk airline, Continental Airlines, for further study of its possible behavior under conditions of free entry and exit from U.S. domestic airline markets. Various possibilities for changing the conditions of market entry have been suggested by recent legislative proposals. The network model can be applied to the Continental Airline system as it existed in 1974 with a given fleet of aircraft, operating costs, traffic and market share in its present operating authority. We then assume that other airlines stay within their present operating authorities, and allow Continental to consider entry and exit into various sets of new markets, or markets which restrictions to their present route authority prevents them from serving. Of course the other carriers will not remain passive, but we can study where and to what extent Continental Airlines might wish to modify its route structure if market entry/exit constraints did not exist. A separate report will provide a complete analysis of these studies. Here we will provide only a brief preview.

V.2 Case Study of Continental Airlines

From 1974 CAB data, it is possible to obtain a complete picture of Continental Airlines traffic, operations, costs, fares and revenues; and its available fleet and schedule service. The present operating authority has an extensive set of restrictions, and we can get the present set of routings used by Continental from the Official Airline Guide. The first efforts were then pointed toward obtaining a base case which replicated the patterns of service and financial and operating results for Continental in 1974. The model results gave such a replication with one exception: the loads on the Hawaii markets were quite low for DC-10 aircraft, and the model preferred to use the smaller B-720B. We prevented the usage of this aircraft on Hawaii routes, and obtained a reduced frequency of DC-10 service. The remainder of the service pattern saw a selection of aircraft types and frequencies very close to the actual 1974 patterns, and similar values for system revenues, passengers, passenger miles, etc.

At this point, it was necessary to discuss how to select new markets which Continental might consider for entry. There were far too many possibilities. It was decided that the markets should be organized around cities or airports, and that in every case, the restrictions on present operating authority should be removed. The new markets were then organized into smaller sets that related to possible corporate strategies to focus on adding markets from New York, Miami, Chicago, Dallas-Fort Worth, and finally a combination of Los Angeles and San Francisco. Here we shall present some results for studies which focussed on New York.

V.3 Free Entry into New York Markets

There were 17 new markets selected from points within the Continental system to New York. Also there were 35 new markets which arose from removing operating authority restrictions. These are listed in Table V-2. A glossary of city codes is provided in Table V-1. We assumed that if Continental entered a new market it became an equal competitor to the existing airlines, and based its share of traffic upon well known market-share-fre-

Table V-1. Code Names for Stations on Continental Airlines Route Map, 1974

CODE	STATION	CODE	STATION
ABQ	ALBUQUERQUE, N. MEX.	SFO	SAN FRANCISCO, CALIF.
AMA	AMARILLO, TEX.	SJC	SAN JOSE, CALIF.
AUS	AUSTIN, TEX.	SPS	WICHITA FALLS, TEX.
BUR	BURBANK, CALIF.	TUL	TULSA, OKLA.
COS	COLORADO SPRINGS, COLO.	TUS	TUCSON, ARIZ.
DEN	DENVER, COLO.		
DFW	DALLAS-FORT WORTH, TEX.		
ELP	EL PASO, TEX.		
HNL	HONOLULU, HAWAII		
IAH	HOUSTON, TEX.		
ICT	WICHITA, KANS.		
ITO	HILO, HAWAII		
[1]JFK	NEW YORK CITY, NEW YORK		
LAW	LAWTON-FORT SILL, OKLA.		
LAX	LOS ANGELES, CALIF.		
LBB	LUBBOCK, TEX.		
MAF	MIDLAND-ODESSA, TEX.		
MCI	KANSAS CITY, MO.		
MIA	MIAMI, FLA.		
MSY	NEW ORLEANS, LA.		
OKC	OKLAHOMA CITY, OKLA.		
ONT	ONTARIO, CALIF.		
ORD	CHICAGO, ILL.		
PDX	PORTLAND, OREG.		
PHX	PHOENIX, ARIZ.		
SAT	SAN ANTONIO, TEX.		
SEA	SEATTLE-TACOMA, WASH.		

[1]JFK is added in accordance with the study. Traffic data used is inclusive of Kennedy, Neward and La Guardia Airports so that JFK really represents New York City region.

Table V-2 New Markets for Continental Airlines, New York City Case Study

[2] Group 1 (17 Markets from Entry into New York)

JFK	DEN*	JFK	MIA*	JFK	SAT
JFK	DFW*	JFK	MSY*	JFK	SEA*
JFK	HNL	JFK	OKC	JFK	SFO*
JFK	IAH*	JFK	ORD*	JFK	TUL
JFK	LAX*	JFK	PDX	JFK	TUS
JFK	MCI*	JFK	PHX*		

Group 2 (35 New Markets from Removal of Restrictions from Present Authority)

ORD	DFW	DFW	HNL	MCI	ICT	SFO	HNL
ORD	IAH	DFW	IAH	MCI	OKC	SFO	LAX
ORD	ICT	DFW	LAX	MCI	PHX	SFO	PHX
ORD	MCI	DFW	MCI	MCI	SEA	SFO	SEA
ORD	MSY	DFW	OKC	MCI	SFO		
ORD	PHX	DFW	PHX	MCI	TUL	DEN	PHX
ORD	SAT	DFW	SAT			DEN	SFO
ORD	SEA	DFW	SFO	OKC	LAX		
ORD	SFO	DFW	TUL	TUL	LAC	MSY	SAT
ORD	TUL	DFW	TUS				

Markets labelled with an asterisk were included in the study both as a non-stop route possibility and as a link of a multi-stop route; these markets had daily demands in excess of 100 passengers. The remaining markets from both groups were included only as a link of a multi-stop flight.

[2] All Group 1 markets were selected based on a minimum daily demand of 50 passengers. The multi-stop routes that included a Group 1 market as a link were selected from the flight itineraries (as published by the Official Airline Guide, May 1974) of carriers serving that market. This resulted in the inclusion of Group 2 markets. Chicago, Dallas-Fort Worth, and Kansas City appear as major entry points (from New York City) into Continental's existing route structure.

quency share relationships for the industry. The 1974 frequency of service in such markets by competitors was obtained from the Official Airline Guide. The market was not split into business and pleasure segments, and market prices were controlled exogeneously.

A series of five cases were run: Case 1 is the base case referred to previously; Case 2 allowed entry into the new markets mentioned above while maintaining normal fare levels and the existing 1974 fleet of aircraft; Case 3 presumed that price competition would occur in these new markets and prices would be reduced by 10% while fares in other markets remained at normal levels; Case 4 presumed that under such circumstances, Continental might also consider acquiring new aircraft whose operating costs would now include depreciation and ownership costs (the B-720B was not made available since it is out of production); Case 5 then considered that further price competition would reduce the fare levels in the new markets by 20%.

The results in terms of market entry and exit from these cases are listed in Tables V-3 through V-6. In general terms, the airline moved strongly into New York markets, and into all longer haul markets. It abandoned services which were marginally profitable in the short haul, low density areas of its system in Texas and New Mexico. A complete list of market entry and exit is provided for each case. There were a larger number of current markets which also received reduced service, particularly in Cases 2 and 3 where the fleet was restricted.

A summary of system data for these series of model runs is presented in Table V-7. It can be seen that the entry into new markets in Cases 2 and 3 doubled the average aircraft stage length, and caused a 50% increase in passenger trip length. System revenues generated by the same fleet of

Table V-3 Market Entry and Exit- Case 2, Normal Fares, Current Fleet 6

Group 1 Markets Abandoned (76 Current Markets)

ALB	COS	DEN	ONT	LBB	LAX	TUL	PDX
ALB	DEN	DEN	PDX	LBB	MAF	TUL	SEA
ALB	ELP	DEN	SAT	LBB	OKC		
ALB	IAH	DEN	TUL	LBB	SAT		
ALB	LBB						
ALB	MAF	ELP	DFW	MAF	AMA		
ALB	MCI	ELP	LBB	MAF	AUS		
ALB	OKC	ELP	MAF	MAF	DFW		
ALB	SAT	ELP	MCI	MAF	OKC		
ALB	TUL	ELP	ORD	MAF	PHX		
		ELP	SAT	MAF	SAT		
AMA	DFW	ELP	SFO				
AMA	ELP			MIA	PHX		
AMA	IAH	HNL	ORD	MIA	SAT		
AMA	LAX	HNL	PDX	MSA	SEA		
AMA	LAB			MSA	TUL		
		IAH	LBB				
BUR	ONT	IAH	MAF	OKC	LAW		
BUR	SJC	IAH	MIA	OKC	MSY		
		IAH	OKC	OKC	PDX		
COS	MCI	IAH	PDX	OKC	SEA		
		IAH	SFO				
DEN	COS	IAH	TUL				
DEN	ELP			ONT	ORD		
DEN	HNL	ICT	MSY	ONT	SJC		
DEN	IAH	ICT	OKC				
DEN	ICT	ICT	PDX				
DEN	LBB	ICT	SEA	SAT	LAX		
DEN	MAF			SAT	SFO		
DEN	OKC	LBB	DFW	SAT	TUS		

Group 2 New Markets entered (35 New Markets)

JFK	DEN	JFK	SAT	ORD	SAT	MCI	PHX
JFK	DFW	JFK	SEA	ORD	SEA	OKC	LAX
JFK	HNL	JFK	SFO	ORD	SFO	OKC	TUL
JFK	IAH	JFK	TUL				
JFK	LAX	JFK	TUS	DFW	IAH		
JFK	MCI			DFW	LAX	DEN	SFO
JFK	MIA	ORD	DFW	DFW	MCI		
JFK	MSY	ORD	IAH	DFW	PHX		
JFK	ORC	ORD	MCI	DFW	SFO	PHX	SFO
JFK	ORD	ORD	MSY	DFW	TUS		
JFK	PHX	ORD	PHX				

Table V-4 Market Entry and Exit- Case 3, Fares Reduced 10%,Current Fleet

Group 1 Markets Abandoned (45 Current Markets)

ALB	COS	DEN	LBB	ICT	OKC	OKC	LAW
ALB	IAH	DEN	SAT	ICT	SEA	OKC	TUL
ALB	LBB						
ALB	MCI			LAX	TUS	ONT	SJC
ALB	OKC	ELP	LBB				
ALB	SAT	ELP	MAF				
		ELP	MCI	LBB	DFW	SAT	SFO
AMA	ELP	ELP	ORD	LBB	LAX	SAT	TUS
AMA	IAH	ELP	PHX	LBB	MAF		
AMA	LAX	ELP	SFO	LBB	OKC	TUL	SEA
AMA	LBB	ELP	TUS				
				MAF	AMA		
AUS	ELP			MAF	AUS		
AUS	IAH	IAH	LBB	MAF	SAT		
AUS	PHX	IAH	SFO				
BUR	ONT			MIA	SAT		
BUR	SJC	ICT	MSY	MSY	TUL		

Group 2 New Markets Entered (26 New Markets)

JFK	DEN	ORD	ICT	MCI	SEA
JFK	DFW	ORD	MCI		
JFK	HWL	ORD	SEA		
JFK	IAH	ORD	TUL	MSY	SAT
JFK	LAX				
JFK	MCI				
JFK	MIA	DFW	IAH		
JFK	MSY	DFW	PHX		
JFK	ORD	DFW	SFO		
JFK	PHX	DFW	TUS		
JFK	SAT				
JFK	SEA				
JFK	SFO	MCI	ICT		
JFK	TUS	MCI	TUL		

Table V-5 Market Entry and Exit- Case 4, Fares Reduced 10%, Expanded Fleet

Group 1 Markets Abandoned (23 Current Markets)

ALB	COS	DEN	LBB	MAF	AMA
ALB	OKC	DEN	SAT	MAF	AUS
				MAF	LBB
AMA	ELP	ELP	MCI	MAF	SAT
AMA	IAH				
AMA	LAX	IAH	LBB	OKC	LAW
AMA	LBB			ONT	SJC
		ICT	MSY		
BUR	ONT	ICT	OKC	TUL	MSY
BUR	SJC	ICT	SEA	TUL	SEA

Group 2 New Markets Entered (49 New Markets)

JFK	DEN	JFK	SFO	ORD	TUL	MCI	PHX
JFK	DFW	JFK	TUL			MCI	SEA
JFK	HNL	JFK	TUS	DFW	HNL	MCI	SFO
JFK	IAH			DFW	IAH	MCI	TUL
JFK	LAX			DFW	LAX		
JFK	MCI	ORD	DFW	DFW	MCI	OKC	LAX
JFK	MIA	ORD	IAH	DFW	OKC	TUL	LAX
JFK	MSY	ORD	ICT	DFW	PHX		
JFK	OKC	ORD	MCI	DFW	SFO	SFO	HNL
JFK	ORD	ORD	MSY	DFW	TUL	SFO	LAX
JFK	PDX	ORD	PHX	DFW	TUS	SFO	PHX
JFK	PHX	ORD	SAT			DEN	PHX
JKF	SAT	ORD	SEA			DEN	SFO
JKF	SEA	ORD	SFO	MCI	ICT	MSY	SAT

Table V-6 Market Entry and Exit - Case 5, Fares Reduced 20%, Expanded Fleet

Group 1 Markets Abandoned (22 Current Markets)

ALB	COS	ELP	MCI	MAF	AMA
ALB	MCI	ELP	TUS	MAF	LBB
ALB	OKC			MAF	SAT
		IAH	LBB		
AMA	ELP			ONT	SJC
AMA	IAH	ICT	MSY	SAT	TUS
AMA	LAX	ICT	OKC	SEA	TUL
BUR	SJC	LAW	OKC		
		LAX	TUS		
DEN	LBB				
DEN	SAT				

Group 2 New Markets Entered (38 New Markets)

JFK	DEN	ORD	DFW	MCI	ICT
JFK	DFW	ORD	ICT	MCI	PHX
JFK	HNL	ORD	MCI	MCI	SEA
JFK	IAH	ORD	MSY	MCI	TUL
JFK	LAX	ORD	PHX		
JFK	MCI	ORD	SEA	OKC	LAX
JFK	MIA	ORD	SFO	TUL	LAX
JFK	MSY	ORD	TUL		
JFK	OKC			SFO	DEN
JFK	ORD	DFW	IAH	SFO	PHX
JFK	PHX	DFW	LAX		
JFK	SAT	DFW	PHX	MSY	SAT
JFK	SEA	DFW	SFO		
JFK	SFO	DFW	TUS		
JFK	TUL				
JFK	TUS				

Table V-7 System Data for Continental - New York Case Studies

	Case 1	2	3	4	5
	Base	+ New Markets	+ Fares x 0.9	+ Expanded Fleet	+ Fares x 0.8
Fleet Size					
DC-10	10	11	11	11 + 29	11 + 16
B727	30	30	30	30 + 57	30 + 53
B720B	0	7	7	1.5	1
DC-9	7	7	7	7	7
System Revenue/ Day ($)	418,130	502,800	479,200	1,263,200	994,634
Contribution to Overhead ($)	129,200	182,400	156,683	423,407	331,178
System Passengers/ Day	13,284	11,859	11,559	32,346	31,415
RPM/Day	13.7×10^6	17.5×10^6	17.3×10^6	51.2×10^6	50.0×10^6
Average Aircraft Stage (Miles)	735	1,329	1,196	1,029	1,041
Average Pax. Trip Length (Miles)	1,033	1,475	1,493	1,583	1,592

aircraft increased by 25% and profit increased by roughly the same amount. The passengers boarded actually decreased in these two cases while the revenue passenger miles increased by 25%.

There was a reasonable expansion of the airline fleet and system operations in Cases 4 and 5. The system almost triples in scale in every system measure. Now any marginally profitable market will be retained. The model does not pick up all the markets of the base case since the new aircraft purchased have higher operating costs which include vehicle ownership costs. These increased costs mean that markets flown by existing aircraft are unprofitable to the newly acquired aircraft.

V.4 Summary

Other case studies will be carried out for other sets of markets. As can be seen from these results, there is quite a dramatic impact of allowing free entry and exit upon the Continental system as it rationalizes its route structure such as to maximize its profitability. There are many other factors which prevent any realistic conclusions to be drawn from the cases presented. For example, New York became a major station for Continental and it is not clear that there is existing airport capacity at New York to accommodate this expansion. Also, the assumption that other airlines would remain fixed is not realistic. There would be yet other airlines trying to enter these new markets, and entering some of the larger markets of the current Continental system. It is difficult to see any equilibrium resulting from such unrestricted entry and exit into major U.S. airline markets.

VI. Summary and Conclusions

In this report we have attempted to explain why conventional economic models are not adequate to describe the behavior of common carrier transportation firms. Essentially, simple models fail both because of the extra degree of freedom* in the matching of supply and demand and because of the cost interrelationships of network operations. We have introduced a network model of a transportation firm's market decisions which answers these two criticisms. We have sketched preliminary exercises of this model. In our exercise economies of scale and jointness in the production of different types of service were illustrated. A second exercise Continental Airlines displayed a modest discontinuance of service in some markets accompanied by a wholescale expansion in others when route authorities were expanded and relaxed.

These developments in economic modeling are of a preliminary nature. We have questioned the fundamentals of earlier thinking without substantially reworking the conclusions which that thinking has reached. Nevertheless continued pursuit of these new directions should at least prevent the repetition of the mistakes of the past and will lead toward a more truthful perception of the transportation industries.

*namely load factor

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DOT-TST-77-81 ALTERNATIVE SCENARIOS FOR FEDERAL TRANSPORTATION POLICY VOLUME IV

NETWORK MODELS FOR TRANSPORTATION POLICY ANALYSIS