A Heuristic Approach to Solve Air Taxi Scheduling Problem

Harish Chavan

Thesis Submitted to the Faculty of Virginia Polytechnic Institute and State University in Partial fulfillment of the requirements for the degree of Masters of Science in Industrial and Systems Engineering

C. Patrick Koelling, Ph.D.
Dr. Antonio A. Trani, Ph.D.
Dr. Michael R. Taaffe, Ph.D.

September, 2003
Blacksburg, Virginia

Keywords: Air Taxi, Small Aircraft Transportation Systems, Scheduling
A Heuristic Approach to Solve Air Taxi Scheduling Problem
by
Harish Chavan
Committee Chairman: Dr. C. Patrick Koelling
Industrial and Systems Engineering

(Abstract)

All passengers travel at the hour most convenient to them. But it is not always possible to find a flight at the right time to fly them to their destination. In the case where service in any one time period is insufficient to meet air travel demanded, it may be expected that some unfilled demand passengers will either delay their flight or will advance it, thus adding to the effective demand of the adjoining time periods.

The obvious alternate means of travel is a rental car. It takes a lot more time than flight, but it is readily available at any given time. This brings us to think of an airline system that will work in a similar fashion; A system that can be named an “Air Taxi System.” This would mean a virtual highway in air space leading to a vast network. The network would be served by small aircraft flying from one city to another. Such a large network having dynamic demand will have many issues to resolve before successfully launching a Small Aircraft Transportation System. One of the most important problems to solve is scheduling of aircraft for such a stochastic demand flow.

The objective of the research is to study a given set of airports with dynamic demand and known aircraft type. The major task will be to analyze the flow of passengers between each origin-destination pair and then schedule flights. The research will be to develop a schedule for a fixed set of airports with dynamic demand and known type of aircraft. The main objective is to maximize demand satisfaction. The study will also analyze the number of aircraft required for a given set of airports and find a method to schedule them.
Acknowledgements

I sincerely thank Dr. Pat Koelling for providing me with constant guidance and support in completion of this endeavor. His kindness and enthusiasm encouraged me over these past two years. I also thank Dr. Michael Taaffe and Dr. Toni Trani for their advice and dedication of time and talent. I thank Ms. Lovedia Cole for helping me through all the paperwork. Lovedia is the backbone of the entire Industrial and Systems Engineering Department.

I cannot thank my parents enough for their blessings and love. Nothing could have ever worked out without their support. I thank Samir and Manjiri (brother and sister-in-law), Rashmi (sister) for taking care of all my worries. I also would like to mention Hrishikesh and Rohit for making me feel at home in the US and Sumeet who is always there to support me.

I would like to thank my roommates and friends at Virginia Tech for making the whole experience a lot of fun. Thanks to Ujval and Madhukar for handling all the paperwork in my absence. Special thanks to Kavita for being there when it mattered the most. I also thank my laptop which never crashed while running long matlab codes. Thank you, Kavita and Smruti for the great food and chai every morning.

Finally, I thank God for taking good care of me and all my well wishers.
# Table of Contents

Chapter 1 – Introduction........................................................................... 1

Chapter 2 – Literature Review................................................................. 4

2.1 Flight Scheduling............................................................................. 4
2.2 Time-of-Day Models.......................................................................... 5
2.3 Frequency Planning Models............................................................... 11
    2.3.1 Linear Programming Models for Frequency Planning................. 12
    2.3.2 Integer Programming Models for Frequency Planning.............. 14
2.4 Minimizing Waiting Time of Passengers......................................... 15
2.5 Minimum Number of Aircrafts Required......................................... 18
2.6 Aircraft Rotation Models................................................................. 24
2.7 Aircraft Scheduling.......................................................................... 25

Chapter 3 – Methodology....................................................................... 28

3.1 Problem............................................................................................ 28
3.2 SATS Aircraft.................................................................................. 30
3.3 Time Unit.......................................................................................... 32
3.4 Demand and Flight Frequency......................................................... 34
3.5 Passenger Waiting Time................................................................... 36
3.6 Flight Assignment and Routing......................................................... 38
    3.6.1 Algorithm 1 – Generate a matrix that will provide data regarding
        the proximity of cities from a particular city individually.................. 38
3.6.2 Algorithm 2 – Develop a schedule for the network ........................................... 44

Chapter 4 – Analysis ................................................................. 57

4.1 Matlab Program ................................................................. 57
4.2 Experiments ................................................................. 58
4.3 Output ................................................................. 60
4.4 Results ................................................................. 61
  4.4.1 Analysis ............................................................... 62
    4.4.1.1 Fleet Utilization ...................................................... 62
    4.4.1.2 Dead Legs ............................................................ 63
    4.4.1.3 Scheduled Flights .................................................. 63
    4.4.1.4 Passenger Load Factor ............................................ 65
  4.4.2 Cost Analysis .............................................................. 67
    4.4.2.1 Cost of new aircraft ................................................ 67
    4.4.2.2 Pilot Salary .......................................................... 67
    4.4.2.3 Cost of Fuel .......................................................... 67
    4.4.2.4 Maintenance Cost .................................................. 68
    4.4.2.5 Miscellaneous Cost ............................................... 68
    4.4.2.6 Cost ................................................................. 69
    4.4.2.7 Cost of Dead Leg .................................................... 69
    4.4.2.8 Cost of Losing a Passenger ....................................... 69
  4.5 Sensitivity Analysis on cost of losing a customer ................................. 73
    4.5.1 Average Cost per seat ................................................ 73
# List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.1</td>
<td>Passenger Demand Per Month As A Fraction Of Mean For Each Year</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Passenger Demand Per Day As A Fraction Of Mean For Each Week</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Passenger Demand On Hourly Basis As A Fraction Of Mean For Each Day</td>
<td>8</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Space-Time Diagram</td>
<td>19</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>Bipartite Graph For Branches From S1, S2, S3, S4</td>
<td>21</td>
</tr>
<tr>
<td>Figure 2.6</td>
<td>Final Solution</td>
<td>22</td>
</tr>
<tr>
<td>Figure 2.7</td>
<td>Routes For All 4 Vehicles</td>
<td>23</td>
</tr>
<tr>
<td>Figure 2.8</td>
<td>Initial Scheduling Program</td>
<td>27</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>Speed of Aircraft</td>
<td>31</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Probability Density Function Of Passenger Arrival</td>
<td>33</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Cumulative Distribution Function Of Passenger Arrival</td>
<td>33</td>
</tr>
<tr>
<td>Figure 3.4</td>
<td>Relation Of O-D Pairs With The Number Of Cities</td>
<td>36</td>
</tr>
<tr>
<td>Figure 3.5</td>
<td>Waiting Time For Passengers</td>
<td>37</td>
</tr>
<tr>
<td>Figure 3.6</td>
<td>Flowchart Of Algorithm 1</td>
<td>40</td>
</tr>
<tr>
<td>Figure 3.7</td>
<td>Flowchart Of Algorithm 2 Part(a)</td>
<td>41</td>
</tr>
<tr>
<td>Figure 3.8</td>
<td>Flowchart Of Algorithm 2 Part(b)</td>
<td>42</td>
</tr>
</tbody>
</table>
Figure 4.16  Average Cost per Seat (Penalty of $700 and $800) .................... 77
Figure 4.17  Average Cost per Seat (Penalty of $900 and $1000)............... 78
Figure 4.18  Average Cost per Seat (Penalty of $1100 and $1200)............. 79
Figure 4.19  Average Cost per Seat per mile ....................................... 80
Figure 4.20  Comparison between different fleet sizes ............................ 82
List of Tables

Table 3.1  Hour Of The Day And Probability Of Passenger Arrival ...............  29
Table 3.2  Eclipse 500 Performance (Eclipse Aviation) .............................  30
Table 3.3  Probability Of Passenger Arrival By Time Unit ..........................  32
Table 3.4  Probability Of Passenger Arrival per Time Unit ......................  45
Table 4.1  Fleet Size for different number of cities ..................................  58
Table 4.2  List of Experiments ..........................................................  59
Table 4.3  Average Cost/ Seat ..........................................................  72
Table 4.4  Percentage of positive factors as compared to the maximum value ..................................................  81
Table 4.5  Percentage of negative factors as compared to the maximum value ..................................................  81