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**"FLEXIBLE NETWORK ROUTING PLAN"**

**for**

**Short-Haul, Low Density**

**Air Transportation System**

A Thesis

Presented for the

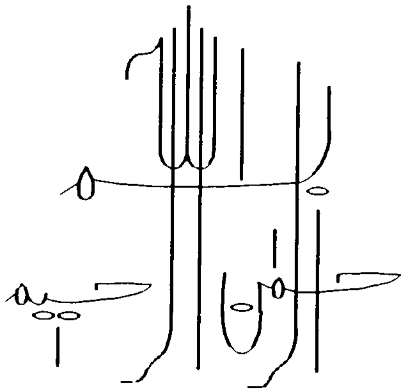
Master of Science

Degree

The University of Tennessee, Knoxville

Azhar K. Raina

May 1993




In the name of ALLAH,
The Mercifull, The Beneficient.

DEDICATED TO

MY LOVING WIFE SHEHNA

CHILDREN MADEEHA AND AHSAN

AND

MY PARENTS

## ACKNOWLEDGEMENTS

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## ABSTRACT


The economic deregulation of the airline industry has prompted operators to drop the smaller communities from basic air service, as economies of scale have ruled out short-hauls. This is partly due to the evolution of hub-and-spoke network strategy. Whereas, the zone routing technique, a combination of both point-to-point and hub-and-spoke routing, yields low operator cost as well as provides the necessary basic air service to the low density service region.

Furthermore, a minimal fleet size with increased frequency can offer a high level of accessibility and maximum utilization of the resources at the same time.

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## LIST OF ABBREVIATIONS

ASM -- Available-Seat-Mile.

ATA -- Air Transport Association.

ATL -- Atlanta, GA. (Hartsfield International).

BNA -- Nashville, TN.

BWG -- Bowling Green, KY.

CAB -- Civil Aeronautics Board.

CKV -- Clarksville, Cooke County, TN.

FAA -- Federal Aviation Administration.

MEM -- Memphis, TN.

MRC -- Columbia, Maury County, TN.

RPM -- Revenue-Passenger-Mile.

SRB -- Cookeville, Sparta-White County, TN.

THA -- Tullahoma, TN.

# INTRODUCTION

The purpose of this research is to continue an ongoing study of a Flexible Air Transportation Service. This service will provide an air connection for the growing industrial communities around Nashville, TN, directly to the major hubs in the region. This research has suggested a viable routing network plan based on the market area survey conducted by the Tennessee Valley Aerospace Region(TVAR)'s task force at UTSI in 1985. This work is part of Phase-I of the work plan prepared by the TVAR Investigation Team's proposal to the U.S. Economic Development Administration, January 1989.

Summary of sections to follow:

Section one outlines the necessity of an air service to this region. Section two explains briefly the physical and economic parameters of the network that are taken into account in this proposal. Section three explains the network routing techniques that are currently in practice by the airlines. Section four discusses the characteristics of the proposed service region. Section five examines the possibilities of deviations from the suggestions made by Haney '88. Section six concludes the proposal with the final plan, and section seven introduces the next step in this study, regarding scheduling of the services.

## 1. PROBLEM IDENTIFICATION (WHY THIS THESIS?)

The Airline Deregulation Act of 1978, has brought about major changes in the airline industry. One such facet of change is the loss of scheduled air service to many smaller communities. Although these communities within our study area offer a reasonable number of enplanements per day, they have been neglected due to the lack of resources for developing the new markets. While an increase in hub operations suits the economic health of the industry, responsibility for providing service to the population at large has been basically overlooked. Overall total enplanements at hubs have increased from 1979 to 1988. Atlanta, GA increased 7.86 percent, Memphis, TN 46.41 percent and Nashville, TN increased 63.74 percent. On the other hand, 148 cities have lost service completely between 1978 and 1991 [FAA records], including Bowling Green, KY and Clarksville, TN within our proposed region. Although most of these communities have demonstrated a gradual rate of growth, 14 cities have fewer weekly departures over the last 13 years.

The reason for this lost service is also closely related to technological advancement within the aviation industry. As the 'economies of scale' have ruled out shorter hops, commuters are reducing their fleet of aircraft with 15 seats or less. In 1980 planes with 15 seats or less accounted for 56 percent of the United States commuter fleet, which in 1984 fell to 37 percent and the figure is expected to drop further by 1996 to a mere 17 percent. Aircraft with 20 to 60 seats are expected to make up more than half of the commuter airlines fleet by 1996 [Kane and Vose, 9TH ed]. This has caused the growing smaller communities to have less to offer to prospective businesses. Flying to their destination is still not a choice for many citizens.

The fact is that air transportation is still an expensive way of travelling. In pressing economic times, air carriers are one of the first to be affected adversely, because of small profit margins. In addition, the competition posed by ground travel modes increases the challenge for a short-haul air service to generate enough passenger demand.

This adverse effect on smaller communities was one of the negative aspects of the Airline Deregulation Act of 1978 brought to the legislators' attention. Therefore, enacted into the new legislation was the 'Essential Air Service (EAS)' plan, which would ensure continued air service to smaller communities until October 1988. However, the 'Airport and Airway Safety and Capacity Expansion Act of 1987' Title II-Section 202, sub-paragraph (d) on Compensation For Service To Other Small Communities states, that it may compensate for up to 75 percent for service to cities that had received air service in the past (i.e. Clarksville and Bowling Green in our network system), and 50 percent for those which have not received any air service in the past (Tullahoma, Columbia, and Cookeville). The Federal Aviation Administration still considers such requests for initial funding, through their EAS office.

Further more it has been shown that,

> "A sizeable traffic volume at Atlanta is generated by travellers from the short haul region who are connecting to other short haul flights or to long haul flights to the outside of the region" [Kanafani and Yuan '77].

This demonstrates the need and feasibility of such service -- a requirement by EAS compensation program. Wherefore, the proposed service would operate under parts 135 and 23 of the Federal Air Regulations.

## 2. NETWORK PARAMETERS

The Flexible Routing Network Plan may be suggested through an understanding of network parameters and their relative effects. Since demand for air service varies throughout the year, some routes may be dropped while others are added. The following sections are intended to assist the planner at any stage of this proposal.

2.1. Load Factor: Load Factor is an important characteristic of an air route.

> "Load factor represents a criterion which can directly or indirectly reflect Economic, Technological and Geographic influences on the short-haul network." [ p47, Kanafani and Chang '79 ].

It is defined as,

$$\textit{Load Factor} = \frac{\textit{Revenue Passenger Miles}}{\textit{Availible Seat Miles}} \qquad (2.1)$$

The term signifies two different meanings depending upon its usage. The break-even load factor is the load factor below which the operator shall loose money. It is determined by the cost of 'operation'. The passenger load factor attained through actual operations, sometimes called the Local

Utilization Factor[1], is different from the first and reflects the return on investment. Both may be compared to determine the economic feasibility of a route, e.g. if the air link MRC-MEM needs at least six revenue passengers on a nine-seat aircraft to pay for that operation, then this link would have a break-even load factor of 67 percent for the operator. But, if the flight is carried out with only two revenue passengers on board it would yield a passenger load factor of 22 percent. The air route that does not yield a load factor greater than the break-even load factor is thus dropped from service.

2.2. <u>Stage length:</u> Stage length is the physical length of route between a Origin-Destination pair. Greater stage length tends to reduce the cost per seat mile by spreading fixed/indirect costs over a larger distance. One way of bringing break-even load factor down is to eliminate routes with shorter stage length. However, our proposed area of service is rather small to allow many choices in this regard ( See Table 4.3. ).

2.3. <u>Cost:</u> Direct and Indirect costs have been defined by Haney '88. These may be broken separately as follows,

---

[1]Kanafani and Yuan '77, suggested that the local utilization factor or local utilization ratio be considered different than the load factor because these exclude through traffic in a non-dedicated network. However, we will not differentiate among these terms here because the study region is a dedicated short haul system anyway.

2.3.1. Direct costs:

Flight operations; crew wages, fuel

Direct maintenance; labor, parts & material

Passenger service; food/refreshments, cabin attendants

Aircraft servicing; non-mechanical maintenance, landing fees

Traffic servicing; baggage, ticket handling

Reservations and Sales;

Advertising and Publicity;

2.3.2. Indirect costs:

Maintenance burden/Indirect maintenance costs; Preventive maintenance, overhead;

Depreciation and Amortization; Also includes payments on capital;

General and Administrative; administrative, legal, accounting et cetera.

Variations in direct cost reflect the changes in fare. But the indirect or fixed costs are independent of mileage travelled and are controlled by cost tapering. 'Cost taper' is a phenomenon that the total cost per available-seat-mile goes down as the length of trip grows. Although this effect does not go on forever, it begins to diminish when an aircraft reaches its endurance limit [O'Connor '89]. The average cost of an airline increases exponentially with the aircraft capacity and decreases exponentially with the stage length [Figures 3.1. and 3.2., Jeng '87]. This reference also gives cost function 'k' for route i, as a function of the ratio of aircraft capacity 'c' to stage length '$l_i$', as

$$k_i = 4.1+(15.6(\frac{c}{l_i})) \tag{2.2}$$

which will be discussed later in section 4.

2.4. <u>Demand:</u> The demand for air routes is quite different when compared to the demand for land routes. A link between an OD[1] pair exists only if the service exists. According to the supply and demand theory, a link or an air route between an OD pair would exist only if there is a demand for it. However, in a low density and low demand region like the region under study, the demand is considered inelastic. It means, that if the supply is increased the demand does not necessarily increase. Although the demand may be increased slightly by aggressive sales promotion, the main revenue would still be expected to come from business travellers. This means that demand and the passenger load factor are directly correlated.

Demand has the most significant and positive effect on the scale economies for operators and passengers alike. Since

---

[1]Origin-Destination.

this study is concerned only with realistic data, it would be a heterogenous demand. In this thesis, demand means 'average passengers per day per OD pair' ( See table 4.2. ).

2.5. <u>Nodes:</u> Non-hub cities are called nodes. Two characteristics of nodes affect the routing technique.

2.5.1. Spatial density of nodes: Closely located cities which generate enough demand would be served by point-to-point operation. Spatially denser nodes with low demand may be served by zone routing ( See section 3.4. ).

2.5.2. Total number of nodes: A larger number of nodes will increase the system size. It would allow us to make better trade offs with more choices but at the same time the complexity of the network would increase multi-fold. This becomes apparent when scheduling considerations are taken into account (see section 7).

2.6. <u>Connectivity:</u> Connectivity is the measure for 'level of accessibility' between OD pairs within a network. Connectivity of a given network is determined by dividing the number of existing air links by the total possible number of links. e.g. the connectivity of the network in figure 6.1. will be,

$$\frac{8}{C^6_2} = 0.5333 \qquad (2.3)$$

Thus a network that has a service for every OD pair, i.e. a fully connected point-to-point operation, will provide the highest level of accessibility to its customers and the connectivity for such a network will be equal to one.

2.7. Time value parameters: Since the nature of the product, i.e. available-seat-miles, is volatile, the schedule time needs to be closely monitored. Various time delays are differentiated by their type and analyzed thoroughly. The work with the most contribution towards a better understanding of time value parameters was done by Jeng '87.

2.7.1. Time value for the travellers: It was determined by a survey that $12.00 per hour may be considered as an average value of a travellers time. It is denoted by the Greek letter del($\delta$).

2.7.2. Schedule delay: Schedule delay is defined as the amount of delay between the desired time of departure by a passenger and the actual time of departure of the flight. Among the time delay parameters it has the least value due the passengers ability to use this delay more effectively than the following two types of delays. As a fraction, it is denoted by Greek letter alpha($\alpha$), such that alpha-del($\alpha\delta$) represents the average time value of passenger schedule delay.

2.7.3. Line-haul delay: Line-haul delay is defined as the amount of delay, between take off and landing of the flight (gate-to-gate). Passengers can utilize this time delay, but not as effectively. This, as a fraction, is denoted by Greek letter beta($\beta$), such that beta-del($\beta\delta$) represents the average time value of passenger line-haul time.

2.7.4. Transfer delay: Transfer delay is the amount of delay time between getting off one flight and boarding the next flight at a connecting hub. It is weighed heavily and has greatest value among time delay parameters, due to the passengers' inability to utilize this time effectively. It is denoted by Greek letter gamma($\gamma$) as a fraction, such that gamma-del($\gamma\delta$) represents average time value of passenger transfer delay.

Other network parameters such as Capacity, Aircraft Travel Time and Average Aircraft Operating Cost are fixed and known since we have already made the aircraft selection. Frequency, as suggested by Haney '88, is reviewed during the discussions on the actual routing plan.

# 3. ROUTING STRATEGIES

Current routing strategies that are in practice with the major airlines have been described here breifly, with their relative and salient features. The last three strategies have been suggested and discussed thoroughly by Jeng '87. Namely, they are:

Point-to-point routing.

Hub-and-spoke routing.

Split routing.

Zone routing.

Sector routing.

3.1. Point-to-Point routing: As the name suggests this style connects all OD pairs in the network with a direct link. This is the mother of air routing strategies, which is very close to land routes. The connectivity is highest, thus seemingly convenient for the passengers. There would be no transfer delays, low frequency of service would result which would thus increase the schedule delay and the average line-haul delay would be higher as well, due to smaller aircraft.

3.2. Hub-and-Spoke routing: This routing resembles the structure of a wheel, small cities called nodes would feed traffic to a larger and centrally located city called a 'hub'. The established links resemble spokes of a wheel, thus the name, hub-and-spoke. The technological development of large size aircraft in the sixties helped evolve this structure. The larger the size of an aircraft the lower would be its break-even load factor, due to its ability to haul a large number of revenue passengers. Such effects are called 'economies of scale'. After the Deregulation in 1978, there has been an increase in the trend towards choosing such routing strategies.

Hub-and-spoke routing has quite a few benefits for both the passengers and the operators. The operators are able to provide a higher frequency out of the hubs as well as offering a larger choice of destinations to the passengers. This may result in lower fares due the economies of scale and lower break-even load factor. However, connectivity is lower. Transfer delay becomes a function of many variables such as weather, hub capacity, efficiency of ground crew at the hub et cetera. Schedule delay is reduced due to higher frequency, while the total line-haul delay increases for a passenger because of being carried the extra mileage. However, the average line-haul delay of the network for all passengers is reduced. A study of the hubbing phenomenon conducted by Ghobrial '83, suggested that even the increased costs at hub airports did not override this strategy's benefits.

3.3. Split routing: Serving a system entirely with either of the two aforementioned strategies is less efficient than dividing the system into groups by their locations, and serving them with split routing. In this type of routing strategy, the neighboring nodes are connected with point-to-point routing and the farther nodes in the system are connected through the regional hub. These regional hubs serve as nodes to feed traffic into a major hub with the hub-and-spoke routing. The idea is to reduce the extra circuity caused by hub-and-spoke routing. The following is a comparison of split routing with hub-and-spoke routing:

- ✓ Transfer delay decreases due to fewer transfers.
- ✓ Schedule delay increases due to less frequent flights
- ✓ Line-haul time decreases due to less circuity.

The break-even load factor for split routing depends upon the combined effects of smaller aircraft and less circuity. The trade-offs for split routing must be understood as well. As the value of line-haul delay increases, the point-to-point operation becomes more efficient due to less circuity. An increase in the value of schedule delay tends to make the hub-and-spoke operation more efficient due to the scale economies. A decrease in the value of transfer delay would again tend to make hubbing more efficient. A special case where all the time delay values are equal, such as is generally true for freight, hubbing is efficient due to its reduced sensitivity to scale economies and circuity effects.

3.4. Zone routing: This strategy is more realistic than split-routing, because the location of nodes is not restricted to the circumference around the hub. Nodes are divided into zones based on their location, within a zone the cities are served by point-to-point operation, and a central node in the zone would serve as node to a larger hub outside the zone. Size and shape of the zone is merely based upon the density of nodes. As demand increases within the zone, the structure of the network approaches point-to-point operation. If size of the the zone increases or decreases either hubbing or point-to-point operation, respectively, can completely replace the zone routing. Transfer and schedule delays in this type of routing are reduced even further, while the line-haul delay may increase slightly. The major advantage is lower break-even load factor for the operator.

3.5. Sector routing: This type of routing strategy reflects the more realistic non-uniform node densities throughout the network. Since the advantages of such routing is evident in a much larger system than being considered for the purpose of this thesis, it will not be described here.

# 4. NETWORK PLANING

This service is being proposed for the region shown in figure 4.1. It is evident that the node density is concentrated in middle Tennessee region, with stage lengths below one hundred nautical miles between the nodes. The operation could be very expensive if not planned properly. The goal would be, first to minimize the operating economics, thus lowering the break-even load factor. Second, maximize revenues by ensuring high passenger load factor.

One way of achieving the goal is through aircraft selection, which was completed in the first part of this research by Haney '88. Fleet sizing and network planning is next, which is the subject of this study. Scheduling, at the final stage, will require stochastic modelling to meet the first goal. In order to meet the second goal of high passenger load factor, There must be high revenue-passenger-miles (RPMs) and low available-seat-miles (ASMs), with reference to equation 2.1. But ASMs must be higher in order to yield high RPMs -- economies of scale. In actual operation all of the seats rarely get filled, and it would not be wise to turn down any revenue passengers as well. So, enough capacity is required to allow for demand increase by aggressive marketing and sales promotion, as well. Since, only an average of 80 percent of the seats yield revenue [O'Connor '89].

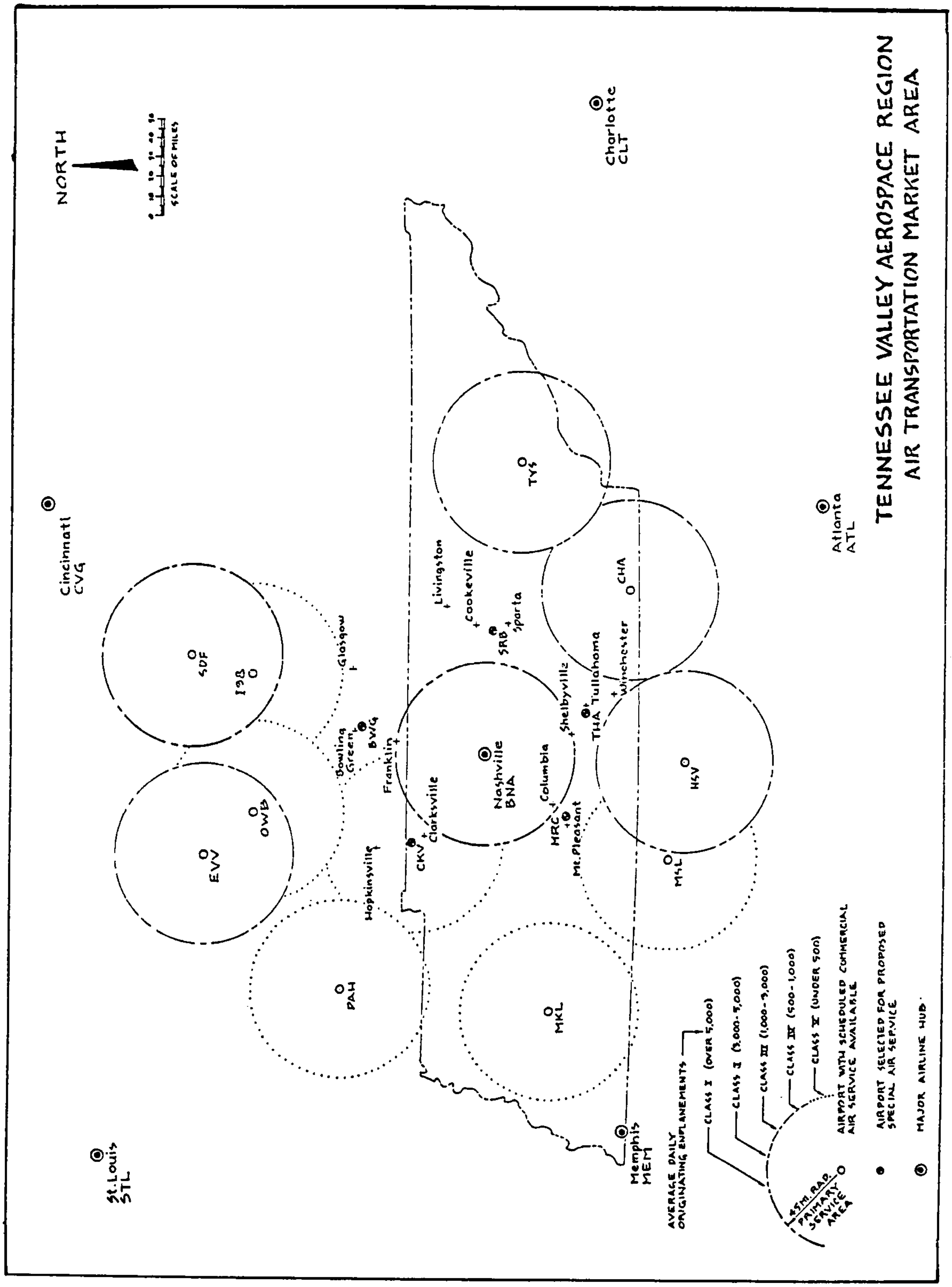



Figure 4.1. Region for the proposed flexible air service Adapted from [5].

First the network strategy is examined, then the frequency of service is assigned to those routes which shall in turn determine the fleet size for this 'plan'. Earlier studies have shown that the strategies should be based upon demand considerations, rather than the spatial configuration of the nodes. The market survey completed by Bailey '85 provides vital information to this process. See figure 4.2.

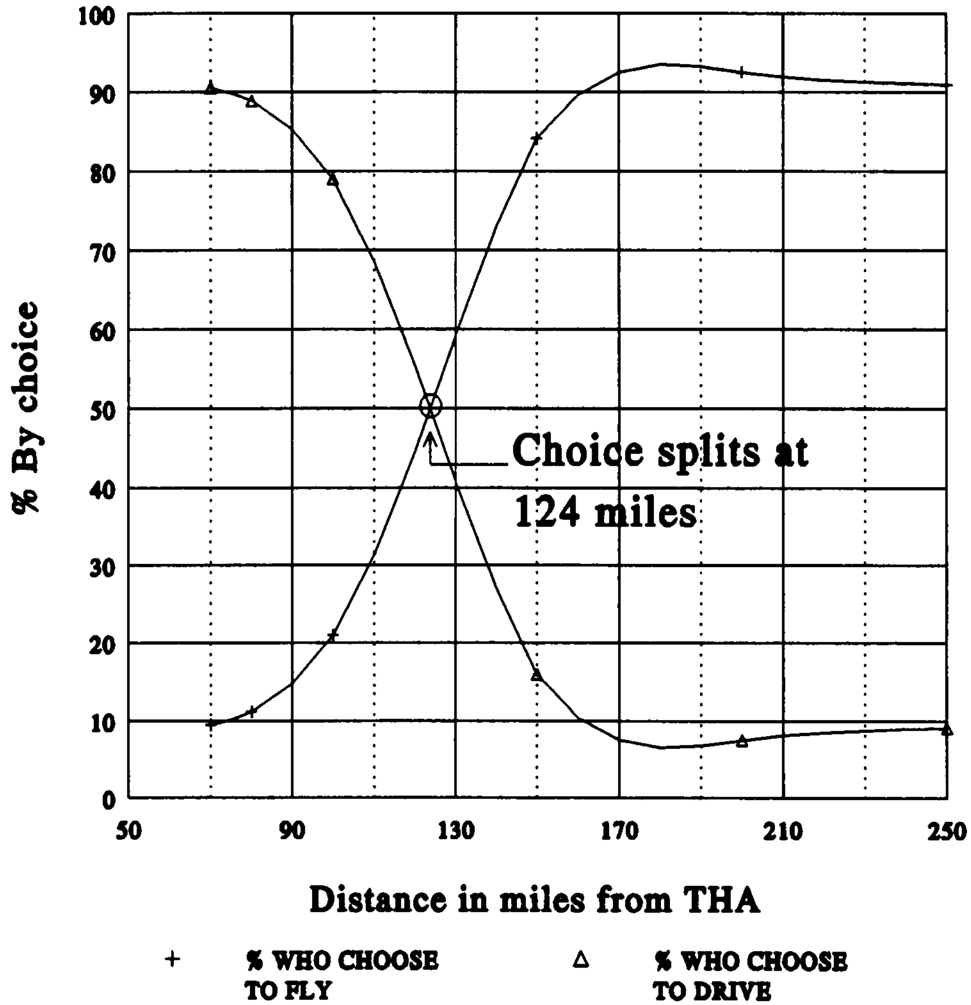



Figure 4.2 Why are the short haul trips dropped?

Extrapolation of market data reveals that the choices made by travellers split at the 124 miles. Passengers prefer to drive if their destination is within approximately 2 hours. For greater distances they prefer to fly. The 20 percent who fall below that mark, who still choose to fly, do not justify the targeting of this study at the short hop traveller. This, in turn, drops those routes that have a stage length of less than 100 miles [p.11-33, Kane and Vose '87]. Even though Nashville is spatially centered to the five origin points and being a medium size hub it may serve as the single dedicated hub, yet it does not seem economically feasible at this time to feed into Nashville. Instead it is necessary to connect this region with major hubs outside the immediate region.

Table 4.1. Expected costs for break-even L.F. determination

Expected direct cost estimates:

AIRCRAFT OPERATION; $130 per hour.
(aircraft, pilot, fuel)

GROUND OPERATION; $210 per hour.
(liaison officer, routine maintenance, baggage handling etc.)

In his conclusion, Kanafani '81, suggests that in order to achieve the same low break-even load factors as in operations with larger aircraft, the short haul networks operated with small size aircraft may have to charge higher fares. Larger aircraft operating on their longest legs can offer a fare of around ten cents a mile to the traveller. However, in this operation it may be necessary to charge about thirty three cents a mile. This could reduce the break-even load factor to 67 percent, based on the estimates shown in table 4.1. which shows the cost of operation at $340 per hour. In terms industry standards, this translates into 0.22¢ per available-seat-mile ($2.00 per mile for 9 revenue passengers). A break-even load factor of 67 percent means that this system must operate with at least six (i.e. 6/9 is .67) revenue passengers on board. For example, this shows the THA-ATL, one-way (OW) fare of $46.00, that is competitive with other modes of travel on these routes, mainly driving. Equation (2.2) yields $5.00 per mile, which is a much higher cost of operation and erroneous due to the fact that it is based on operations with large jet engine aircraft. The figures above were developed by current industry survey.

A slightly higher cost of operation of say $425 per hour (i.e. $2.50 per mile) may still be acceptable. In terms of the industry standards, the cost would then be 0.28¢ per available-seat-mile, which is still not excessive by the

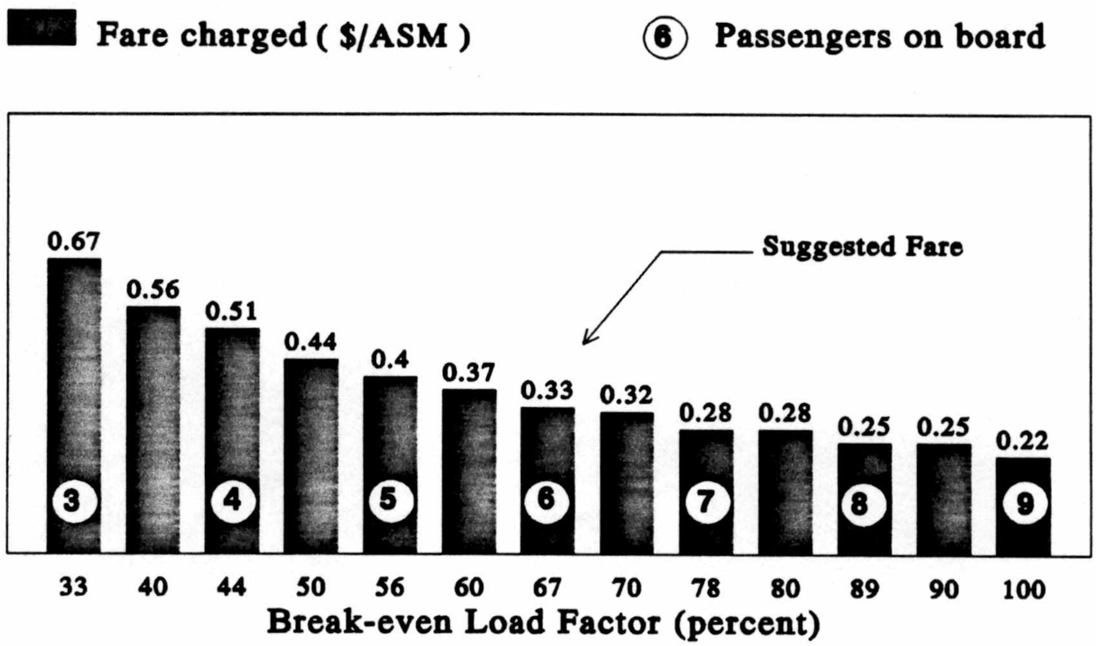



Figure 4.3. Break-even Load factor vs Fare charged.

standards of service being provided. This reveals, for example, the THA-ATL OW fare of $58.00.

Figure 4.3. is a graph showing the relationship between break-even load factor and fares charged in dollars per available-seat-mile. The route fares could be determined by multiplying the $/ASM value at the desired break-even load factor and the stage length of the route from table 4.3. If the cost of operation was to be recovered with five revenue passengers, that is a lower break-even load factor of 56 percent, then the fare charged would rise as well, for example, the THA-ATL OW fare will now be $56.00 as compared to $46.00 at 67 percent break-even load factor vis-a-vis the

choice of a higher break-even load factor of 78 percent will exhibit an even lower THA-ATL OW fare at $39.00.

Before deregulation, when the CAB was responsible for route selection and network planning, the break-even load factor was observed to be around 55 percent. Since then, it has had wide fluctuations between 50 and 70 percent. The choice of 67 percent for break-even load factor value, being on the high end of spectrum, is an indication of a short-haul, low density network.

Kanafani and Chang '79, while calibrating the route choice model for a short haul network, realized that travellers are sensitive to the following characteristics of a route. In order of preference they are;

i) Cost.
ii) Schedule frequency.
iii) Travel time.
iv) Service is non-stop or not.

Cost, has already been discussed earlier in this section. When capacity on a route is increased the break-even load factor would decrease. Kanafani '81, suggests that increased capacity on a route may be offered through increased frequency, while using smaller aircraft. It is only possible, however, if there is enough demand for higher frequency.

Table 4.2. Origin-Destination daily demand and their connectivity.

| Nodes | THA | CKV | BWG | SRB | MRC | ATL | MEM | STL |
|---|---|---|---|---|---|---|---|---|
| THA | - | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| CKV | * | - | 1 | 1 | 1 | 2 | 1 | 1 |
| BWG | * | * | - | 1 | 1 | 2 | 2 | 2 |
| SRB | * | * | * | - | 1 | 2 | 2 | 2 |
| MRC | * | * | * | * | - | 2 | 2 | 2 |
| ATL | 14.1 | 18.5 | 13.6 | 5.2 | 6.5 | - | NA | NA |
| MEM | 5.8 | 8.2 | 4.4 | 4.8 | 2.3 | NA | - | NA |
| STL | 5.3 | 6.2 | 3.1 | 1.9 | 2.2 | NA | NA | - |

* - No data available
NA - Not applicable

Demand in passengers/day
Connectivity is '1' for direct link, '2' for one enroute stop

The projected demand by Bailey '85, between points of travel in the study region are shown in lower three rows of table 4.2. The highest number of passengers are interested in travelling to Atlanta, then Memphis and St. Louis. The first six rows of the table show 'level of accessibility' between OD pairs based on their demand. A direct link is denoted by '1' and so on. Table 4.3. shows their respective stage lengths, in the lower-left hand side and the corresponding time of haul over those distances, in the upper-right hand side. These numbers correspond with the selected aircraft's economy cruise speed.

Table 4.3. Origin-Destination distances and the duration of flight.

| Nodes | THA | CKV | BWG | SRB | MRC | ATL | MEM | STL |
|---|---|---|---|---|---|---|---|---|
| THA | - | :33 | :34 | :19 | :17 | :49 | 1:05 | 1:40 |
| CKV | 94 | - | :18 | :34 | :23 | 1:22 | :55 | 1:07 |
| BWG | 95 | 52 | - | :24 | :33 | 1:18 | 1:13 | 1:16 |
| SRB | 54 | 97 | 69 | - | :34 | :55 | 1:20 | 1:13 |
| MRC | 47 | 65 | 92 | 86 | - | 1:03 | :50 | 1:26 |
| ATL | 138 | 231 | 222 | 155 | 178 | - | NA | NA |
| MEM | 184 | 156 | 208 | 226 | 140 | NA | - | NA |
| STL | 282 | 189 | 215 | 281 | 245 | NA | NA | - |

Distance in Nautical-miles Time in HR:MIN format

The search for an optimum network strategy has been a subject of numerous reports. Yet, none has considered a network near this study's scale of size and demand. Heuristic studies are a source of information for the purpose of this thesis. In his findings Jeng '87, concluded that,

> "Demand has positive and very significant impacts on the use of point-to-point operation. However, the number of nodes and the area size have negative and very insignificant impacts."

The point-to-point operation has a high price to the operator though. It can not be employed to its highest level of accessibility here due to fewer aircraft. Neither can the hub-and-spoke operation be used effectively due to smaller capacity of the selected aircraft. Split routing can not be defined clearly for the study region due to the fact that node locations are densely located on one side when considering major hubs outside the immediate region. Whereas, the zone routing technique best suits the demand size and location of nodes.

A zone is established and within the zone nodes are served by point-to-point operation to the best of the fleet's ability. By 'best of the fleet's ability' is meant that a flexible routing plan is proposed within the zone. The dotted lines in figures 6.1., 6.2. and 6.3. represent those routes which may be followed in case passenger load factor falls below 33 percent ( i.e. only 3 revenue passengers on board ) or if the capacity is full. This could be decided within the last two hours, before the scheduled take off time which could be the deadline for making reservations. After transporting travellers to a regional hub by point-to-point operation, they may be carried to one of the major hubs. Thus, they can be offered a higher frequency of flights out of these regional hubs. The nodes which would generate higher daily enplanements are selected as regional hubs in the zone. These are Clarksville and Tullahoma depending upon the direction of the flight. This will reduce overhead costs associated with equipment handling, its maintenance and other ground services. The network may be thought of as having a hierarchy of hubs, discussed by Kanafani and Chang '79. By adopting the zone routing strategy it is assumed that all of its benefits mentioned in section 3.4 of this thesis are applicable.

## 5. DEVIATIONS FROM SUGGESTIONS MADE by Haney '88

5.1. Swearingen-Merlin III: The aircraft selection by Haney '88, fails to take into account the weighted ranking of the aircraft. The candidate aircraft no. 11, Swearingen-Merlin III holds up its ranking, except for the field length and initial cost. The field length is still acceptable and is within the limits of 5000 feet. All of the candidate airports can accommodate this length as well as the prospective airports in the region that would lie outside the Primary Service Area. In addition to higher speed, this aircraft offers longer range, better endurance, much greater Time Between Overhauls(TBO) i.e 5400 hours as compared to 1800 hours for the selected aircraft. Furthermore, it is one of the 'pilot friendly' aircraft in its class[Jagitsch '93].

The cost difference(i.e. $322K compared to $320K purchase price and $14.8/hr compared to $10.3/hr engine operating cost) is almost negligible between the two candidate aircraft. The Merlin III has a nearly 30 percent improvement in speed and trip time achievable at no extra cost to the travelers. However, the Swearingen-Merlin III prices quoted, have been for models ten years older than those for the Piper Cheiftain's. The survey shows the comparable prices of the former to be currently around $600K-$700K range for the same year model which does indeed make a great difference.

5.2. Helicopters: Helicopter(s) have also been considered to serve whole or a part of the network. When compared to an equal size operation with turboprops, the direct costs with helicopters amounted to a mere 11 percent as compared to 48 percent in fixed wing operations. This low cost could help keep the break-even load factors to a minimum, provided there exists a viable solution to reduce the indirect costs, namely;

- Higher acquisition costs
- Higher insurance rates
- Higher Maintenance[1] costs
- Low utilization and limited service life and
- Dis-economies of small/dispersed operations.

These costs can impair a small business especially for an upstart operation like this. Considering the costs together, a typical 30-seat aircraft at 100 mile stage length revealed $0.13/ASM for turboprops and $1.24/ASM for helicopters . This indicates an expense roughly equal to nine times that of a fixed wing operation. This high cost is a key inhibitor to the success of civil transport helicopters [ Vertiflite, Jan./Feb.'93 ] . A smaller operation with twin prop aircraft would reflect a similar result, though slightly higher than turboprops the cost of operation at $0.22/ASM is still preferable to the choice of using helicopters, while ground

[1]Includes labor and parts for corrective and preventive maintenance both.

transportation is still competitive being the cheapest option.

5.3. <u>Tiltrotors</u>: The characteristics of the service region discussed in section 4. are best suited for an operation by civil tiltrotor aircraft. But, "the all-new designed civil tiltrotor aircraft will appear after the year 2000 due to the long lead times required for development and certification" [Macyko '91]. The smaller version, with eight seats CTR-800, however, will appear even later, than the larger and more economically viable aircraft. Nevertheless, it is foreseen that the tiltrotors will offer various benefits, such as:

- They will solve the problem of airport gridlock and ground delays.
- Small cities could be revitalized at little cost for building remote vertiports.
- Vertiports will extend the effective life of existing airports by freeing up runway slots for the higher passenger airlines.
- Environmental noise disturbances will be minimal with steep approach and departure flight profiles flown by tiltrotor aircraft.
- This service is economically competitive with conventional fixed-wing turbo-prop aircraft when the 'value' of total travel time savings is included.

- A tiltrotor is not merely a helicopter and it can operate within a much larger flight envelope than conventional airplanes.

Since 'tiltrotor' is not a viable technology at the time of this study, the aircraft selection made by Haney '88 will be observed.

# 6. ROUTING PLAN

6.1. <u>Routing:</u> The zone routing strategy with flexible point-to-point operation within the zone, suits the spatial location of nodes in the service region. As mentioned earlier in this thesis, it also offers the possibility of increased frequency between the regional and major hubs. This is due to the fact that part of the fleet is relieved from direct links between each node in the region and a major hub. This makes the operations less expensive by ensuring a hub-to-hub connection and offering conditional service to the smaller nodes which do not generate enough enplanements for a direct link to the major hubs. In other words routing within the zone may be changed at any time during its operations, depending on the load factor of that route. The liaison officer between the customers and the operator, may be authorized to make that judgement call based on a minimum and a maximum number of passengers on that route.

Operating within the zone with the selected aircraft, this could be written as,

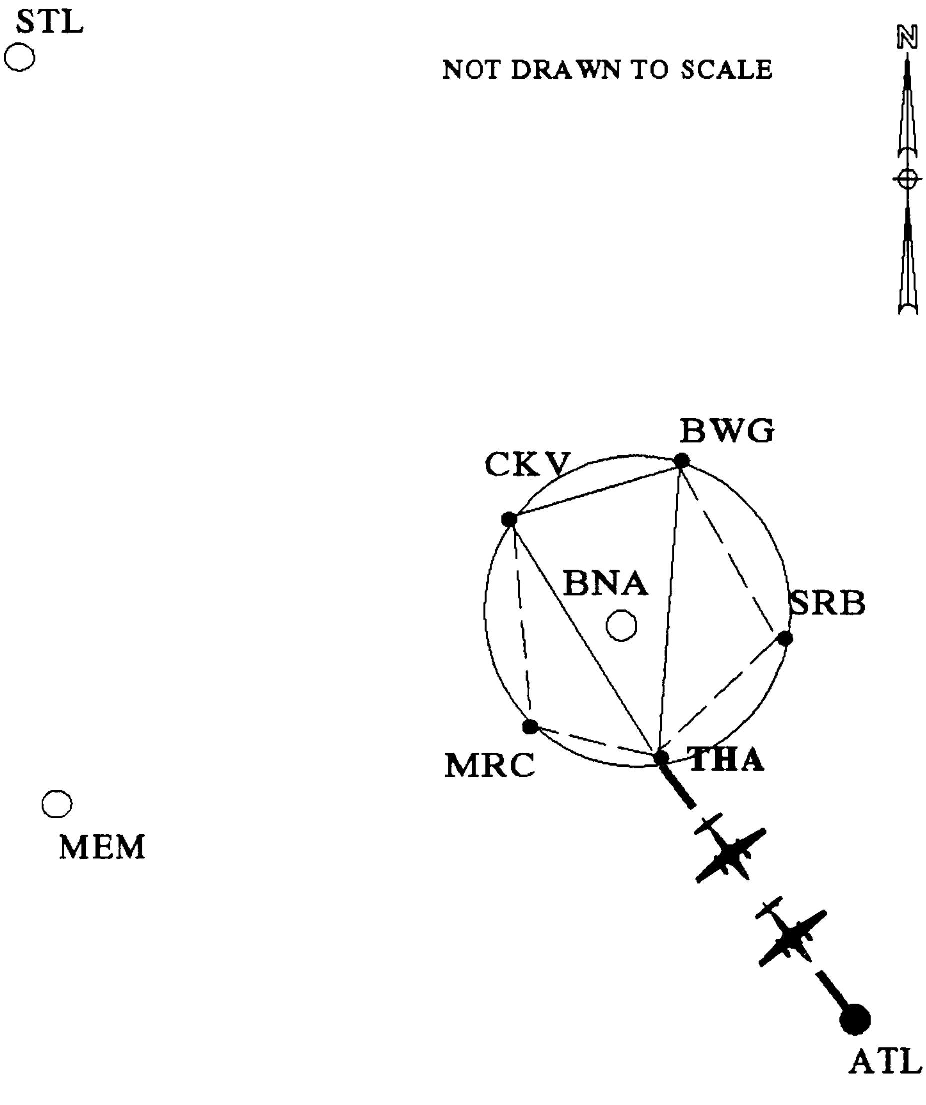
- a link does not exist if there are 3 passengers or less on a route,
- a flexible link exists if there are 3 to 6 passengers and
- a link exists if there are 6 passengers or more

A link, within the zone is dropped if there are less than three passengers vis-a-vis a link is established if there are more than six passengers on a route. Scheduling will also be affected by doing so, it will be investigated briefly in section 7. Proposed zone routing strategies on this basis, for each of the three major hubs, are being presented separately in figures 6.1., 6.2. and 6.3. The flexible air route MRC-MEM would be carried out if the flight has at least six passengers on board, otherwise it will be re-routed, terminating at CKV where it will pass its passengers on to the CKV-MEM flight. Other flexible routes will be operated similarly.

6.2. <u>Frequency:</u> Based on demand parameters, the link frequency is determined for each route. It is done with the flexible routing strategy in mind. An equation is given by Gordon and Neufville '73 [Equation no. 9, p213], to determine the frequency of a link. It is determined as a function of capacity of aircraft, volume of passengers and gate-to-gate line haul time. Although the scale of these operations is too small as compared to the one considered for developing the equation, its heuristics will be followed.

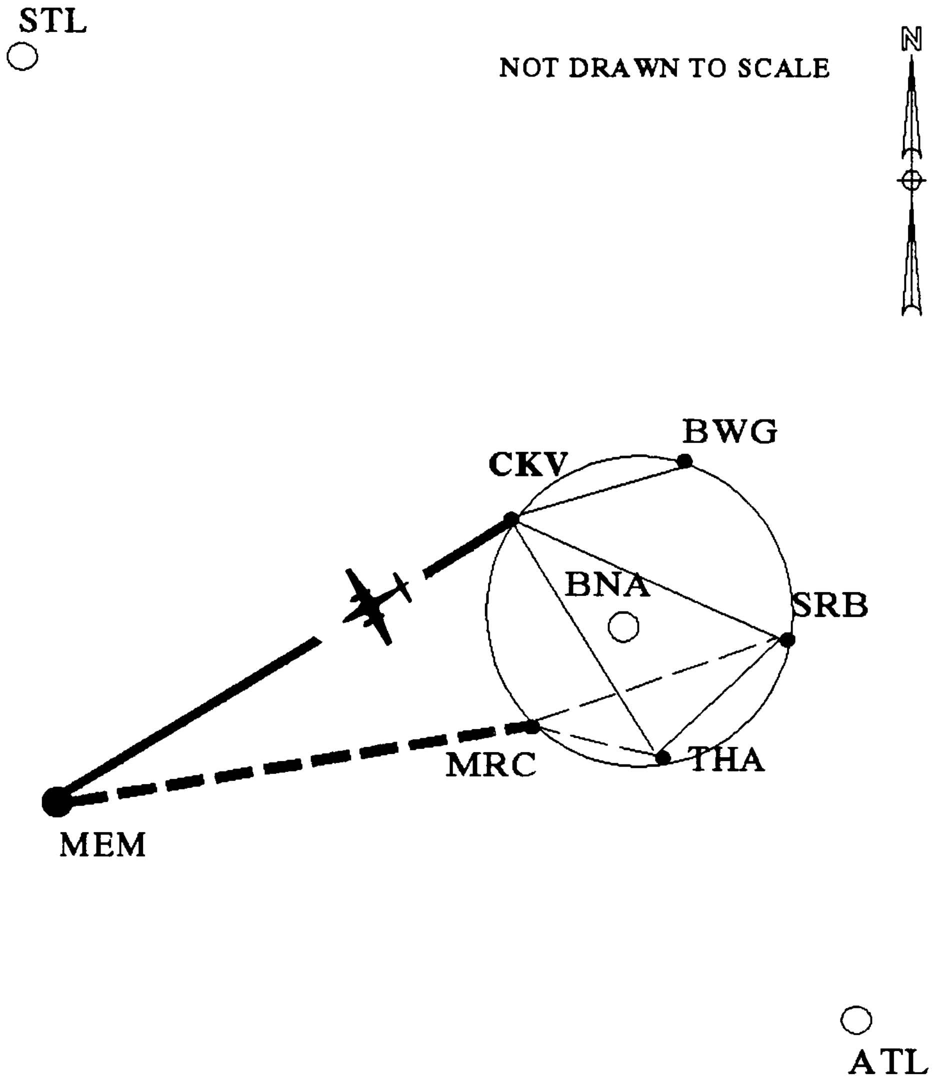
> "Each link is first of all assigned the minimal number of aircraft necessary to meet the demand, $v_i/c$. The remainder of the fleet is allocated among the links according to a square root law."

Where 'v' is the demand on route 'i', and 'c' is capacity of aircraft. According to this study the minimum number of



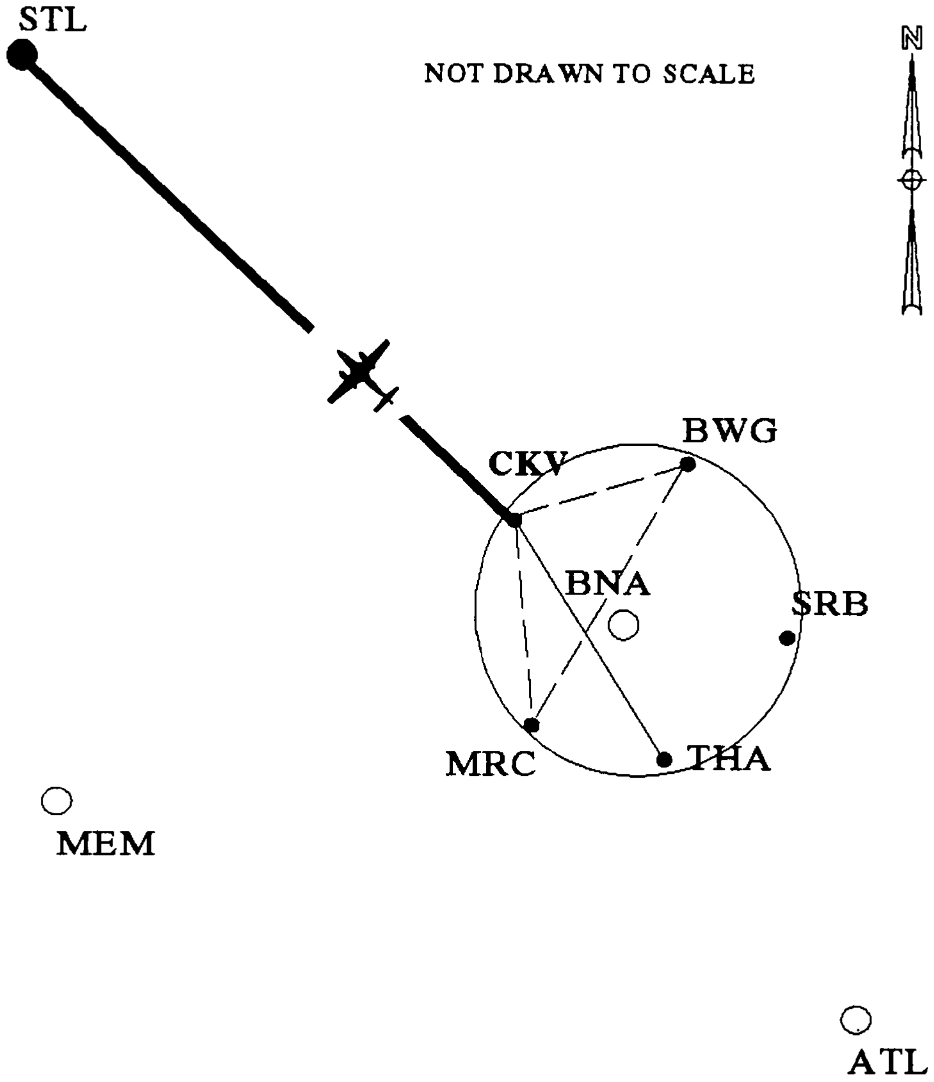

Network Connectivity is '0.5333'

Figure 6.1. Zone routing for Atlanta -- ATL.




Network Connectivity is '0.5333'

Figure 6.2. Zone routing for Memphis -- MEM.




Network Connectivity is '0.3333'

Figure 6.3. Zone routing for St. Louis -- STL.

aircraft required to serve the network is twelve, at a break-even load factor of 100 percent. However, to our benefit, all passengers do not desire to travel at the same time of the day. Thus, in addition, it would be possible to provide more frequency on those routes with minimal fleet size. Figure 6.4 is a graph, developed for the fleet size in relation to the break-even load factor.

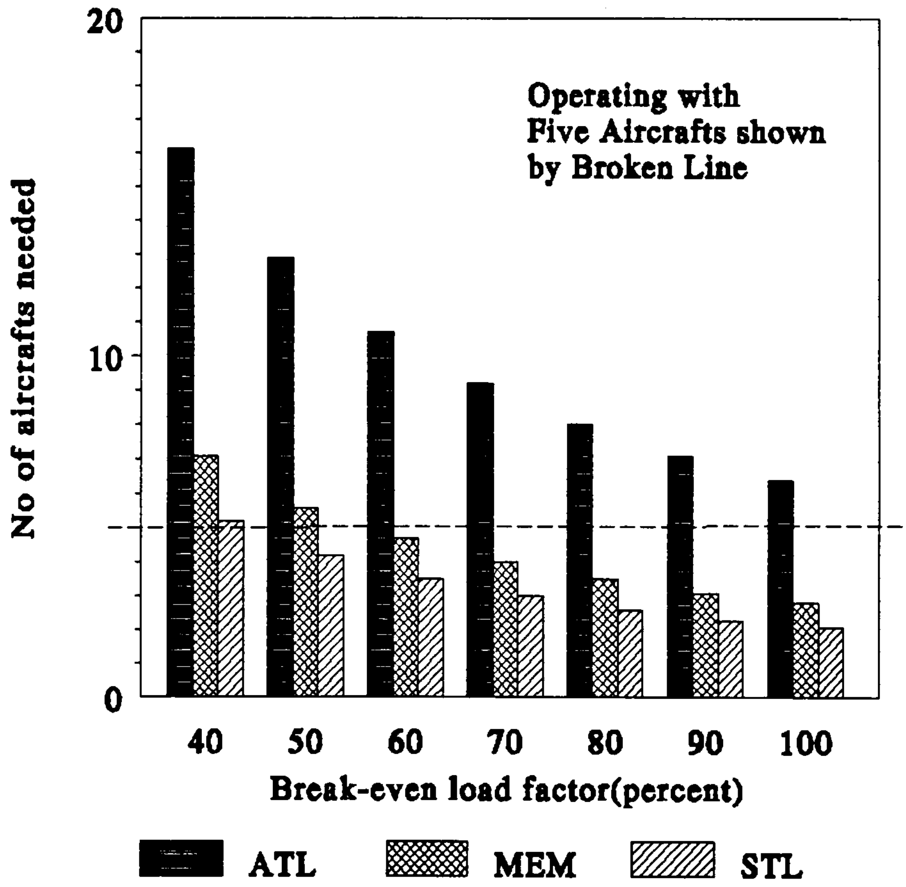



Figure 6.4. Fleet size vs break-even load factor

The Proposed fleet size of five aircraft, operating at 67 percent break-even load factor is appropriate for the projected demand level. A study by Burns '78 cites a previous research by Glenn '72 as stating, that

> "the enhanced profitability that can come from the use of smaller aircraft flying more frequently and making fewer stops on routes where demand is not to high. In fact, Glenn cautions against the use of aircraft that are too large".

He further emphasized the fact that fleet size, relative to aircraft size, offers opportunity for increased frequency and direct routing. The routes demanding the most service are THA-ATL, CKV-ATL and BWG-ATL indicating an increased frequency needed on these routes. Two aircraft are suggested for THA-ATL air route for this reason and one aircraft each for CKV-MEM and CKV-STL. While the fifth aircraft can be placed at CKV hub at all times as a support to either route out of CKV. One aircraft per route for CKV-MEM and CKV-STL may be a necessity during the demonstration phase of this service, but the need to acquire a larger fleet can be assessed later depending upon the success of operation.

Assuming 18 hours of operation a day, earliest flights can depart at 6:00 AM. The frequency during a normal day of operation is proposed as a minimum of;

- six flights on the THA-ATL-THA air route,
- two flights on the CKV-MEM-CKV air route and
- two flights on the CKV-STL-CKV air route

This frequency is based on the total projected demand for each of the three major hubs ( see table 4.2. ). The network within the zone has the highest connectivity, equal to one, which serves two purposes;

- provide basic air service to the community and
- fill the capacity for longer hub-to-hub hauls.

Since the routing system is flexible, mainly within the zone, suggested routes need not be followed strictly. Whereas, the demand at BWG warrants a direct link with both THA and CKV. Similarly, nodes MRC and SRB generate weaker demand thus requiring flexible links.

## 7. SCHEDULING INVESTIGATION

Looking ahead, scheduling offers a real time challenge to the planner. Seeking to secure space at ATL, MEM and STL hubs for enplaning and deplaning our passengers is one scheduling problem, while offering a time of departure suitable to all passengers is another. This last problem is particularly true since our service region stretches over two time zones. Such scheduling problems are what major airlines' planners face everyday.

Wells '89, states four types of scheduling techniques as follows:

"7.1. Skip-stop: It refers to the practice of providing service to points A,B,C,D,E,F,G, and so forth by scheduling flights in the following manner: A,C,E,G or A,D,G, or similar combinations in which one or more of the intermediate stations are 'skipped', with service being provided by other flights.

7.2. Local service: Shorter-range aircraft make all stops on a segment and connect at larger intermediate stations to or from long-range aircraft.

7.3. Cross-connections: Points are connected by cross connections through a common hub. It is similar to hubbing.

7.4. Nonstops: Points are connected directly with each other -- much similar to a point-to-point operation."

Of the above 'local service' is being proposed due to its similarity to the zone routing strategy, which by definition fits the characteristics of our service network. However flexible operations would need to be redefined appropriately in anticipation of connections desired by passengers at major hubs.

In addition to increased frequency within the zone, further revenues could possibly be generated by carrying passengers or payload on the 'positioning flights'.

## 8. SUMMARY AND RECOMMENDATIONS

The zone routing strategy is being suggested to serve the study region, using three configurations. The service may be launched, for demonstration purposes, beginning with a minimal fleet size of five aircraft and then expanding it later based on the project's success. Tullahoma and Clarksville are being proposed as regional hubs. One aircraft is assigned to Clarksville-Memphis and Clarksville-St. Louis route each, for a minimum frequency of two flights per day on each route. Two aircraft are assigned to the Tullahoma-Atlanta route with a minimum frequency of six flights per day. Inner routes of the zone may be served with the same aircraft, by short flights to the proposed regional hubs. The fifth aircraft may be stationed permanently as a relief aircraft to operations out of Clarksville.

Nashville may be considered as a hub in the future studies, for serving the proposed region, due to the reason that it can significantly reduce the problems related to flight scheduling. The flights to the three major hubs may be reduced or dropped, considering the demand for those routes. However, this will change the structure of the network, zone routing could then be replaced by split routing technique.

An aggressive sales and marketing promotion would need to be launched before the actual operations begin. The actual operations could be started with negligible cost for updating the ground facilities, since the proposed airports offer the basic services for passengers. Furthermore, the Global Positioning Systems are available which could be employed with a little addition of avionics on board the selected aircraft. However, consideration must be made for the requirement for Traffic Alert and Collision Avoidance System (TCAS), for FAR part 135 operators after the year 1995.

An extensive amount of work has been done, by earlier studies, on network optimization with the mathematical modelling approach. The software available from these studies is written on punch cards, if this work could be translated on current machines and a computer model tailored to this size of operation the work can magnify the schedule planner's efficiency by the ability to perform quick 'what if' analysis.

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## VITA

Azhar Khurshid Raina was born at Haripur, Pakistan on January 23, 1962. He attended high school there, graduating with honors in 1975 he went to the Pakistan Air Force Intermediate College in Peshawar and graduated with an F.Sc. certificate in 1977. He graduated from the North-West Frontier Province (NWFP) University of Engineering and Technology, Pakistan with a B.E. in Mechanical Engineering in 1982. He then worked at a refrigeration plant for a year. In the summer of 1983, he was married and is now blessed with a daughter and a son. In the fall of that year he was offered a fellowship to attend a comprehensive computer training program presented for the first time by the government of Pakistan.

Azhar joined the Telephone Industries of Pakistan (TIP) in 1985. He visited the United States the same year and thought of pursuing his M.S. in Systems Engineering. He decided to specialize in Aviation Systems, and entered the University of Tennessee in 1988, after resigning from the TIP. He graduates with that major in the spring of 1993.

Azhar was awarded the status of a 'Professional Engineer' by the Pakistan Engineering Council. He is an associate member of the Society of Flight Test Engineers and the Institute of Industrial Engineers, a member of the Society of Reliability

Engineers and a Competent Toastmaster at the Toastmasters International.

He hopes someday, to find an electron that he can trust [16].