Network Study of Subsidized Air Service

W.M. Swan*
Massachusetts Institute of Technology, Cambridge, Mass.

A fleet assignment model that uses linear programing to maximize the cash income of an airline system is used to study the alternatives in providing air services in low-density markets. Issues examined are cost of using larger aircraft vs small turboprops, cost advantages of including the services in a larger network vs serving them independently, and fuel costs in low-density vs high-density markets.

Background

THE regional air carriers in the United States were certificated to supply air service to low-density traffic points. Since this service is operated at a loss, the Civil Aeronautics Board (CAB) provides a subsidy. In the past five years, commuter air carriers have offered unsubsidized services in similar low-density markets using small turboprop aircraft such as the DeHavilland Twin Otter and the Beech 99. The question is, how much can be done using commuter airlines or small turboprop aircraft to reduce the cost of providing low-density services?

The question cannot be answered by noting a series of city pairs that need to be served and calculating the difference in operating costs for one aircraft or operator and another. As we shall try to show, the cost of serving these markets depends on how they fit into a network of transportation services. There are places where services can be provided by adding a stop to existing (profitable) flights, and there are other places where combining two or three services on one flight minimizes losses by building a satisfactory onboard load for the last legs of the trip. On the other side, elimination of a service terminates all of the revenues from passengers originating at that point, no matter what their destination.

The Flight Transportation Laboratory at Massachusetts Institute of Technology has a fleet assignment model that simulates airlines' planning of flight itineraries and aircraft to take advantage of these network effects. The model has an extraordinary feature useful for short-haul and low-density work: the demand in any market can rise and fall with the level of service expressed in terms of frequency, number of stops, and aircraft type. This fleet assignment model can simulate the planning of a regional carrier under various operating policies. The financial results and level of service provide a basis for assessing policy options.

Role of Fleet Assignment Activities

Figure 1 illustrates the place of fleet assignment activities in industry planning. A fleet assignment is merely an allocation of aircraft types to routes, and passengers to the resulting flights. Ideally, the widest possible combinations of routes and aircraft are considered, and only the best set of interlocking activities is chosen. A large number of combinations of frequency, vehicle, and route are possible.

A long-range fleet assignment will be made for a period 5-10 yr in the future. Although routes and frequencies are available, the relevant output is the fleet plan, i.e., the time history of aircraft acquisitions and sales. Aircraft manufacturers typically automate a heuristic solution to the fleet assignment problem in order to run fleet planning studies for their customers.

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*Research Engineer, Flight Transportation Laboratory.

For policy studies, we reproduce this long-range fleet planning activity using the linear programing fleet assignment model. The linear programing formulation assures an optimal solution over a broad range of operating conditions. For policy studies, it is not critical that the solution be optimal, but it is of great value that the degree of optimality be the same whether the solution is near the existing conditions or represents a great departure from the familiar patterns of fleet and routing. Ideally, multiple fleet assignments for consecutive years and seasonal variations should be run. However, in this exploratory research this was not done; only a single fleet assignment was made for each case.

The long-range fleet assignment eventually becomes the basis for the allocation of the available aircraft fleet to routes. This process, usually done manually with considerable skill, produces a list of aircraft flights over the airline network. This initial fleet assignment then must be scheduled into a timetable for passengers, planes, and crews. For policy studies, the latter steps are unnecesssary.

Fleet Assignment Model

In theory, the objective of any U.S. carrier is to maximize profits subject to the rules of operation. In the linear programing formulation used in the fleet assignment model, this purpose translates into an objective function that is the excess of total revenues over expenses. Any number of rules are added as contraints. Regulations establish some of the contraints: cities have to be served a minimum number of times a day, and fares are established by the CAB. The marketplace creates a list of practical constraints: a maximum average load factor must be set for each link in the network. Passengers carried cannot exceed the demand that the level of service "inspires." Onboard loads must be built by combining travelers on nonstop, one-stop, and two-stop services. In some cases, the fleet of available aircraft is limited. Further constraints can be added, such as a limited fuel availability or maximum landing slots at an airport.

Within these constraints, the fleet assignment model builds a network of aircraft service (flights in the airline guide) and predicts the passenger flows. In the end the useful flights, the appropriate aircraft, and the daily frequency are selected over the whole system so that no change or combination of changes could improve the net contribution to fixed overheads and profits. This reproduces the effort of an airline planning its fleet for some future year. Operating costs, passengers carried, revenues, and so on can be totaled to give the overall results as shown in Fig. 2.

Input Data

The first input to the model is the available aircraft types. For the regional carriers, small jets such as the DC-9 or the Boeing 737 are available. In addition, a 40-seat turboprop such as the FH-227 or Convair 580 is used for low-density work. In some of the policy studies below, a smaller turboprop was added to the available fleet. Operating cost,

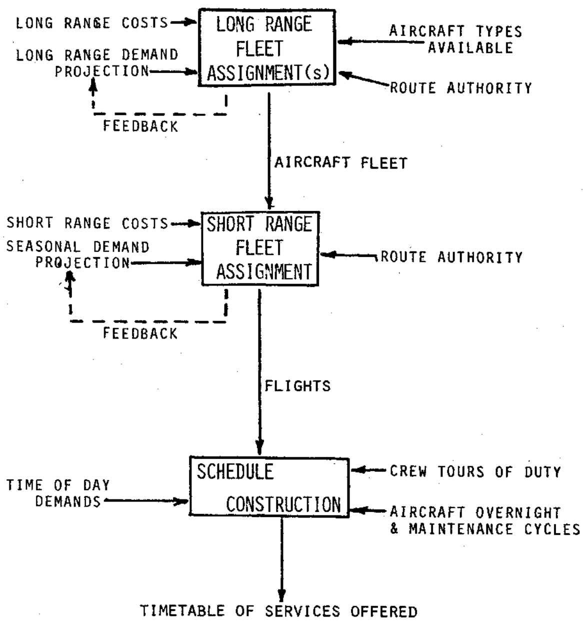

Fig. 1 The place of fleet assignment activities.

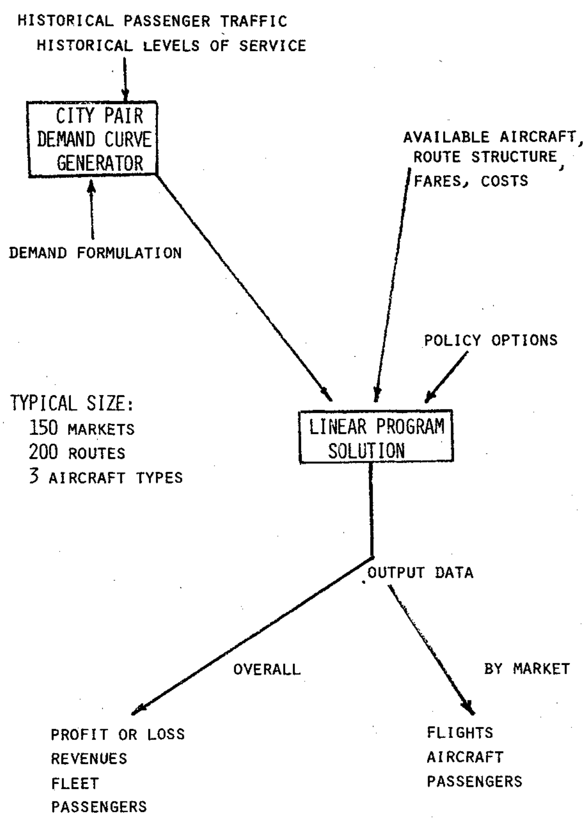

Fig. 2 The use of a fleet assignment model.

seating capacity, range, and passenger appeal were needed for each aircraft. Passenger appeal is used to adjust the level of service. Typically a turboprop was considered only 90% as effective as a jet in attracting passengers. CAB data was used for the operating costs, with two adjustments: 1) depreciation was replaced by a "rent" that approximated the dry lease cost of the particular aircraft type; and 2) the CAB did not have the data for small turboprop aircraft. Airline operating costs for these aircraft were calculated by finding the fraction of the operating costs of the 40-passenger turboprop according to the Air Transport Association Formula (ATA-67†) and

†This is an empirically derived formula for predicting the relative direct operating costs of commercial aircraft.

Table 1 Long-run marginal costs for 1971 regional airlines[a]

Indirect operating cost (IOC)
$2.75/passenger boarding
$0.0006/passenger mile
$20.00/aircraft departure
$0.30/aircraft mile

[a]Yield was 89% of the tourist fare; landing fees were $0.18/1000 lb gross weight.

multiplying this fraction times the reported operating costs for the 40-seat aircraft. The result fell between the costs experienced by commuter airlines and reported regional experience in small experimental operations.

Other costs were associated with activities such as aircraft departures, seat miles, and passenger boardings. The numbers used were estimates of long-run marginal indirect operating costs (see Table 1). They were in line with regional airline experience. Fares were derived from the Official Airline Guide (OAG). An average yield for the airline was applied to dilute these fares to represent the per passenger revenues. A list of route options was created, starting with flights already flown and adding other fruitful possibilities for combining or simplifying services. The airline's route authorities were not exceeded.

The last, most important, and most difficult input was the curve that plotted demand in each city pair market against frequency of service in that market. Historical on-line‡ origin-destination data exists, and the corresponding level of service was available from old OAG's. A demand model that is well behaved and that can be explained in terms of perceived travel time was used to develop a curve from the preceding information. The formula was

$$\text{demand} \sim 1/(\text{travel time} + \text{average wait})^{1.3}$$

The average wait was half the average headway. This relationship is illustrated in Fig. 3. In this figure, frequency of service is used, although the term "level of service" is emphasized above. In practice, a simple conversion was made. For instance, a one-stop service in a noncompetitive low-density market would have an equivalent nonstop frequency of service of 0.85. The actual values for conversion varied from market to market, depending on the range, competitive conditions, and existing service levels.

Outputs from the Fleet Assignment Model

If the constraints specify the minimum levels of service, and if maximum profits or minimum loss has been achieved by the linear programing solution process, then only three outputs are essential for policy purposes: net profits or losses, aircraft used, and passengers carried. The details of frequencies, onboard loads, and flights offered are available, as they would be from an airline's fleet planning exercise. If the fleet plan were followed, the airline eventually would convert this information into a schedule. For policy issues, it in necessary only to be assured that a reasonable schedule is feasible. With a few exceptions, such a schedule is possible.

Results of Case Studies

Four of the eight regional carriers were modeled as just described. The four were Frontier, Hughes Air West, Ozark, and Southern. Information for the year 1971 was used for the studies. The actual passengers, revenues, and fleet were predicted by the model using the regulatory and fleet constraints of the time. Differences occured for three reasons: 1) failure of the model to take into account idiosyncracies of

‡On-line data includes in the regional airline's demand passengers who connect to other airlines. As much of 90% of the traffic is connecting, but only the local part of the trip appears in the regionals' revenues or costs.

particular markets; 2) failure of the airline to take advantage of routes or combinations of routes which were to its benefit; and 3) the inevitable errors in the large quantity of input data. Errors were corrected as found.

Subsidy losses and the number of subsidized points were predicted correctly. In general, a small increase in frequency of service improved the airline's operations. This meant a slight increase in the desire for 40-passenger turboprops over the larger jets.

Comparison Study 1: Cost of Subsidized Service

To show how a fleet assignment model is used in policy studies, the first case predicts the cost of subsidized air service for the four carriers studied. Two fleet assignments were made, one with and one without constraints on the minimum levels of service. In the first case, all points on the airline's route authority must be served by at least four departures a day, unless a smaller number of departures already is permitted by the CAB. Although the regulations require that points be served along specified routes, in practice connections to any useful destination are allowed for subsidized points. In the second fleet assignment, all minimum service constraints were removed, and no services need be offered at a loss. The total contribution to fixed overheads and to profits for the four airlines was $65.8 million in the case of forced minimum services. Profits and contribution totaled $94.3 million in the unconstrained case. The difference, $28.5 million, is an estimate of the marginal cost of providing the subsidized services. This compares with $30.4 million received by the carriers for the year in question, a suprisingly good agreement.

Comparison Study 2: Network Economies

The preceding comparison predicted the marginal cost of providing subsidized air service. This is not what it would cost to provide the same levels of service without intergrating profitable and unprofitable flights into a common network. To illustrate this, a short study was run using Ozark Airlines as a case in point. All of the markets voluntarily (profitably) served in the preceding study were removed from the system. The remaining low-density markets were required to be served at the usual minimum levels of service, as before. The resulting losses were 50% higher than in the case where service could be integrated into the profitable network. Network influences are undeniably important.

Comparison Study 3: Economies of Market Density

Economists claim with some justice that there are little or no economies of scale in the air transportation business. By this they mean that airlines serving large geographical networks are not cheaper or more profitable than their smaller compatriots. Unfortunately, the term "economies of scale" also may refer to the savings from producing more output in the same place (as in a large factory) rather than in separate places (as in two small factories). To prevent confusion between the statements of economists and the second concept, we shall refer to the savings of operating airlines in larger markets as the economies of market density. The question is, do they exist? Are there any economies of market density in the air transportation business? According to Table 2, the answer is yes.

Table 2 Economies of market density

	A	B
Year	1971	1976
Demand	100	120
Revenue passenger miles	100	143
Contribution to overhead	100	156
40-seat aircraft-hr	100	88
75-seat aircraft-hr	24	45

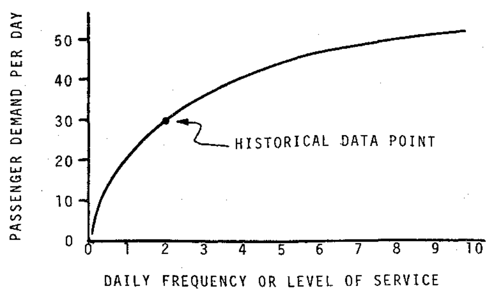

Fig. 3 Typical city pair demand curve.

In case B of Table 2 the same airline, in this case Ozark again, was run using projected 1976 demands. No changes were made in costs, fares, or route authority. Only the demand curves changed; they changed by a 20% increase in available demand. The results were clear. While expanding to carry 20% more traffic, Ozark increased the level of service so much that a further 20% increase in air travel occured. The improved service came from higher frequencies, more direct flights, and slightly reduced use of the turboprop aircraft. By being able to use a higher percentage of larger aircraft, profits rose even more than revenues. Apparently, significant economies of market density may exist, at least in the low-to-medium-density air transportation markets.

As an aside, an interesting point showed up in this study. The use of smaller aircraft only slightly changed with the large growth of airline size. Is this a hint that in a mature transportation network the need for smaller vehicle sizes is relatively constant with growth in total travel? The question may bear exploring.

Comparison Study 4: Use of Small Turboprop Aircraft

It has been suggested that regional carriers use equipment ill-suited to the services they perform. Smaller aircraft could serve the low-density points at lower total cost. The counter argument claims that larger aircraft can be used efficiently to build loads by multistop flights. There is truth in both of these statements. Take, for instance, the two out of four airlines with fewer isolated points to serve: Ozark and Southern. Together they serve 32 subsidized points out of a total of 101 cities. The subsidy determined in study 1 was $5.6 million per year. A new fleet assignment was made assuming that a 19-seat turboprop was included in the fleet of available aircraft.

Table 3 Turboprop aircraft cost comparison

Number of seats	40	19
DOC with depreciation as in text, $	189	129
Passenger appeal factor	0.95	0.85
Handling cost per departure, $	20	10
IOC per aircraft mile,$	0.3	0.1
Landing fee, $	7.80	2.50
Range limitation, miles	600	200
Field length, ft	4000	3000

Table 4 Commuter cost structure

1971 long-run marginal costs
Indirect operating costs:
$1.50/passenger boarding
$5.00/aircraft departure
Yields, fares, and landing fees as before
Direct operating cost for 19-seat aircraft: $125/hr

Table 5 Fuel use in simulated 1971 operations

	Gal. of fuel	Passenger miles	Passenger miles/gal
Normal operations of four regional carriers	304×10^6	4.51×10^9	15
Operations without service to subsidized points	260×10^6	4.23×10^9	16
Difference of above: net subsidized operations	44×10^6	0.28×10^9	6.4
Commuter replacement at subsidized points	18×10^6	0.25×10^9	13.6

Table 3 compares the costs with the 40-seat turboprop in use in 1971. This smaller aircraft would save only $0.2 million of the subsidy, and it would serve 120,000 less passengers per year. Furthermore, the fleet is too small and the services too disjointed to be within the range of the cost assumptions. On the other hand, Hughes Air West and Frontier operate a less dense network of services. Subsidy totals $22.8 million for service to 98 out of 161 points on their systems. By using a smaller aircraft and readjusting the routings to take advantage of the new vehicle, the same services could be flown for only $11.1 million. A total of 65 of these vehicles would be used. Small turboprop aircraft are the answer some of the time.

Comparison Study 5: Commuter Replacement

Another possibility for altering subsidized service is to allow regional carriers to withdraw from subsidized markets, and arrange for the commuter carriers to replace them. Currently, this is done by replacement agreements and by flow-through subsidy in one experiment. For the fleet assignment study of this, the markets served without a loss were removed from the system once again. An airline with a commuter carrier's cost structure (see Table 4) was permitted to operate a 19-seat turboprop in the remaining markets. At the present size and rate of growth, commuter's costs are much reduced from those of regional airlines. As before, there was an east-west split in the outcome. In the less dense and more isolated western market, only 17% of the subsidized markets were profitable for the commuter operators. East of the plains states, 28% of the subsidized regional carrier markets could be operated profitably by the commuters. These are markets where substitution agreements are likely to continue to be possible. Voluntary commuter replacement will occur in only a fraction of the subsidized markets.

Comparison Study 6: Commuter Bid System

The defunct concept of putting subsidized air service out to bid to the commuter carrier can be examined from a cost point of view by a further comparison study. Removing all of the city pair markets served willingly by the regional carriers in case 1, the remaining system can be offered to the commuter carriers. Specifiying the usual minimum service constraints, losses are $12.0 million for service to all four regional carrier's subsidized markets. The total subsidy need was reduced from $28.5 million to $16.5 million by use of the small turboprop aircraft by the regional carriers, and from $16.5 million to $12.0 million by the employment of operators skilled in using these aircraft. The commuter bid system might have had considerable economic advantages.

Fuel Study

By doing some arithmetic on the results already obtained, observations can be made on the fuel efficiency of subsidized air service. For the total of the four airlines studied, the fuel efficiency of the subsidized part of the service was less than half of the passenger miles per gallon of the unsubsidized parts of the network (see Table 5).§ The mileage of subsidized services was roughly 7 passenger miles/gal. However, the substitution of commuter-operated 19-seat turboprop aircraft on the subsidized routes brings the miles per gallon in these markets back up to near 13. Low-density air service uses a disproportionate amount of fuel because of low load factors, but this need not be the case if the appropriate size of aircraft is employed.

Conclusions

Case studies on four regional carriers suggest that the use of small turboprop aircraft for providing subsidized service can create savings of 50%. Operation either by commuter carriers or by regional airlines in possible. The economies of market density and of network density are significant. Changes in route authority should be examined by the participants in this light on a case-by-case basis. Considerations of fuel economy run parallel with those of cost saving. Using smaller aircraft improves fuel economy by a factor of 2.

§The figures are higher than achieved in practice because of the optimal nature of the linear program solution.