Advanced Airline Planning Models as a Tool for Developing Regulatory Policy

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INTRODUCTION

This paper introduces a much more detailed economic theory of the firm for carriers who supply transportation services over a network of markets. Three levels of analysis are defined for transportation economics – a system level, a market level, and a network level. One particular airline model for analysis at the network level is introduced, and then applied to a study of a potential liberalization of route authority for Continental Airlines – a medium sized U.S. airline presently restricted to routes generally in the south-western portions of the U.S.A.

ECONOMICS OF THE TRANSPORTATION FIRM

Let us define three levels of economic analysis for public tranportation systems: a system level, a 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 even though this will lead us to the use of rather complex computer based analytical tools. In this section, we will describe the three levels of analysis, and explain the reasons for this viewpoint.

System Level Economics

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 system output a homogeneous good called a passenger-mile (or seat-mile or ton-mile) which is produced in some ill defined, general market. System consumption of input factors in the form of labor, fuel, and transportation facilities is expressed in terms of total system expenditures, and then unit costs for output are expressed in terms of dollars per passenger-mile.

At this macro-level of aggregation, many ideas essential to the understanding of transportation economics cannot be expressed. The basic error is to assume that buyers are purchasing an economic good called a passenger-mile. They actually purchase a quantity of transportation service of a specific kind in an individual market well defined by its origin and destination. The service purchased in one such market is not substitutable in any other market. The quantity of services purchased is best measured simply by passengers in each market. It is necessary to describe the quality of services purchased in its various dimensions of trip time, trip frequency, punctuality, onboard comfort or class of service, etc. Ton-miles, passenger-miles, or seat-miles are measures of the amount of work required to deliver the service, not a measure of the quantity or quality of the service itself. For most issues in transportation economics, treating the transportation firm as a factory which produces passenger-miles is grossly inadequate.

Market Level Economics

Since we can see that buyers are purchasing transportation services in a market defined by an origin and destination, the next level of analysis is to study demand and supply in such a market. In particular, the theory of transportation demand requires that demand functions be defined in such markets. Models of market demand have been developed which present the daily demand measured in passenger-departures per day or per week averaged over some longer time period as a function of price, quality of service variables (such as trip time, service frequency, punctuality, etc.), and demographic descriptors of the regions represented by origin and destination points. As well we may know something about the cyclic variations of this expected market demand value, and the stochastic variations around it.

Market Demand (Passenger-Departures)

Let us denote such an average value by D^{mc}, the average passenger-departures per day expected in market m using a class of service, c. (We can extend the index c to cover demand for cargo, mail, etc. if carried simultaneously as in the airline case.) A model of market demand for D^{mc} would normally be a function of the complete set of prices for the different classes of service, and some of the qualities of service variables for each class. In particular, for the study of U.S. airline firms where competitive services exist in most markets, it is important to introduce the carrier frequency of service in the market, n^m, as a demand variable. The market share of demand obtained by an airline is strongly dependent

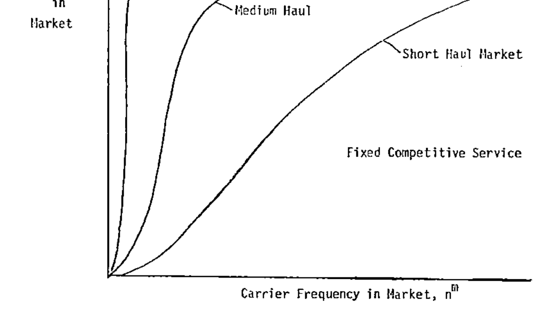


Figure 1 – Typical Traffic-Frequency Curves for a Market

upon its frequency share. For fixed competitive conditions, there exists a "Traffic-Frequency" curve of the form shown in Figure 1 which is derived from demand models and market share models. Notice that these curves saturate as increasing frequency is offered. The saturation point is a function of competitive frequencies, and length of haul for the market.

Network Level Economics

In contrast to the demand function which is defined for each city-pair market, the supply function is defined on a network. Only in the case where the complete network is one single, isolated market can we define the supply function for a market. In the usual case, vehicles move along multistop routes in a network and provide service simultaneously to groups of markets. If we have such a network system, we must perform our analysis at the network level. For the U.S. domestic airline system only one third of the flights are non-stop, and the traffic from other markets usually exceeds the local demand for any non-stop portion of a flight.

Let us define some new terminology. We shall define a route r as a series of consecutive links in a network followed by a vehicle trip (or "Flight" in airline terms). There is a large set of possible routes, denoted $\underline{R}$, which exist under the route authority granted to a carrier by some regulatory agency. There are a set of markets associated with each route. Similarly, we define a path p as a series of consecutive portions of vehicle routes followed by demand in a network travelling from its origin to its destination. In this paper, we shall denote such paths by the index r to simplify our notation. Finally, we define a segment, l, as a link in the network, or as a non-stop portion of a vehicle route. Segment l has a variety of vehicle routes, passenger paths, and markets which traverse it.

a) Market Demand on a Network

As before we define D^{mc} as the daily demand of class c in market m, but now we split this demand into portions which follow path r in the network, D_r^{mc}. If we define the set of paths r which demand in market m may follow as $\underline{R}^m$; then

$$D^{mc} = \sum_{r \varepsilon \underline{R}^m} D_r^{mc}$$

We now can denote the totality of traffic of a given class which flows over a segment by D^{lc}. We need to indentify the set of markets which use link l of a route r, $\underline{M}_r^l$, and the set of routes which contain link l, $\underline{R}^l$, then

$$D^{lc} = \sum_{r \varepsilon \underline{R}^l} \sum_{m \varepsilon \underline{M}_r^l} D_r^{mc}$$

This segment traffic, D^{lc} consists of *"local demand"* from the market of the link l, and *"non-local demand"* from all other markets which use link l. For example, if the link l goes from A to B, the local demand originates in A and terminates in B: The non-local demand consists of two types; 1) demand which transits station A or B on board a vehicle whose route includes the segment, 2) demand which connects at A or B from one vehicle route to another. (Because of this traffic, even a non-stop flight will have non-local demand on board).

If non-local demand flows are small over the network, we can perform market level analysis for each segment of the network. As stated above, this is not true of the U.S. domestic airline system. In this case, there are roughly 500 cities served and therefore roughly 125,000 markets. Only 1250 segments exist, or about 1% of the total markets get non-stop service. However, these are major markets which produce roughly 75% of the passenger demand. The remaining 25% of passengers come from the other 99% of the nation's markets and must traverse two, three, or more segments. They do so in such a way that they outnumber the local passengers - on these 1250 segments local demand averages only 43% of the total segment flow.[1]

b) Supply on a Network

Where before the supply decision variable n_v^m the daily frequency by vehicle type v in the isolated market m, now it becomes n_{vr}, the daily frequency by vehicle type v along the route r which serves multiple markets.

i) Vehicle Departures

The number of vehicle departures in a market is still determinate. Let us define n_r, the *frequency of single vehicle, or through service on a route.*

$$n_r = \sum_v n_{vr}$$

Then, we can find n^m, the *frequency of single vehicle service in a market.*

$$n^m = \sum_{r \varepsilon \underline{R}^m} n_r$$

where $\underline{R}^m$ is the set of vehicle routes which serve market m. But now n^m consists of services with multiple stops. If we define $\underline{R}^{ms}$ as the set of routes which serve market m in exactly s stops, then we can define *frequency of sdstop service in a market,* n^{ms}

$$n^{ms} = \sum_{r \varepsilon \underline{R}^{ms}} n_r$$

If desired, we can also find the "through" services by vehicle type (n_v^m and n_v^{ms}). However, it is impossible to count the frequency of connecting services in a market. Although we know the frequency of service on portions of vehicle routes which make up a connecting demand path, we will not know the number of connections (or connection times) until the timetable is constructed.

We can also find n^l, the *frequency of service over a segment*

$$n^l = \sum_{r \varepsilon \underline{R}^l} n_r$$

Thus, while the supply decision variable is n_{vr}, we can derive the frequency of single vehicle services for a market, segment, or route from it.

ii) Seat Departures

Similarly, we can count the number of seats (or space) offered on a given route to a given class of demand, q_r^c

$$q_r^c = \sum_v S_v^c \cdot n_{vr}$$

But we cannot count the number of seats (or space) offered to a given market of the network. Even for a given class of service, the space on board a vehicle following a non-stop or multistop route is being offered to several route markets and many connecting markets simultaneously, usually under an indeterminate first come- first served policy. We cannot decouple this sharing of the quantity of supply offered to multiple markets.

This is a very important result in the analysis of transportation systems at the network level. Let us repeat it for emphasis. *We cannot determine the quantity of seats (space) being supplied to a market embedded in a network of services.* Thus, we cannot compare market supply and demand, or market revenues and costs.

We can count the supply of seats (space) for any demand class traversing any segment of the network, q^{lc};

$$q^{lc} = \sum_{r \in \underline{R}^l} \sum_v S_v^c \cdot n_{vr}$$

where $\underline{R}^l$ is the set of routes containing segment l. Note that in the case of a single link network, this quantity reduces to the market supply and we perform market level analysis.

c) Demand/Supply Rations on a Network

In the network, it is the segment supply of seats (space), q^{lc}, which must exceed the average segment traffic, D^{lc}, for a given class of demand and every segment of the network;

$$q^{lc} > D^{lc} \quad \text{for all } l, \text{ all } c$$

Thus, we can define a segment average load factor, $\overline{LF}^{lc}$

$$\overline{LF}^{lc} = \frac{D^{lc}}{q^{lc}} \quad \text{for a segment l, class c}$$

We cannot find the load factor for a market since q^{mc} is indeterminate. We cannot find the load factor for a route except by weighing the route segment load factors by the segment distance. Thus, we define the average load factor for a route, $\underline{LF}^{rc}$

$$\overline{LF}^{rc} = \sum_{l \epsilon r} \frac{D^{lc}.d^l}{q^{lc}.d^l} \left(= \frac{RPM^r}{ASM^r} \right) \text{for a route r, class c}$$

where RPM^r = average revenue passenger miles for the route

ASM^r = available seat miles flown on the route.

For complete carrier systems, this ratio of demand-miles to space-miles is commonly used to compute a system average load factors.

d) Supply Costs on a Network

i) Vehicle Operating Costs – we can determine the costs, c_v^l operate a vehicle type v over a segment l given its distance or trip time. By summing over the segments of a route, we obtain the costs, C_{vr} to operate vehicle type v over route r.

ii) Station Operating Costs – The costs per passenger (class c) can be determined for each passenger route for demand of class c in market m, c_r^{mc} This value would be the sum of station loading/unloading operations along the route. These costs can also be made a function of the level of station demand operations if desired.

iii) System Fixed Costs – As in the market level analysis, there may be fixed costs, FC, for the system which do not vary directly with supply and demand variables in the short term.

From the above, we express the total supply costs for the network as,

$$TC = \sum_r \sum_v c_{vr} \cdot n_{vr} + \sum_c \sum_r \sum_m c_r^{mc} \cdot D_r^{mc} + FC$$

By associating the station loading and unloading costs with a segment, we can determine the total variable costs for a segment, TVC^l, and for a route, TVC_r. We cannot determine the variable costs for a market since multiple markets share the vehicle operating costs.

When we turn to average costs per seat, we again have difficulties with an arbitrary allocation unless we assume there is only one demand class. Even then, since there are fixed costs for the whole system, we cannot find any average costs per seat unless we make some arbitrary allocation of fixed costs to routes, segments, or markets.

For a single class of demand, we can find the average variable costs per seat for a segment or route since we have shown that we can determine (TVC^l, q^{lc}) and (TVC_r, q_r^c). For a market, we cannot determine either of these quantities. *Average variable cost per seat cannot be found for a market imbedded in a network even if there is only one class of service.*

For marginal costs per seat, we have the same difficulties with the discreteness of seat supply discussed in the market level analysis. *No true marginal costs per seat can be determined for a segment, route, or market.* However, we can determine the incremental costs of adding a frequency and its block of seats to a segment or route. We cannot find the incremental costs per seat added to a market since the seats are shared by multiple markets, but we can find the costs of adding one more market frequency with a specified number of stops, $\frac{\Delta TC}{\Delta n_{ms}}$

Notice how this would be accomplished on the network. If we require one more frequency in a market, all of the routes and vehicle frequencies can be re-examined with a view to changing vehicle size, vehicle routes, and demand paths. We would not necessarily add one more service non-stop, or along the shortest route available in the market because this would normally be expensive. Instead we would rearrange the pattern of service in the surrounding portion of the network to achieve this increase at perhaps zero cost, or at least some small fraction of the cost of simply adding another frequency in the market.

Similarly, if we ask for one more frequency across a segment, n_l, the incremental costs $\frac{\Delta TC}{\Delta n_l}$ would be minimized by rearranging the patterns of service in adjacent portions of the network. For a segment, we can also ask for the incremental cost of adding more seats, $\frac{\Delta TC}{\Delta q_{lc}}$, when only one class of service exists. *To find the incremental costs of adding a frequency of service to a segment or market, or of adding seats to a segment we need to re-route the pattern of services in the network. We must work at the network level to find incremental costs.*

This capability of rerouting can give a large network carrier a competitive advantage over local carriers on a segment. Because of "feed" or non-local demand, the large carrier may offer a high frequency of service and many seats whether or not any local demand is carried. Its incremental costs of adding a frequency or more seats may be quite low. In the absence of pricing policies which require fairness across merkets, the large carrier has significant discretionary powers to reduce price in any individual market of its network down to the level of its incremental costs.

e) Revenues and Profitability on a Network

The current fare structure for U.S. domestic airline service makes the price for service in each market depend upon a terminal charge plus the distance between origin and destination along the shortest authorized routing (which generally is non-stop, great circle distance). Is is not the sum of the local fares along the segments of the demand path, and consequently we cannot associate revenues with a segment. Also, since demand paths will connect portions of more than one vehicle route, we cannot associate revenues with an aircraft route.

Thus while we can find the variable operating costs for a segment or route as described in the previous section, we cannot determine their revenues, and hence their contribution to system fixed costs. On the other hand, we can determine the revenues from each market, but cannot determine the operating costs for the market.

Thus, we cannot determine the contribution to system overhead for a segment, a route, or a market in a transportation system which operates on a network.

This is a remarkable conclusion. We cannot look at any part of the pattern of services on a network and make a statement as to its profitability. Of course, this has not deterred analysts from making arbitrary allocations of costs and revenues in order to obtain arbitrary values of profitability for a segment, route, or market.

We can determine the revenues, costs, and profitability for the complete system;

$$REV = \sum_m \sum_c Y^{mc} \cdot D^{mc}(n^m)$$

$$\pi = \sum_m \sum_c (Y^{mc} - c^{mc}) \cdot D^{mc}(n^m) - \sum_r \sum_v c_{vr} \cdot n_{vr} - FC$$

As in our market analysis, we have made the market demand a function of market frequency of service, n^m. Since this depends on n_{vr}, the profit π is optimized by finding the best set of decision variables, $\underline{n}_{vr\ opt}$. If we could express D^{mc} as a function of price and service frequency in which case the profit would be maximized by finding the best set of decision variables, $\underline{Y}^{mc}$ and $\underline{n}_{vr\ opt}$. The set of optimal market prices would depend in a rather complex way upon the network structure, cost and demand functions, and available aircraft.

Notice that suppliers will be optimizing over their network of services, and will not be optimizing in each market independently. Each supplier in a market will behave differently depending upon his surrounding network. Even if their supply costs are similar, a different network would lead competitive suppliers in a market to serve it differently, and choose different prices in absence of competition. It is difficult to perceive any market equilibrium in the case where supplier networks only partially overlap and there is an absense of regulation over prices and entry. Remember that marginal costs for a market are indeterminate, so we cannot find a normative standard to guide regulatory pricing policies aimed at achieving economic efficieny.

At present, U.S. airline regulatory practice posts prices across all markets in the nation, and closely controls the route authority of each carrier. Given a set of prices, $\underline{Y}^m$, and a route authority, $\underline{R}$, each airline has to make a decision on the set of supply variables, $\underline{n}_{vr}$. In the longer term, the carriers select vehicle types and make decisions about applying for new route authority to optimize their individual system profitability. If the Civil Aeronautics Board changes the posted prices in different markets, $\underline{Y}^m$, or the route authorities, $\underline{R}_a$ for different airlines, the carriers will react by rearranging their patterns of service, and purchasing different aircraft in the longer term.

Adding a single segment to a route authority will affect many markets besides the local market. Adding it to different route authorities will have varying impacts- for some carriers the new segment will greatly improve profitability even if the traffic and revenues from the local market are negligible; for other carriers, the segment may be only valuable for its local market.

If we wish to study the effects of changing fare structures, or route structures on an airline we need to use the network level of economic analysis. In the next section, we present a particular network model for the airline firm which we shall subsequently use to study the impacts of freeing regulation over entry and market prices.

A MODEL FOR THE AIRLINE FIRM

In this section, we will describe a computer model for an airline firm which works at the network level of economic analysis. It consists of a series of equations which we can solve to find a profit maximizing set of supply decisions for an individual carrier using techniques from mathematical programming. It is one of several such models developed in the flight Transportation Laboratory at M.I.T. in recent years. The model is designated FA-4, and optimizes system profit by choosing $\underline{n}_{vr}$ given a set of market prices and a set of Traffic-Frequency curves which presume fixed competitive conditions in all markets.

For the analyst, the input information concerning market prices, traffic-frequency curves, available aircraft, operating costs, station capacities, minimum required levels of service, route authorities is easily entered into preprocessor computer programs which set up the mathematical problem. This is then solved using a standard mathematical programming code (in our case, MPSX from IBM). The solution is then presented to the analyst by a post-processor program which tabulates the data into a comprehensible summary format. Sensitivity to changes in various input data such as route authority, market prices, new aircraft, etc. can quickly and easily be obtained. In effect, he has a computer tool for economic analysis of a given airline system operating over a network of routes.

MODEL FA-4, AN AIRLINE FLEET ASSIGNMENT MODEL

Objective Function

Find the optimal set of supply decisions, $\underline{n}_{vr}$, which maximizes operating income, given a set of demand functions for each market of the system which depend upon the frequency of services offered, and subject to various operating constraints.

$$\text{Maximize } \pi_{op} = \sum_r \sum_m \sum_c (Y_r^{mc} - c_r^{mc}) \cdot D_r^{mc} - \sum_r \sum_v c_{vr} \cdot n_{vr}$$

where π_{op} is operating income. The first term represents net revenues from all markets. The second represents vehicle operating costs. Since D_r^{mc} is a function of n^m, which in turn is a function of n_{vr}, we are seeking to find an optimal set of n_{vr} values.

Constraints

1a) Market Demand depends on Market Frequency of Service

For each market, we may construct a linearized traffic frequency curve as a function of a weighted frequency of service, $\bar{n}^m$ which discounts one stop, two stop, and connecting services relative to non-stop service;

$$\bar{n}^m = \sum_s w^s \cdot n^{ms} \quad \text{for any markte, m}$$

Then, the non-linear relationship between demand and service is represented by a series of linear terms;

$$D^{mc} = \sum_i d_i^{mc} \cdot n_i^m \quad \text{for any market m, class c}$$

$$\bar{n}^m = \sum_i n_i^m \quad \text{for any market m}$$

where n_i^m is a frequency variable for each term. d_i^{mc} is the slope representing the rate of demand increase with frequency term i.

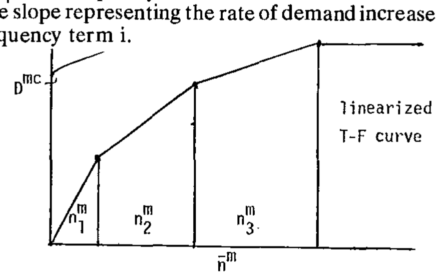


Figure 2

1b) Market Demand is served over a set of routes, $\underline{R}^m$

We allow the demand in a market to follow a set of paths in the network; i.e. D^{mc}_r is an output variable showing how demand class,c, in a market is served;

$$\sum_{r \varepsilon \underline{R}^m} D^{mc}_r \leqslant D^{mc} \quad \text{for all markets in all classes,c}$$

Note we do not insist that all market demand must be served. In certain cases we may not be able to supply sufficient vehicle capacity to the system and be forced to refuse potential demand from certain markets of classes.

2) Sufficient Capacity must be Supplied to each Segment

For each segment the maximum allowable average load factor, $\overline{LF}^{lc}_{max}$ for each demand class, must be determined so that peak loads will exceed capacity offered only on a small percentage of days;

$$\pi^{lc} \leqslant \overline{LF}^{lc}_{max} \cdot q^{lc} \quad \text{for all segments,l all classes,c.}$$

where D^{lc} is defined previously as average segment traffic of class c.

q^{lc} is defined previously as segment space capacity for class c.

3) Sufficient Station Capacity must exist for Vehicles and Demands

a) Vehicle Departures

For any station k, the number of vehicle departures, N_k, may be restricted by an upper limit NU_k.

$$N_k = \sum_{r \varepsilon \underline{R}^k} \sum_v n_{vr} \leqslant NU_k \quad \text{for any k}$$

At stations where there may be limits on daily operations due to ATC or gate capacities, the upper limit on aircraft operations may be applied. Also, constraints may be placed on maximum daily operations by vehicle type at the station.

b) Demand Departures

Although not usually needed for today's airline terminals, it is possible to include a limit on station loading operations for any demand class, DU^c_k;

$$D^c_k = \sum_{m \varepsilon \underline{M}_k} \sum_r D^{mc}_r \leqslant DU^c_k \quad \text{for any station k, any class c}$$

where $\underline{M}_k$ is the set of markets which use path r to originate or connect at station k.

4) Sufficient Flight Hours must be available from each Vehicle Fleet

Generally, the airline has a limited number of flying hours available for each type of aircraft. The assignment of an aircraft, type v to fly a route r will use U_{vr} available block hours of flight time. There is an upper limit to the hours of average daily utilization, U_v, for each fleet of vehicle types. Thus,

$$\sum_r U_{vr} \cdot n_{vr} \leqslant U_v \quad \text{for all aircraft types, v}$$

For longer term studies, additional fleet can be leased or purchased, and present vehicles can be sold at forecast used market prices. Financial constraints for the airline can be included over a series of future planning periods and the model is extended to become a corporate financial and operations planning model.

5) Specified Minimum Levels of Service

While economic criteria may indicate otherwise, there may be policy or political reasons to maintain a minimum level of service in certain markets or at certain stations.

a) Market Minimum Service

We may wish to specify a minimum daily frequency of service of s-stops in market, N^{ms};

$$n^{ms} \geqslant N^{ms} \quad \text{for any market in any number of stops,s}$$

Alternatively, we can specify a minimum daily frequency of S-stops or less, NS^m;

$$\sum_{s = o,S} n^{ms} \geqslant NS^m \quad \text{for any market m}$$

Both of these constraints can be written for a particular vehicle type if desired

b) Station Minimum Service

We may wish to specify a minimum daily frequency of station departures at stations of low demand generation. Thus, there may be a lower bound, NL_k, on station operations at such stations similar to the upper bound for busy stations specified in 3a).

$$N_k = \sum_{r \varepsilon \underline{R}_k} \sum_v n_{vr} \geqslant NL_k \quad \text{for any station k}$$

Again, there may be some desire to have a lower bound specified for any given type of vehicle.

AN APPLICATION TO AIRLINE REGULATORY POLICY ANALYSIS

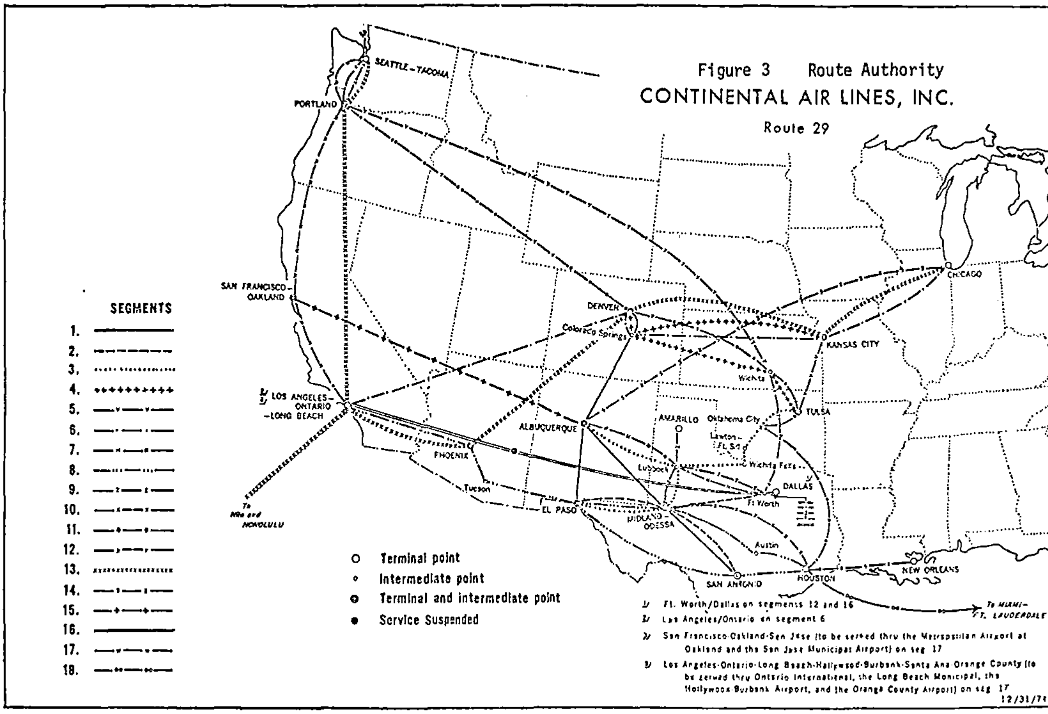
For the past few years, there has been some interest in relaxing the economic regulation of domestic air transportation in the U.S.A. Proponents of "regulatory reform" have argued that with freer entry to markets, airline competition (or the threat of competition) would move market prices to values which would increase the "economic efficiency" of the air transportation system. Opponents have countered that free competition would lead to abandonment of the less lucrative markets and an unstable destructive competition in price and service in the major markets. There have been several legislative proposals for new policies to govern the economic regulation as administered by the Civil Aeronautics board. Although these proposals are always accompanied by glowing descriptions of the benefits they will bring, it is difficult, perhaps impossible, to evaluate their impact in any credible fashion.

In this section we will describe an application of the network model FA-4 to examine in a general way to the issues of relaxed entry controls. It is a case study of Continental Airlines as it existed in the domestic air transportation system in 1974. We remove all restrictions from within its present route authority, and extend a small set of new segments to New York. We assume, unrealistically, that all other airlines remain passive at their 1974 patterns of service, and ask a series of questions – "If Continental Airlines had this expanded route authority, what would its new pattern of service look like? What markets and cities would it abandon? What new markets would it enter at the existing levels of competition? If we lowered prices in these new markets by 10% or 20% would Continental still enter them? Would Continental acquire new aircraft and expand its service?"

The general issue to be addressed with such network analysis is whether or not the potential exists for a radical restructuring of the current airline networks. Is has been claimed that the present structure of airline competitive services is more or less in equilibrium, and that under relaxed entry controls one can expect only minor changes by the management of each airline. As we shall see, our case study of Continental Airlines indicates that this not true.

Continental Airlines Case Study

Using data for the calendar year 1974, we have esta-



blished a network model of Continental Airlines, a medium sized trunk airline which serves cities in the southwest area of U.S.A. A list of cities served by Continental and their three letter airline code are given in Table II.

However, Continental is not free to supply service between any pair of these cities. Its route authority consists of 18 routes added to their original authority at various times in the past thirty years. Figure 4 shows a map taken from CAB documents which gives some indication of its pattern of service. A full reading of the route authority is required to understand the various restrictions specified. Continental has been aggressive in seeking new route authority and willing to accept restrictions as a strategy in overcoming objections from other airlines. At a later date, it can try to remove the restrictions placed on an original award.

For example, it has a route authority, segment 13 which goes from Hawaii to Los Angeles, then splits to go on to Portland/Seattle and across the continent to Phoenix, Denver, Kansas City, and Chicago. Normally such an authority would allow non-stop service between any of the listed cities. But in this case, the award was part of an expansion of service of Hawaii and segment 13 restricts Continental to carrying only Hawaiian passengers, i.e. it is a "closed door" restriction to passengers in other markets. As a result Continental does not fly at present between Phoenix and Denver, Kansas City, or Chicago or between Seattle and Phoenix, Chicago, or Kansas City. We assume that such restrictions on service between cities already on the Continental system would be removed.

The demand data is taken from the CAB Airline O & D data for the year June 1973 - June 1974. This data provides information on the traffic flow on a given airline under the pattern of services offered. We obtain the annual average passengers per day for each carrier in a city pair market less any interline traffic data. (For markets where this interline data is significant, we may include it). We know the frequency of services by each carrier and by Continental, and using a simple "market-share equals frequency share" model we construct a traffic-frequency curve for present and prospective markets.

The aircraft operating costs and other data are given in Table 1 for the Continental Fleet as it existed in June, 1974. Aircraft variable operating costs are expressed in terms of segment distance. The assumed average yield, sales costs, passenger service costs, and traffic servicing costs are given in Table 2. This results in a net revenue value for a passenger in each market. The data supporting these tables is taken from CAB reports for Continental Airlines in the calendar year 1974.

With these data assembled, the first run was a "base case" run to establish that the model reproduced the pattern of service offered by Continental under the 1974 route authority, i.e. we should see the same aircraft flying the same routings and frequencies, the same market shares, revenues and operating costs.

Initial base case runs indicated that traffic on Continental's Hawaiian routes was too low and the model selected the smaller B720B over the DC-10 aircraft even though its costs per seat were much higher. In view of Continental's recent acquisition of these DC-10 aircraft and the use of similar widebody aircraft by competitors in these markets, we prevented the use of B720-B aircraft on these routes. The base case then used DC-10 aircraft at a frequency of service below the actual Continental service for 1974. The B720-B aircraft remained ineligible for Hawaii service in all subsequent study cases.

A comparison of actual and base case system values is given in Table 3. A detailed comparison of the nonstop and multistop service frequencies for all markets of the 1974 Continental system can be made using Table 7 (Compare actual service NS/MS with Case 1, base case).

It is necessary to select a strategy for expansion of the route authority which management might follow under a scenario of liberalized entry controls. Here we shall show only one such strategy which is based upon adding New York city to the system. It is called the JFK Case study, although due to lack of airport gates at JFK the service might be based at Newark airport which is currently underutilized. From New York there are 12 new segments added to cities already served by Continental. These are listed in Table 4 along with an associated set of 45 new possible multistop routings for aircraft as service is continued within the Continental system. There are 17 new markets from New York associated with these 12 segments (See Table 8).

As well, the elimination of the present restrictions on Continental route authority will add 34 new markets which are also contained in the set of 45 JFK routings. No new routings besides those JFK routings were selected, although this would be possible when the restrictions are eliminated. So a total of 51 new markets accompanies the 12 new segments and 45 new routings. This is a small subset of the strategies which the management of Continental might persue.

Given this expanded route authority, a series of computer cases were run under varying assumptions. Case 1 is the base case representing the 1974 actual patterns of service by Continental. Case 2 introduces this new route authority at normal market prices using the 1974 aircraft fleet. Case 3 presumes that in the new markets added, Continental would have to match price reductions of 10% by incumbent carriers. Prices in other markets remained at normal levels. Case 4 further presumes that Continental could purchase or lease additional DC-10, DC-9, and B-727-200 aircraft whose operating costs now include their ownership costs. Case 5 then extends the price reductions to 20% in the new markets with the assumption that the fleet could be expanded.

Results from the New York Case Studies

The impact of expanding the Continental network to New York with the normal fleet and prices is indicated by the results of Case 2. In general terms, the short haul mid-continent services in Texas and New Mexico are abandoned and the fleet is used in highly competitive long haul markets, predominantly from New York. Notice that the short haul services are profitable in the base case, and that the restricted fleet availability causes them to be abandoned when more profitable markets and routes are possible. Most of these markets will return when more aircraft can be obtained in later cases.

The service along the new routings out of JFK (New York) for Case 2 are shown in Table 5. The segment New York-Chicage is flown 10 times per day with a variety of routings to points like Los Angeles, Kansas City, Denver, New Orleans, and Seattle. Notice that New York-Chicago as a non-stop routing is not flown. The DC-10 and B-727-200 aircraft are both used on these routes. The next segment is New York-Denver which is flown 4 times per day, followed by New York to Dallas twice per day, continuing to Houston and San Francisco. Then, we see that the model places Continental strongly into the transcontinental markets New York to Los Angeles, and San Francisco with non-stop flights per day each. These probably would be other new competitors entering these two markets which would reduce its attractiveness. We have assumed that all other carriers remain passive while Continental restructures its system.

Table 6 shows the service levels in all 17 new markets from New York. Notice that the model places Continental strongly into the New York-Miami market with 10 flights per day. Again, it is unrealistic to assume that only Continental decides to enter this market.

A summary of new markets entered is given in Table 7. Of the 51 new markets available under this expanded route authority, only 20 are entered in Case 2. Of these, only one is presently a monopoly, single carrier market. Most of them (12) are presently two carrier markets, while six are three carrier markets, and one is a four carrier market. The larger markets already have competitive service while any monopoly market is probably very small.

Table 7 also categorizes the pattern of markets abandoned. Of the 119 markets on the Continental system, 32 are monopoly markets, and 19 of these are abandoned in Case 2. In fact, Case 2 abandons service in 76, or 64% of Continental's present markets. Interestingly, the percentage abandoned is lowest for the three competitor markets where only one out of four is abandoned.

The top ten monopoly markets of Continental are examined in Table 8. In seven of these, service is abandoned. One receives reduced service while in the last two, service is actually improved. Finally, out of the pattern of market abandonment, several cities are completely abandoned as listed in Table 9.

In Table 10, we see the summary of system results. For Case 2, revenues increase from 418,000 \$/day to 503,000 \$/day, and the contribution to overhead increases from 129,000 \$/day to 182,000 \$/day. Notice that passengers boarded actually decreases by 10% while revenue passenger miles increases from 14 million to 17.5 million per day. The average passenger trip length has increased from 1033 miles to 1475 miles, and the average aircraft stage length from 735 to 1329 miles. There is a switch to longer haul markets, and longer stage length service pattern.

In Case 3 we assume that there is price competition which reduces the level of prices by 10% in the new markets. This decreases their attractiveness to the model which is seeking a profit optimal pattern of service. We can see the reduction of service in the new markets and routes by comparing Case 3 with Case 2 in most of the Tables 5-11. For example, the New York-Chicago and beyond routes we halved to a level of 5 flights per day; New York-Los Angelos is reduced from 7 to 2 flights/day; New York-Miami is reduced from 10 to 3 flights per day.

Similarly, service in existing markets is restored in Case 3. From Table 10 there was service is only 35% of the existing markets in Case 2, but in Case 3, service is offered in 62% of them. For example, services from Denver to Albuquerque, Colorado Springs, and Houston, and from Houston to Midland/Odessa, Miami, Oklahoma City and Tulsa are resumed. Remember once again that prices in these markets remain at their normal levels since we assume no competitive entry by other airlines.

From Table 10, we see that system revenues and contribution to overhead are reduced in Case 3. Passengers per day and their average length of haul remain constant but aircraft stage lengths decrease as the older shorter haul markets are re-entered. The increases in system revenues and contribution to overhead are only half the increases of Case 2 over Case 1.

From the results of Cases 2 and 3, it was obvious that the limited fleet available was a major constraint on the amount of service offered by the system. Cases 4 and 5 remove this constraint with the general result that the system triples in size in Case 4, and still doubles in size in Case 5 where fares are further reduced 20% in the new markets. In these cases, most of the existing markets are served (92%), plus a major entry is made into the new and newly unrestricted markets made available to the system by this case study.

In Case 4, the system acquires 29 DC-10 and 57 B-727-200 aircraft. All 15 of the available B-720B aircraft are placed in service even though they are relatively expensive. System revenues, revenue passenger miles, and passengers almost triple. Contribution to overhead more than doubles, but, ofcourse, we cannot expect overhead costs to remain constant with such large charge. Now all of the new segments are strongly entered as gateways into the existing Continental system.

The reduction of fares in new markets moderates this system expansion in Case 5. Only 16 new DC-10 and 53 new B727-200 aircraft are acquired, and the B720B fleet is grounded. Now system revenues, and contribution are only doubled, but passengers and revenue passenger miles are still tripled. Passenger trip length increases further to an average of 1592 miles.

These last two cases give some indication of the potential for competitive entry which exists in the present airline network. Here we have held the other airlines constant, and allowed Continental to acquire aircraft and enter a set of new markets along a few gateway segments from New York. In a sense we might say that Continental puts all the additional service into these markets that the other airlines plus Continental would provide in a more realistic scenario. Normally, market share results depend upon the number of competitors as well as their frequencies of service. Twc new competitors offering 5 flights/day each against two old competitors with 5 flights/day each will obtain equal shares in the market for everyone with a tendency for head to head, simultaneous departures of four aircraft. If there is only one new competitor with 10 fights/day, he will obtain more than 50% of the markets and will be scheduling an extra five departure times throughout the day. This "S-shaped" market share curve has not been used in this case study. Continental's markets shares would have been higher and more profitable if it had been used. As a result, the market expansion gives an indication more representative of equal share, industry entry.

Table 1 – Aircraft Operating Data – Continental Airlines, 1974

Aircraft	*Number*	*Utilization hrs/day*	*Seats*	*Operating Cost $/hour*	*$/mile*
DC10	11	10.2	200	1194	118 + 2.27d
7275	30	9.7	124	728	576 + 1.44d
720B	15	9.5	106	959	738 + 1.83d
DC9S	7	6.0	71	595	384 + 1.25d

Source – Aircraft Operating Cost and Performance, CAB (Redbook), 1974

Table 2 – Passenger Yield and Ground Operating Costs – Continental Airlines, 1974

1. Revenue Yield
   For 1974, yield = $13.60 + .056d
   where d = market distance
2. Promotion and Sales Costs
   Assume 12% of revenues from above yield
3. Passenger Service
   Assume 2 $/boarding + .005d
4. Traffic Servicing
   Assume 2 $/boarding + (100 $/departure + 1.5 $/1000lb. GW) The last two erms are added to aircraft costs.

From above, Y^m = ompetitors. (13.6 + .056d) x 0.88
= 11.97 + .49d
C^m = 4 + .005d
$Y^m - c^m$ = 7.97 + .044d

Source – CAB Form 41

Table 3 – Base Case Comparison with Actual Continental System

	Continental Actual 1974	*Base Case*
[1]Passengers Carried (000)	5,053	4,849
Revenue Passenger Miles (10)	5,645	5,008
[2]Revenues $ (000)	348,790	346,878
[3]Operating Expenses $ (000)	297,951	272,781
Flying Operations	152,320	131,405
Passenger Service	44,760	34,736
Aircraft & Traffic Servicing	59,358	65,015
Promotion & Sales	41,513	41,625
Total Variable	297,951	272,781
Depreciation (Flight Equipment)	34,799	27,126
General & Administration	22,686	21,822 (estimate)
Total Fix	57,485	48,948
Interest Expense	27,356	?
Average Stage Length (miles)	551	735
Average Passenger Trip Length (miles)	869	1,033

[1] On line Origin-Destination Passengers.
[2] Schedule Passenger Revenues Only.
[3] Depreciation Expenses and General & Administration Expenses omitted.
[4] 8% of all costs except depreciation.

Table 4 – New Aircraft Routes – JFK Case Study

1. JFK-ORD
   continuing to DEN, MCI, DFW, LAX, MSY, SEA, SFO
   continuing to LAX-HNL, PHX-LAX, MCI-DEN, IAH-SAT, PHX-SFO
2. JFK-MCI
   continuing to DFW, LAX, PHX
   continuing to DEN-SEA
3. JFK-DFW
   continuing to IAH, LAX, SAT, SFO
   continuing to LAX-HNL, TUS-PHX
4. JFK-TUL
   continuing to OKD-DFW, OKC- LAX
5. JFK-MSY
   continuing to IAH, IAH-SAT
6. JFK-DEN
   continuing to LAX, PHX, SFO
7. JFK-PDX
   continuing to SEA
8. JFK-SFO
   continuing to LAX, SEA, HNL
9. JFK-LAX
   continuing to LAX, SEA, HNL
9. JFK-LAX
   continuing to HNL
10. JFK-MIA
11. JFK-IAH
12. JFK-SEA

Table 5 – Continental Daily Frequency by Aircraft Routing – JFK Case Study

JFK ROUTES	*TOTAL DAILY FREQENCY* Cases *1*	*2*	*3*	*4*	*5*
A) *ORD Gateway Routes*					
1. JFK-ORD	0	0	0	0	4
2. JFK-ORD-DEN	0	1	0	0	0
3. JFK-ORD-MCI	0	0	0	0	0
4. JFK-ORD-MCI-DEN	0	1	0	0	0
5. JFK-ORD-DFW	0	1	0	1	1
6. JFK-ORD-LAX	0	4	4	7	8
7. JFK-ORD-PHX-LAX	0	0	0	3	2
8. JFK-ORD-LAX-HNL	0	0	0	0	0
9. JFK-ORD-MSY	0	1	0	1	0
10. JFK-ORD-SFO	0	0	0	0	0
11. JFK-ORD-PHX-SFO	0	0	0	1	0
12. JFK-ORD-IAH-SAT	0	0	0	2	0
13. JFK-ORD-SEA	0	2	1	5	5
Total	0	10	5	20	20
b) *DEN Gateway Routes*					
1. JFK-DEN	0	3	4	1	2
2. JFK-DEN-PHX	0	0	0	2	0
3. JFK-DEN-SFO	0	1	0	6	10
4. JFK-DEN-LAX	0	0	0	1	2
Total	0	4	4	10	14
c) *DFW Gateway Routes*					
1. JFK-DFW	0	0	0	0	0
2. JFK-DFW-IAH	0	1	1	1	1
3. JFK-DFW-LAX	0	0	0	4	0
4. JFK-DFW-SAT	0	0	0	0	0
5. JFK-DFW-SFO	0	1	0	3	3
6. JFK-DFW-LAX-HNL	0	0	0	0	0
7. JFK-DFW-TUS-PHX	0	0	0	0	0
Total	0	2	1	8	4
d) *LAX Gateway Routes*					
1. JFK-LAX	0	7	1	0	0
2. JFK-LAX-HNL	0	0	1	6	8
Total	0	7	2	6	8

JFK ROUTES	*TOTAL DAILY FREQUENCY* Cases *1*	*2*	*3*	*4*	*5*
e) *SFO Gateway Routes*					
1. JFK-SFO	0	7	5	0	0
2. JFK-SFO-HNL	0	0	0	9	0
3. JFK-SFO-SFA	0	0	0	0	0
4. JFK-SFO-LAX	0	0	0	0	0
Total	0	7	5	9	0
f) *MSY Gateway Routes*					
1. JFK-MSY	0	1	0	9	1
2. JFK-MSY-IAH	0	0	1	2	0
3. JFK-MSY-IAH-SAI	0	0	0	1	1
Total	0	1	1	12	2

Table 6 – Competition and Level of Service in New JFK City-Pair Markets

City	*Pairs*	*Competitive Service* *No. of Carriers*	*NS/MS*	*Continental Service* *Case 2*	*Case 3*	*Case 4*	*Case 5*
JFK	DEN	2; UA, TW	6/3	4/1	4/0	5/1	13/1
JFK	DFW	2; AA, BN	14/4	2/2	1/0	8/1	5/1
JFK	HNL	2; UA, AA	1/1	0/2	0/1	0/15	0/8
JFK	IAH	3; DL, EA, BN	7/10	0/2	0/2	1/6	0/2
JFK	LAX	3; AA, TW, UA	13/8	8/5	2/4	6/15	8/10
JFK	MCI	2; TW, UA	2/5	1/1	0/0	7/0	8/0
JFK	MIA	3; EA, NA, DL	30/6	10/0	3/0	10/0	10/0
JFK	MSY	2; DL, EA	6/6	1/1	0/0	4/1	1/0
JFK	OKC	3; TW, AA, Bn	1/4	0/0	0/0	0/1	0/0
JFK	ORD	3; AA, UA, TW	49/15	10/0	4/0	20/0	20/0
JFK	PDX	2; UA, NW	0/4	0/0	0/0	1/0	0/0
JFK	PHX	2; AA, TW	3/5	1/1	0/0	0/8	0/5
JFK	SAT	3; BN, EA, AA	0/10	0/0	0/0	0/3	0/1
JFK	SEA	2; UA, NW	3/2	1/2	0/1	0/6	0/6
JFK	SFO	3; AA, TW, UA	9/14	7/1	5/0	8/9	0/13
JFK	TUL	3; AA, TW, BN	1/5	0/0	0/0	1/0	0/0
JFK	TUS	2; AA, TW 0/8	0/0	0/0	0/0	0/0	0/0

Table 7 – Entry and Exit in Continental's Markets

Entry – New Markets Entered in JFK Case Study

CASE	*1*	*2*	*4*	*5*
One-Competitor Market	1	0	1	0
Two-Competitor Market	12	7	23	15
Three-Competitor Market	6	5	9	8
Four-Competitor Market	1	0	2	0
Total New Markets	20	12	35	23

Exit – Abandonment of Continental's Existing Markets, JFK Case 2

Continental Markets

	%	*Number*	*Abandoned Case*	*%*
Monopoly Markets	27%	32	19	60%
1 Competitor Market	52%	62	42	68%
2 Competitor Market	18%	21	14	67%
3 Competitor Market	3%	4	1	33%
Total	100%	119	76	64%

Table 9 – Cities Abandoned in JFK Case Study – Flights/Day

		Case 2	*3*	*4*	*5*
AMA	Amarillo	0	0	0	0
LBB	Lubbock	0	0	3	3
MAF	Midland-Odessa	0	2	4	2
OKC	Oklahoma City	0	1	6	6
TUL	Tulsa	0	1	3	2
SJC	San Jose, Calif.	0	3	4	3
ICT	Wichita	0	1	2	3
LAW	Lawton-Fort Sill	0	0	0	0
SPS	Wichita Falls	0	0	0	0
AUS	Austin	1	0	1	1

Table 8 – Top Ten Monopoly Markets of Continental in Terms of Passengers, 1974

Market		*Case 2 Service*	*Daily On-line O-D Passengers*	*Distance in Miles*	*Carrier Share (%)*
Denver	Wichita	*	310	428	1.00
Colorado Springs	Chicago	+	228	918	0.99
Denver	Tulsa	*	214	549	0.96
Seattle	San Jose	*	198	695	1.00
Portland	San Jose	*	170	566	1.00
El Paso	Houston	*	142	673	1.00
Colorado Springs	Los Angeles	+	118	822	1.00
Houston	Phoenix	*	110	1015	1.00
Burbank	Portland	*	90	818	1.00
Burbank	Seattle	–	84	941	1.00

* Abandoned in *JFK Case 2 Study*
– Reduced Service "
\+ Improved Service "

Table 10 – System Results, New York Case Studies

	Case 1 BASE	*Case 2* (1)+NEW MARKETS	*Case 3* (2)+NEW MARKET FARES x0.9	*Case 4* (3)+ EXPANDED FLEET	*Case 5* (4)+NEW MARKET FARES x0.8
FLEET SIZE					
DC-10	10	11	11	11 + 29	11 + 16
B727	30	30	30	30 + 57	30 + 53
B720B	0	7	7	15	1
DC-9	7	7	7	7	7
System Rev/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
Pax/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
Avg. a/c stage (miles)	735	1,329	1,196	1,029	1,041
Avg. pax trip length	1,033	1,475	1,493	1,583	1,592
No. of markets abandoned	—	76	45	23	22
% of original markets served	100%	35%	62%	92%	92%
No. of new markets entry	—	35	26	49	38

Table 11 – Code Names for Stations on Continental Airlines Route Map, 1974

Code	*Station*
ABQ	ALBUQUERQUE, N. MEX.
AMA	AMARILLO, TEX.
AUS	AUSTIN, TEX.
BUR	BURBANK, CALIF.
CAS	COLORADO SPRINGS, COLO.
DEN	DENVER, COLO.
DFW	DALLAS-FORT WORTH, TEX.
ELP	EL PASO, TEX.
HNL	HONOLULU, HAWAII
IAH	HOUSTON, TEX.
ICT	WICHITA, KANS.
ITO	HILO, HAWAII
JFK[1]	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.
SFO	SAN FRANCISCO, CALIF.
SJC	SAN JOSE, CALIF.
SPS	WICHITA FALLS, TEX.
TUL	TULSA, OKLA
TUS	TUCSON, ARIZ.

[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.

CONCLUSIONS

1. There are three levels of economic analysis of transportation systems - a system level, a market level, and a network level. If the transportation firm is supplying services over a network of markets, it is essential to work at the network level in studying its behavior. We can construct and apply computer models for the transportation firm, (at least for airline systems) which should be useful to the planner or policymaker on certain issues.

2. At the network level;

a) we cannot determine the quantity of seats (space) being supplied to a market imbedded in a network of services.

b) average variable cost per seat cannot be found for a market imbedded in a network.

c) marginal costs per seat cannot be found for a route, segment, or market in a network.

d) we cannot determine the contribution or profit for a route, segment, or market in a transportation system which operates on a network.

3. Extending the analysis of a firm to the analysis of the industry may not be possible. Is is not clear that there is any network equilibria when the networks for individual firms only partially overlap. As a result, we may not be able to study the economic behavior of competitive firms, even for a given segment of the network.

4. A potential for a major restructuring of the existing airline networks exists under conditions of free entry.

5. Adding a major new city to an airline system introduces profitable new service opportunities even in the face of existing competitors and lowered fares. Linking one new segment into an airline network may bring several new markets.

6. Due to limited resources in the form of aircraft and crews, an individual airline system will drop existing profitable markets, routes, and cities in order to enter more profitable ones even though they face competition in the form of multiple competitors, high frequency of service, and lowered prices.

7. In the longer term, there are indications that individual airline systems will find it profitable to acquire more aircraft of smaller capacity which allow them to expand their route system such that they enter major markets as additional competitors. If this produces a viable economic equilibrium, the increased use of smaller aircraft means higher operating costs, increased fuel consumption, and increased noise impact on the communities around airports.

FOOTNOTE

1. The Domestic Route System – Analysis and Policy Recommendations, A Staff Study by the Bureau of Operating Rights, Civil Aeronautics Board, U.S.A. October 1974, (see Tables 5, 6, 7 based on 1972 data).