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A FRAMEWORK FOR ASSESSING THE ROLE OF AIRCRAFT TECHNOLOGY IN ENHANCING SYSTEM CAPACITY

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Projections of future air travel indicate that the capacity of the existing airport and air traffic control system will be outstripped. Despite the many benefits of hubbing for airlines and passengers, increased aircraft operations at major hubs imply some disadvantages that include congestion delay, increased workload on air traffic controllers, noise, and pollution. This paper presents a framework for assessing the role of aircraft technology in relieving congestion at major hubs and enhancing system capacity. The proposed model can be used as a tool in assessing capital investments in the air transportation infrastructure, support for new aircraft technology, and creation of new services by air carriers.

INTRODUCTION

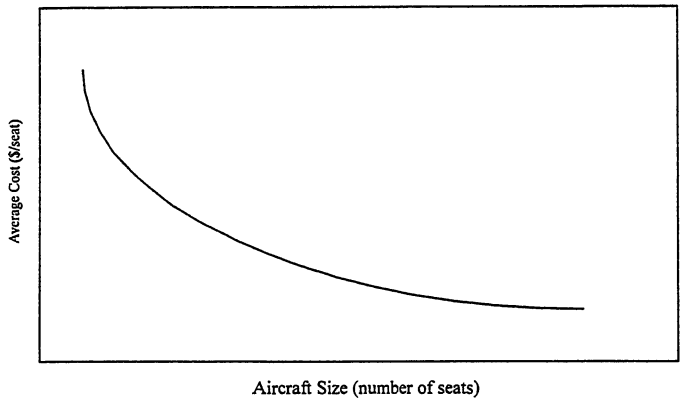
Air travel is growing at a rate that outstrips the capacity of the airport and air traffic control system, resulting in mounting congestion and delay. The consequences for the air transportation industry and the traveling public are higher cost, greater inconvenience, and declining quality of service. The need for increased airport capacity in the United States has reached crisis proportions. In 1991, twenty-three airports experienced congestion delays of more than 20,000 hours. This translates into $32 million in cost at each of these airports (FAA, 1993). The number of these airports is expected to increase to 33 by 2002, unless capacity improvements are made. The number of air passengers is expected to increase by 64% in 2005, and the number of flights at the largest 100 airports is expected to increase by 38% (Fields, 1995).

Despite the vast structure of the U.S. airport system network, the system is characterized by concentration at a few large nodes (hubs) that account for more than 80% of total passenger enplanements. This concentration is usually referred to as the hubbing phenomenon of air networks. Network hubbing is a pattern in which the origin-destination traffic is routed through one or more airports rather than being served nonstop. Increased aircraft operations at a hub are not necessarily due to high origin and destination demand to and from the hub city, but rather due to the additional volume of connecting passengers routed through the hub.

Airline hubbing is motivated by the economic advantage of operating large aircraft and by increased flight frequencies. **Figure 1** sketches the relationship between average operating cost per seat and aircraft size (number of seats) for a given flight stage length. By consolidating passengers on a few flights to and from selected airport hubs, an airline can take advantage of the resulting higher volumes by using relatively large and efficient aircraft (Ghobrial, 1983; Kanafani & Ghobrial, 1982). Airlines also can raise the frequency of service at the hub to offset passengers' increased travel time occasioned by the need to transfer. By dominating a hub through frequency concentration, an airline can establish regional identification with passengers and enjoy relatively high enplanement share (Ghobrial & Sousa, 1987).

Increased aircraft operations at major hubs can result in some negative economic impacts: (a) delays for passengers and airlines, (b) increased workload and stress levels on air traffic controllers and the need to upgrade the air traffic control facilities, and (c) excessive capital expenditures to improve the capacity of congested hubs. Using data for airline operations in 1986, Ghobrial and Fleming (1992) estimated that airlines incurred about $78 million in delay-related costs at Hartsfield-Atlanta International Airport, and passengers incurred the equivalent of $160 million in departure and arrival delays. Using 1986 data on one-way unrestricted airfare of 126

Figure 1
A conceptual relationship between average cost per seat and aircraft size.



markets served by Delta Airlines in 1988, Ghobrial (1990) found that passengers who connected at Hartsfield-Atlanta airport paid an average of $24 more than what they would have paid had they flown nonstop or connected at another hub such as Dallas/Fort Worth.

A number of factors seem to influence the future structure of the airport system. These include:

1. Growth in air travel between large cities and other cities will result in increased flight operations at large hubs and, consequently, higher delay levels.
2. Growth in air travel between medium-medium hubs, small-medium hubs, and small-small hubs may justify operating profitable nonstop flights between these spoke cities. This will, in turn, lead to "dehubbing" of the airport system and to less congestion at major hubs.
3. Increased levels of congestion delay at large hubs may outweigh some of the economic benefits of network concentration and may lead to dehubbing of the system.
4. Introduction of new aircraft technologies: Small aircraft could become more efficient economically, and newer larger aircraft could be developed to use existing runways and gates without further drastic expansions.

It seems that while some of the above forces drive the airport system toward greater concentration, others help relieve congestion at large airports by flying passengers nonstop and/or redistributing some of the connecting traffic to less congested airports. The future airport system may be structured such that these two sets of forces are in equilibrium. **Figure 2** shows the effect of the above forces on the airport system network.

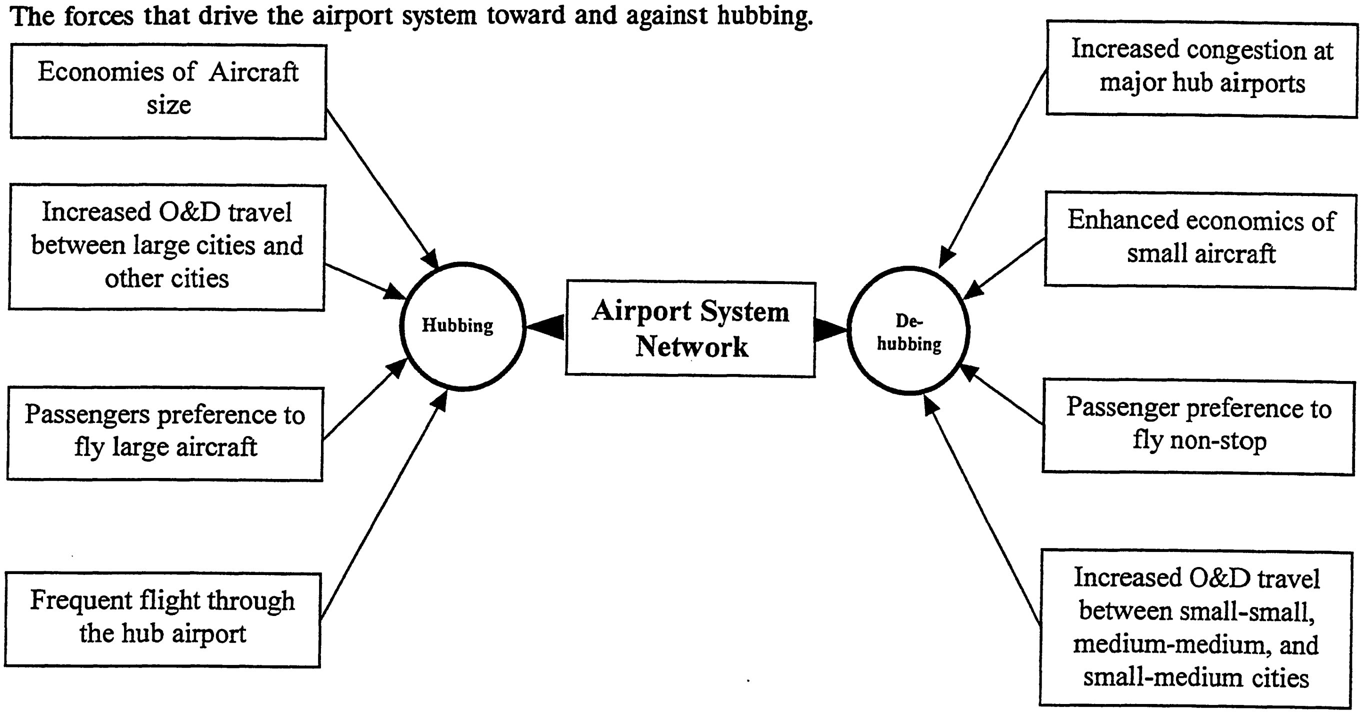
THE ROLE OF SMALL AIRCRAFT TECHNOLOGY

A comparison of today's airline networks with those of the mid-1970s amply demonstrates that the airport system network has changed from a grid type structure to a hub-and-spoke. As discussed above, to take advantage of the economies of scale of large-size planes, airlines drop the nonstop services on thin traffic links (markets) and route passengers through hub airports. Increased congestion at these hubs may outweigh the benefits of hubbing, and may offset the diseconomies of aircraft size.

To demonstrate the role of small aircraft technology in relieving congestion at major hubs and in enhancing system capacity, we compare two airport network structures as shown in **Figure 3. Figure 4** is a conceptual relationship between the average cost per passenger and volume of traffic at the hub airport H. The first scenario is a hub-and-spoke pattern in which an airline operates a large-size aircraft. To take advantage of economies of aircraft size, passengers between spoke cities are routed through hub H. As the origin-destination traffic increases between the hub city and other cities, and between the spoke cities themselves, aircraft operations at hub H will also increase. This increase will result in increased congestion delay at airport H, which may outweigh some of the economic benefits of hubbing. This relationship is shown in Figure 4 (Curve A). The second scenario is more of a grid network while hubbing still takes place at airport H; the spoke cities are connected directly and passengers are flown nonstop by small aircraft. In this scenario, passengers are relieved of the inconvenience of connecting at the main hub and from longer trips. Passengers and airlines also are relieved from the extra travel time and cost of congestion delay at hub H. Figure 4 (Curve B) shows the average cost per passenger for this scenario.

It is clear from Figure 4 that there is an equilibrium stage where airlines can offer point-to-point service between spoke cities and maintain the same cost level. In addition, earlier studies by Ghobrial and Fleming (1992) and Ghobrial and Kanafani (1995) showed that passengers prefer flying nonstop over connecting at a major hub because of less airside delay at the hub, less

Figure 2
The forces that drive the airport system toward and against hubbing.

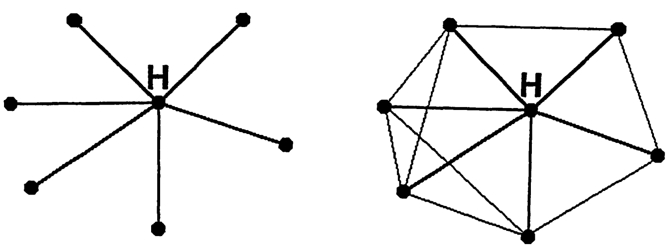


travel time, and less fear of missing luggage and/or connecting flight.

ASSESSING THE ROLE OF AIRCRAFT TECHNOLOGY

The following section provides a framework for modeling the airport network system. The model can be used to assess the role of aircraft technology in enhancing system capacity. It takes into consideration the economic and operating characteristics of different aircraft in the fleet, economic conditions of airline operations in competitive markets, passenger assignment to different routes in a multi-route system, and the different operational constraints at particular hubs, such as congestion delay. The model consists of the following modules:

Figure 3
A hub-and-spoke pattern (left), and a grid network with hubbing at H.



1. Input data:

(a) Physical structure of the network (i.e., cities in the network and length of links between each city pair).

(b) Possible connecting routes between each city-pair which usually include nonstop, connecting at a major hub (such as Atlanta, Chicago, Denver), and connecting at a less congested secondary hub (such as Nashville, Charlotte, Memphis).

(c) Economic and operating characteristics of each aircraft in the fleet. For the purpose of this study, the model can generally be applied for two scenarios: operating large aircraft type in the network, and operating a fleet that consists of large and small aircraft. A comparison of the two scenarios will help assess the role of small aircraft technology.

2. Passenger-route assignment module:

This is similar to traffic assignment in urban transportation. Given the origin-destination demand between each city-pair in the network, the model distributes that demand among all routes joining the end cities. The demand on each route depends on the levels of service on that route. These levels of service include aircraft type, airfare, flight frequency, travel time, and travel pattern (i.e., nonstop and connecting routings). Urban transportation literature include many techniques to assign passengers to different routes joining the origin and destination points (see Kanafani, 1983). Probabilistic assignment models have been used widely in modeling air transportation networks. Kanafani and Ghobrial (1982, 1985) and Ghobrial and Kanafani (1995) calibrated a logit model (a member of the probabilistic choice models) to assign passengers to routes connecting some city-pairs in the U.S. southeastern region. Logit models are based on developing a utility function that include the levels of service attributes on routes joining the origin-destination cities.

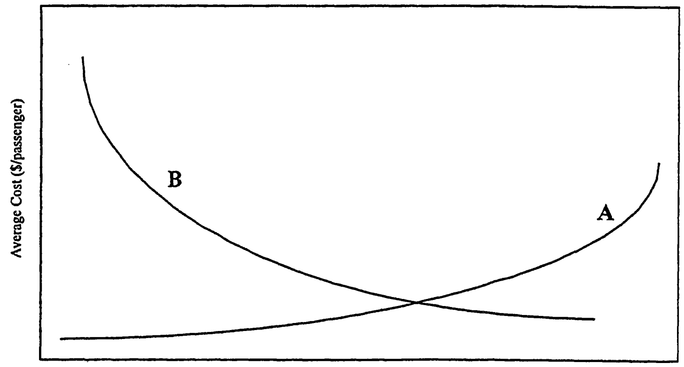
3. Network equilibrium:

As shown in Figure 2, two forces drive an airport system toward and against hubbing. For instance, higher flight frequencies on routes connected to a major hub result in higher volumes of passengers assigned to these routes. However, longer travel time on these routes along with congestion at the hub can result in some passengers flying directly between the spoke cities and/or connecting at less congested secondary airports. Given a certain fleet composition, an airline assigns aircraft types to and flight frequency on each route to minimize its operating costs (including congestion delay cost) on that route. Note that aircraft type and flight frequency on each route are assigned iteratively and according to passenger volumes and the economic characteristics of aircraft in the fleet. Because of the interdependence (i.e., two-way relationship) between passenger demand on a given route and supply of flights, fleet assignment and frequency planning are performed such that both the demand and the supply are in equilibrium.

4. Profitability constraints:

From the perspective of airline operations, aircraft type and flight frequency are assigned on each route in order to achieve a certain profitability level. Airlines are assumed to operate above a certain minimum load factor level to achieve profitability. The model will thus delete

Figure 4
A comparison between average cost and airport system configurations.



all routes with load factors below the minimum. The process of assigning passengers, aircraft type, and flight frequency is then repeated for the new set of available routes between city-pairs.

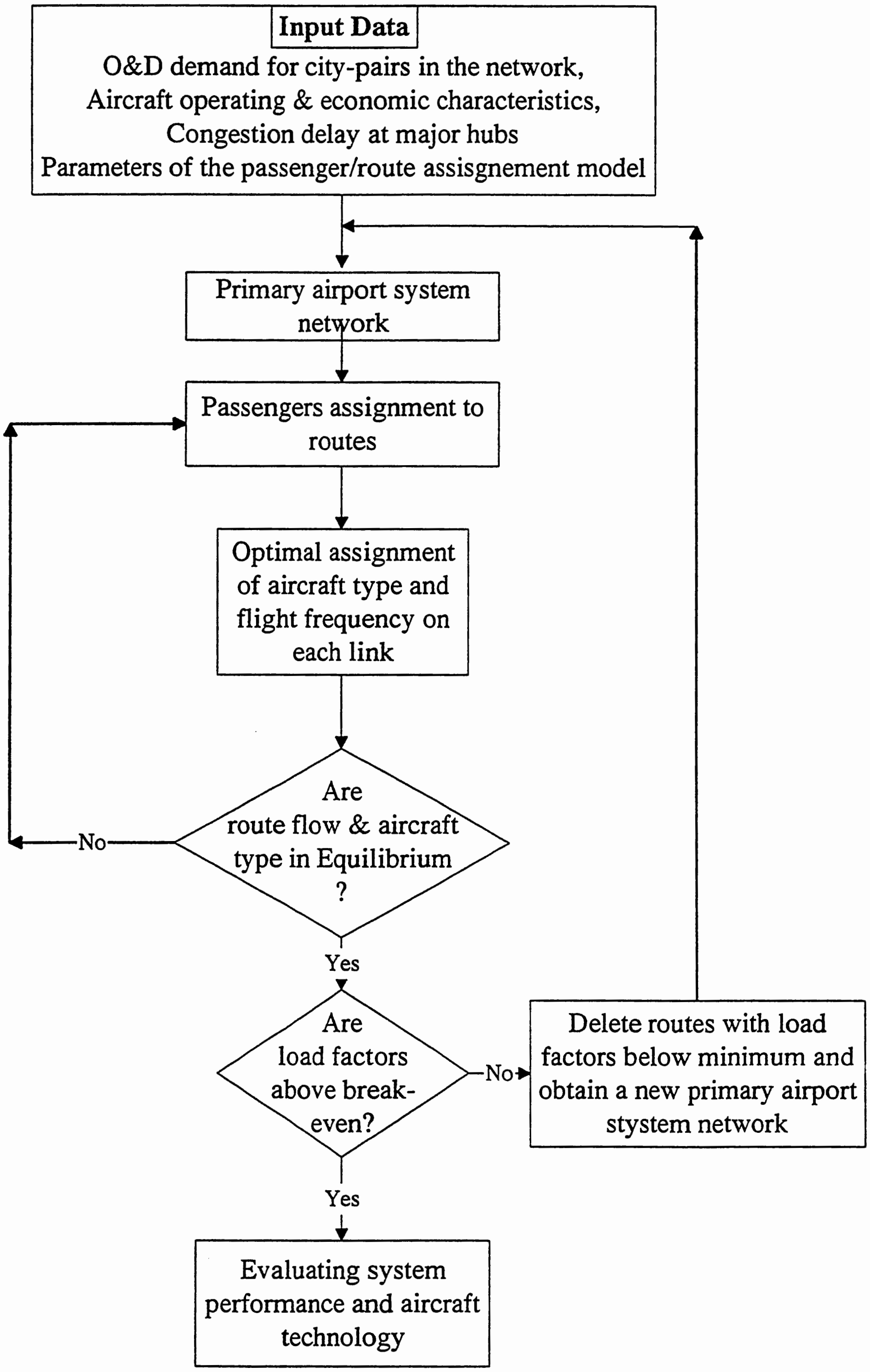
Overall, the network planning process is completed when equilibrium on each route in the network is attained and the resulting load factors on all routes are above the minimum. At this stage, some measures of system performance and passengers levels of service are calculated. A flow chart of the model is depicted in **Figure 5.**

APPLICATIONS OF THE MODEL

To assess the role of aircraft technology in enhancing system capacity, the above model can be applied for different scenarios of existing and future small aircraft technologies. For instance, the model can be applied to the U.S. southeastern region with Hartsfield-Atlanta airport as a major connecting hub. Nashville, Tennessee; Charlotte, North Carolina; Birmingham, Alabama; and Jacksonville, Florida, are secondary hubs in the region. Ghobrial and Kanafani (1995) used this region as a case study to forecast the future of hubbing and de-hubbing in the U.S. airport system.

For any scenario, the model determines the equilibrium network structure, taking into consideration congestion delay at major connecting airports. The results of the analysis can be synthesized in a series of airport system configurations. The analyst can then assess the

Figure 5
A conceptual flow chart of the airport system planning model.



role of existing and future small aircraft technologies on:

1. Future traffic at major hubs and the associated delay costs to airlines and passengers.

2. The levels of service for passengers, including travel time, frequency and stochastic delays, and average airfare levels.

3. Airline cost per passenger mile and profitability levels.

4. Impact on workload for air traffic controllers and requirements for future capital investments in the ATC system for the case study.

Based on these results, some technical and policy implications can be drawn regarding capital investments in the air transportation infrastructure, support for new aircraft technology, and creation of new services by air carriers.□

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