Integrated Optimization Model for Airline Schedule Design:
Profit Maximization and Issues of Access for Small Markets

by

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Abstract

The purpose of the National Airspace System Strategy Simulator is to provide the FAA with a decision support system to evaluate long-term infrastructure and regulatory strategies. The NAS strategy simulator consists of several modules representing the different entities within the NAS embedded in a system dynamics framework. The MIT Airline Scheduling Module is the module within the NAS Strategy Simulator that represents the decision making process of the airlines with respect to the schedules that they fly.

The MIT Airline Scheduling Module is an incremental optimization tool to determine schedule changes from one time step to another that best meets demand using available resources. The optimization model combines an Integrated Schedule Design and Fleet Assignment model and a model, based on Passenger Decision Window model, that determines passenger preference for itineraries. We simultaneously establish frequency, departure times, fleet assignment, passenger loads and revenue within a competitive environment.

Optimization methods often lead to extreme schedule decisions such as eliminating service to markets, often small markets, that are not financially profitable for the airlines. This is of grave concern to government policy makers as rural access to markets, goods and services is a politically charged subject. The issue is to understand what is likely to happen in small communities if the government doesn’t respond in some way and how much subsidy, if any, would it be necessary to encourage airlines to maintain service in these markets. The approach we will use is based on economic policy and cost-benefit analysis.

Thesis Supervisor: John-Paul Clarke
Title: Associate Professor of Aeronautics and Astronautics
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Chapter 1

Introduction

I  MIT Airline Scheduling Module

The National Airspace System (NAS) Strategy Simulator is being developed by the Federal Aviation Administration (FAA) to evaluate long-term infrastructure and regulatory strategies. The NAS Strategy Simulator consists of several modules (representing the different entities within the NAS) embedded in a system dynamics framework. The MIT Airline Scheduling Module (ASM) is the module within the NAS Strategy Simulator that represents the decision making process of the airlines with respect to the schedules that they fly.

The approach that is used in the MIT Airline Scheduling Module to generate the airline schedule is driven by a simple observation: because the airline industry is characterized by intense competition and a high cost structure, an airline must continuously adjust its schedule and fleet assignment to minimize cost, meet passenger demand and thus maximize its potential revenue. Therefore, airlines rely on advanced optimization techniques to develop mission-critical decision support systems for management and control of airline operations.

In this thesis, we present the details of an optimization model to generate a schedule that maximizes the profit of the airline. This model simulates the fundamental airline decisions that occur during the planning process.

II  Airline Decision Making Process

II.1 Overview of the Airline Planning Process

The primary product of an airline is its flight schedule: a feasible plan of the cities and corresponding times from/to which the airline will operate flights. Efforts to differentiate this product from that of competitors include being first to introduce new aircraft types,
increasing frequency of service, increasing the quality of in-flight catering and advertising [Doganis, 1991].

The objective of minimizing costs and maximizing revenues is achieved through careful planning. An overview of the airline planning process is shown in Figure 1-1. As shown in the figure, the airline planning process has five major components: fleet planning, schedule planning, revenue management, crew scheduling, and airport resource planning [Lohatepanont, 2002]. These five steps may be explained as follows:

1. In the fleet planning step, the airline decides whether to purchase or lease new or used aircraft and what type of aircraft should be bought or leased.

2. Schedule planning is defined as the design of system-wide flight patterns that provide optimum public service, in both quantity and quality, consistent with the financial health of the carrier [Wells, 1994].

3. Given a fleeted schedule, the purpose of revenue management is to maximize the revenue subject to the seat capacity and the fare types. An ideal revenue management system consists of two distinct but closely related components [Belobaba, 1987]: differential pricing, and seat inventory control.

4. In crew scheduling, the objective is to find the minimum cost assignment of flight crews (pilots and/or flight attendants) to flight legs subject to several restrictions, such as maximum flying time or minimum rest time requirements.

5. Finally, airport resource planning deals with gate allocation, slot allocation (if applicable), and ground personnel scheduling.

As is to be expected from the order in which they occur, fleet planning and schedule planning are long-term strategic decisions that provide a basis for the airline business and are typically revised only a couple of times a year. Revenue management, crew scheduling, and airport resource planning are more tactical decisions, and made for immediate or short-term application.
Figure 1-1: An Overview of the Airline Planning Process

Schedule planning is one of the most vital and critical decision making steps in the airline planning process. It consists of three major components: schedule design, fleet assignment, and aircraft rotations. Most of the time, schedule planning starts from an existing schedule, with a well developed route structure. Changes are then introduced to the current schedule to reflect changing demands and/or changes in the operating environment.

The schedule design step is arguably the most complicated step of all and traditionally has been decomposed into two sequential steps: frequency planning and timetable development.
In frequency planning, one determines the appropriate service frequency in a market. In timetable development, one places the proposed services throughout the day subject to network considerations and other constraints.

The objective of fleet assignment is to assign the available aircraft to the flight leg in the schedule such that the seating capacity on the aircraft closely matches the demand for the flight to which an aircraft is assigned. Or, in other words, to minimize the number of passengers that cannot be served because there are not enough seats on the aircraft.

The objective of the aircraft rotation step is to find a set of maintenance feasible rotations for the available aircraft (a rotation is a sequence of connected flight legs flown by a single aircraft that respects the maintenance rules of the airlines and regulatory agencies) given the fleeted schedule and the available number of aircraft of each type [Lohatepanont, 2002].

**II.2 Interaction between Supply and Demand**

Traditionally, airline schedule planning is performed under the assumption that total demand is known and is fixed regardless of changes in the schedules. However, the relationship between supply and demand is non-linear and depends on numerous interrelated parameters. Thus, it is difficult to evaluate the impact of one scheduling decision much less determine the right decision.

The Integrated Schedule Design and Fleet Assignment Model, or ISD-FAM [Lohatepanont, 2002], captures the interaction between demand and supply in that it takes into account the following situation: if a flight was not profitable because passengers did not choose it when selecting their itinerary and it thus turned out that the operating costs were higher than the revenue generated, then the airline's interest is best served by taking this flight out of its schedule. However, the airline's interest is also served by adding more flights in promising markets to increase service frequency and capture more market share. Therefore, the goal is to determine the flights that the airline should take out and the flights that it should add. The Extended Schedule Design and Fleet Assignment Model, or ESD-FAM [Lohatepanont, 2002], went a step further by simultaneously updating market shares as changes are made to the schedule.
II.3 Competitive Environment

However there is a limitation to the ESD-FAM: while market shares are updated as changes are made to the schedule of one airline, it is assumed that the schedules of its competitors are fixed. Obviously this does not correspond to what happens in reality since airlines are continuously and simultaneously modifying their schedule.

Understanding and simulating the competitive environment within which the airline is operating is thus a major difficulty in airline’s decision making. This competitive environment heavily affects the airline’s ability to attract significant market shares. Indeed, when an airline decides to change its schedule either by adding or taking out a flight or by up increasing or decreasing capacity on a flight leg, it changes the total supply distribution and therefore affects the demand distribution among all the airline competitors. Consequently, the competitive environment within which the airline is operating should be key to any schedule design decision.

III Focus of the Thesis

III.1 Combining Existing Models

The MIT Airline Scheduling Module developed in this thesis integrates two complementary approaches regarding the airline industry that have so far been studied separately: Airline Schedule Planning and Airline Passenger Choice Theory.

Airline Schedule Planning is the generation of the schedule that maximizes the airline’s profit given assumed passenger preferences. In other words, the input is the exact number of passengers that will effectively travel on a flight leg or an itinerary if the latter happens to be scheduled by the airline given capacity constraint. In this case, the demand data are thus considered as fixed and the output is the schedule and the corresponding fleet assignment solution.

Airline Passenger Choice Theory models passenger preference for a given schedule. Contrary to Airline Schedule Planning, Airline Passenger Choice Theory takes a fleted schedule as input and determines the passenger flow over the network given capacity
constraint. In this case, the schedule is fixed beforehand and the output is the load for each scheduled flight.

The ASM developed in this thesis has been designed to take both approaches into account and thus bring the integration of the airline scheduling process a step further by coupling two different models:

- The Extended Airline Schedule Design and Fleet Assignment Model or ESD-FAM, which simultaneously solves the schedule generation problem and the fleet assignment problem, and

- The Decision Window Model or DWM, which simulates Airline Passenger Choice.

Instead of forecasting how many passengers the airline will capture given its fixed schedule and then computing the airline’s profit, we want to design the airline’s schedule so as to maximize the airline’s profit.

### III.2 Using a Recursive Approach

As previously underlined, understanding and simulating the competitive environment within which the airline is operating is critical to the airline’s decision-making. The approach presented in this thesis is from the point of view of an airline that is aware of the particular competitive environment in which it is doing business and that is thus seeking a methodology to make rational decisions about its own schedule for the next time period. The resulting ASM model is thus based on an iterative process. The idea is that combining both Airline Schedule Design and Airline Passenger Choice Theory within a recursive process will improve the airline’s abilities, when it is designing its schedule, to model the processes that occur in real life.

Given the aircraft availability of the airline in the future (possible scenarios: acquisition, retirement, no change) and a pre-specified list of candidate flight departures, the ASM Model is an automated tool, which designs the schedule for the next time period that will attract the most passengers and maximize profit by maximizing revenues while minimizing operating costs.
III.3 Access for Small Markets

That being said, if schedule decisions are purely driven by optimization methods, service to small markets may often be eliminated. This is of grave concern to government policy makers as rural access to markets, goods and services is a politically charged subject.

Indeed, when the Airline Deregulation Act passed in 1978 in the USA and gave airlines almost total freedom to determine which markets to serve domestically and what fares to charge for that service, the Essential Air Service (EAS) program was put into place to guarantee that small communities that were served by certificated air carriers before deregulation maintain a minimal level of scheduled air service. The U.S. Department of Transportation currently subsidizes commuter airlines to serve approximately 100 rural communities across the country that otherwise would not receive any scheduled air service.

In other words, deregulation has a positive effect for the airline industry and, more generally, for the travelers. However, it creates some significant challenges, which must be tackled if the country wants to continue to enjoy these benefits in the future. One of the key issues is the need to ensure that small regional markets receive the best possible service.

IV Thesis Outline

The outline of this thesis is as follows. In chapter 2, we review some existing models and detail their respective contributions and limitations. In part A of chapter 2, we present the Extended Airline Schedule Design and Fleet Assignment Model, which generates the airline’s schedule given the demand. In part B of chapter 2, we present two models that allocate the demand given the airline’s schedule: the Frequency Share - Market Share Model and the Decision Window Model. In chapter 3, we present our MIT Airline Scheduling Module, which combines the models developed in chapter 2, and detail our solution approach. A case study and examination of the potential benefits of our integrated model and solution approaches are presented in chapter 4. In chapter 5, we broaden the discussion by investigating policy issues of access for small markets. Finally, in chapter 6, we conclude with recommendations and possibilities for future research directions.
Chapter 2

Overview of Existing Models

Part A: Modeling Airline Schedule Design Given Demand

Extended Schedule Design and Fleet Assignment Model (ESD-FAM)

The Extended Schedule Design and Fleet Assignment Model (ESD-FAM) was developed by Manoj Lohatepanont in 2002.

I Notations

For convenience and reference, we list all notations for sets, decision variables, and parameters in this section.

I.1 Sets

\( P \): The set of itineraries in a market indexed by \( p \) or \( r \).

\( P^o \): The set of optional itineraries indexed by \( q \).

\( A \): The set of airports, or stations, indexed by \( a \).

\( L \): The set of flight legs in the flight schedule indexed by \( i \).

\( L^f \): The set of mandatory flights indexed by \( i \).
\( L^0 \): The set of optional flights indexed by \( i \).

\( K \): The set of different fleet types indexed by \( k \).

\( T \): The sorted set of all event (departure or availability) times at all airports, indexed by \( j \).

The event at time \( j \) occurs before the event at time \( j+1 \). Suppose \( |T| = m \); therefore \( t_1 \) is the time associated with the first event after the count time and \( t_m \) is the time associated with the last event before the next count time.

\( N \): The set of nodes in the timeline network indexed by \{\( k; o, j \}\}.

\( CL(k) \): The set of flight legs that pass the count time when flown by fleet type \( k \).

\( I(k, o, t) \): The set of inbound flight legs to node \{\( k; o, j \}\}.

\( O(k, o, t) \): The set of outbound flight legs to node \{\( k; o, j \}\}.

\( L(q) \): The set of flight legs in itinerary \( q \).

### 1.2 Decision Variables

\( t'_p \): The number of passengers requesting itinerary \( p \) but the airline attempts to redirect to itinerary \( r \).

\( f_{k,i} \): \( =1 \) if flight leg \( i \in N \) is assigned to fleet type \( k \in K \); \( =0 \) otherwise.

\( Z_q \): \( =1 \) if itinerary \( q \in P^o \) is selected; \( =0 \) otherwise.

\( \zeta_q = (1 - Z_q) \): \( =0 \) if itinerary \( q \in P^o \) is selected; \( =1 \) otherwise.

\( y_{k,o,t} \): The number of fleet type \( k \in K \) aircraft that are on the ground at airport \( o \in A \) immediately after time \( t_j \in T \).
$y_{k,o,s_1}$: The number of fleet type $k \in K$ aircraft that are on the ground at airport $o \in A$ immediately before time $t_j \in T$. If $t1$ and $t2$ are the times associated with adjacent events, then $y_{k,o,s_1} = y_{k,o,s_2}$.

1.3 Parameters/Data

$CAP_i$: The number of seats available on flight leg $i$ (assuming fleeted schedule).

$SEATS_k$: The number of seats available on aircraft of fleet type $k \in K$.

$N_k$: The number of aircraft in fleet type $k$, $\forall k \in K$.

$N_q$: The number of flight legs in itinerary $q$.

$D_p$: The unconstrained demand for itinerary $p$; i.e., the number of passengers requesting itinerary $p$.

$Q_i$: The unconstrained demand on leg $i$ when all itineraries are flown.

$fare_p$: The fare for itinerary $p$.

$b_p^r$: Recapture rate from $p$ to $r$; the fraction of passengers spilled from itinerary $p$ that the airline succeeds in redirecting to itinerary $r$.

$\delta_i^p$: $=1$ if itinerary $p \in P$ includes flight leg $i \in N$;

$=0$ otherwise.

$\Delta D_q^p$: Demand correction term for itinerary $p$ as a result of canceling itinerary $q$. 


II ESD-FAM Methodology

II.1 Incremental Changes

As stated earlier, the traditional approach to schedule development is sequential; it consists of three steps: schedule design, fleet assignment, and aircraft rotation. In the ESD-FAM approach, market service frequency, departure times (given a pre-specified list of candidate flight departures), and fleet assignments are all determined simultaneously.

The ESD-FAM assumes that the schedule is daily (the same set of flights are flown every day) and uses an incremental approach to schedule design. In other words, instead of building a schedule from scratch, the ESD-FAM takes a base schedule (the daily schedule at the current time period) as input and makes some changes to it (add new flight leg, remove current flight leg) so as to generate the schedule for the next time period. It is in agreement with industry practice and therefore reasonable to assume that the new schedule will be based on the current schedule to which a number of modifications are introduced.

More specifically, the ESD-FAM takes two sets of flight legs as inputs: (1) mandatory flights, and (2) optional flights; the potential modifications in the schedule would only affect the set of optional flight legs. Note that the flight legs flown in the current schedule may be in either of these two sets. The set of optional flights may include flight legs that have not been flown so far. The set of mandatory flights do not include any flight leg that has not been flown so far because the decision whether this flight leg should be flown is precisely what the model should determine. However, it is theoretically possible to include flight legs that have not been flown so far in the set of mandatory flights if necessary.

II.2 Passenger Flow Adjustment

The ESD-FAM uses two mechanisms to adjust passenger flows:

1. Demand correction terms, and
2. Recapture rates.
With demand correction terms, the ESD-FAM aims at capturing demand and supply interactions by adjusting the unconstrained demand on alternate itineraries \( p \in P \) in a market \( m \) when an optional itinerary \( q \in P^o, (p \neq q) \) is removed using demand correction terms \( \Delta D^p_q \)'s. The total unconstrained demand (market share) of the airline in a market \( m \) is therefore altered by
\[
D_q + \sum_{p \in P, p \neq q} \Delta D^p_q \left(1 - Z_q\right).
\]

With recapture rates, the ESD-FAM simulates the reallocations on alternate itineraries \( r \in P \) in market \( m \) of passengers who would have liked to travel on an itinerary \( p \in P \) when this itinerary \( p \) is capacitated, using the recapture rates \( b_p^r \)'s. This does not affect the total unconstrained demand (market share) of the airline in market \( m \).

### III ESD-FAM Objective Function

The objective of the ESD-FAM is to maximize schedule contribution, defined as revenue generated less operating cost incurred.

The operating cost of a schedule (\( O \)) can be computed as follows, once fleet-flight assignments are determined:
\[
O = \sum_{k \in K} \sum_{i \in L} c_{k,i} f_{k,i}
\]

The total revenue of a schedule can be computed from the following components:

1. Initial unconstrained revenue (\( R \)):
\[
R = \sum_{p \in P} \text{fare}_p D_p
\]

2. Lost revenue due to spill (\( S \)):
\[
S = \sum_{p \in P} \sum_{r \in P} \text{fare}_p t'_p
\]

3. Recaptured revenue from recapturing spilled passengers (\( M \)):
\[
M = \sum_{p \in P} \sum_{r \in P} b^r_p \text{fare}_p t'_p
\]
4. Changes in unconstrained revenue due to market share changes because of flight leg addition or deletion ($\Delta R$):

$$\Delta R = \sum_{q \in P^0} \left( fare_q D_q - \sum_{p \in P, p \neq q} fare_p \Delta D_q^p \right)$$

The contribution maximizing objective function of the ESD-FAM is therefore:

$$\text{Max } R - \Delta R - S + M - O$$

An equivalent cost minimizing objective function can be obtained by ignoring the constant initial unconstrained revenue ($R$), which was computed for the schedule with all optional flights flown, and reversing the signs of all other elements:

$$\text{Min } O + (S - M) + \Delta R$$

IV  ESD-FAM Formulation

The formulation for the Extended Schedule Design and Fleet Assignment Model is the following:

$$\text{Min } \sum_{k \in K} \sum_{i \in L^e} c_{k,i} f_{k,i} + \sum_{p \in P} \sum_{r \in P} \left( fare_p - b'_p fare_{r'} \right) t'_p + \sum_{q \in P^0} \left( fare_q D_q - \sum_{p \in P, p \neq q} fare_p \Delta D_q^p \right) (1 - Z_q)$$

Subject to:

1. $$\sum_{k \in K} f_{k,i} = 1 \quad \forall i \in L^f$$
2. $$\sum_{k \in K} f_{k,i} \leq 1 \quad \forall i \in L^o$$
3. $$\sum_{i \in L^f(k,o,t)} f_{k,i} - \sum_{i \in L^o(k,o,t)} f_{k,i} = 0 \quad \forall k, o, t$$
4. $$\sum_{o \in O} y_{k,o,t} + \sum_{k \in K} f_{k,i} \leq N_q \quad \forall k \in K$$
5. $$-\sum_{p \in P, p \neq q} \delta_i^p \Delta D_q^p (1 - Z_q) + \sum_{k \in K} f_{k,i} SEATS_i + \sum_{r \in P} \sum_{p \in P} \delta_i^p t'_p - \sum_{r \in P} \sum_{p \in P} \delta_i^p b'_p t'_r \geq O_i \quad \forall i \in L$$
6. $$-\sum_{q \in P^0} \Delta D_q^p (1 - Z_q) + \sum_{r \in P} t'_p \leq D_p \quad \forall p \in P$$
7. $$Z_q - \sum_{k \in K} f_{k,i} \leq 0 \quad \forall i \in L(q)$$
8. $$Z_q - \sum_{i \in L(q), k \in K} f_{k,i} \geq 1 - N_q \quad \forall q \in P^0$$
The 1st set of constraints is the set of cover constraints for mandatory flights ensuring that every mandatory flight is assigned to a fleet type. The 2nd set of constraints is the set of cover constraints for optional flights allowing the model to choose whether or not to fly flight \( i \) in the resulting schedule; if flight \( i \) is selected, a fleet type has to be assigned to it.

The 3rd set of constraints ensures the conservation of aircraft flow.

The 4th set of constraints is the set of count constraints ensuring that only available aircraft are used.

The 5th set of constraints is the set of capacity constraints ensuring that the number of passengers on each flight \( i \) does not exceed its capacity. The term \( \sum_{p \in P} \sum_{q \in P^o} \delta_{i}^{p} \Delta D_{q}^{p} (1 - Z_{q}) \) represents corrected demand at flight level when optional itineraries \( q \in P^o \) are deleted.

The 6th set of constraints is the set of demand constraints ensuring that the model does not spill more passengers than demand for the itinerary. The term \( \sum_{q \in P^o} \Delta D_{q}^{p} (1 - Z_{q}) \) corrects the unconstrained demand for itinerary \( p \in P \) when optional itineraries \( q \in P^o \) are deleted.

The 7th and 8th set of constraints are itinerary status constraints that control the \{0,1\} variable, \( Z_{q} \), for itinerary \( q \). Specifically, the 7th set of constraints ensures that \( Z_{q} \) takes on value 0 if at least one leg \( q \) is not flown and the 8th set of constraints ensures that \( Z_{q} \) takes on value 1 if all legs in \( q \) are flown.
V Conclusion

The ESD-FAM model has two interesting features. First of all, the ESD-FAM approach simultaneously determines market service frequency, departure times (given a pre-specified list of candidate flight departures), and fleet assignment. Secondly, the ESD-FAM approach uses demand correction terms to alter the total unconstrained demand (market share) of the airline in market \( m \) when schedule changes (add/remove) are made to itineraries serving this market.

One way to enhance the ESD-FAM model would be to establish a mechanism to modify the demand for a market \( m \) when the service frequency of this market changes. By doing so, the supply-demand interactions and the competitive environment would be considered during the schedule design process to determine the profit-maximizing schedule that satisfies fleeting constraints.

The ESD-FAM does not provide a way to simulate the importance of fares since fares are only used as parameters when computing the unconstrained revenue and the revenue lost or gained when optional flights are deleted or added. A way to improve further the model would thus be to incorporate the effects of fares by linking the profit maximizing objective function of the ESD-FAM and a revenue management model.
Part B: Modeling Demand Allocation Given Airline Schedule

Frequency Share - Market Share Model

1 Objective of the Frequency Share - Market Share Model

One of the simplest and most commonly used ways to describe the airline competitive environment is to determine market share as a function of frequency share in an isolated O&D market. These models are Frequency Share - Market Share Models (FS-MS).

1.1 Basic S-curve Model

The relationship between frequency share and market share is not linear. For a given competitor i, $MS_i$, the market share of total passenger demand for airline i, is a function of $Freq_i$, the two-way frequencies for airline i and all its competitors j (Eq. 1). The coefficient $\alpha$ is an exponent representing the advantage of carriers with higher frequency shares. It typically has values between 1 and 2.

$$MS_i = \frac{Freq_i^\alpha}{\sum_j Freq_j^\alpha} \quad (Eq. 1)$$

This model is based on the assessment that if an airline increases its service frequency, it will, as a result, capture more passengers. The relationship between frequency share and market share is represented by a curve with a S-shape (as shown in figure 2-1), hence very often referred to as the S-curve model.
1.2 Extended Frequency Share – Market Share Model

The basic FS-MS model has been extended [Melconian and Clarke, 2001] to include through and connecting flights by modifying the meaning of \( Freq_i \) to include not only nonstop flights, but a weighted sum of all available flights (Eq. 2). The extended model includes a term for flights with one stop and flights with one connection; flights with more than one stop, more than one connection, or both a stop and a connection are not included in the model.

\[
Freq_i = Freq_{\text{nonstop}} + b.Freq_{\text{onestop}} + c.Freq_{\text{onecomp}}
\]  

(Eq. 2)

The parameter \( b \) is the value of one-stop flights, and the parameter \( c \) is the value of one-connection flights. These are fractions of the value of a non-stop flight, and should in all cases be between 0 and 1. The results are presented in the following table (Table 1).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>1.107</td>
</tr>
<tr>
<td>$b$</td>
<td>0.233</td>
</tr>
<tr>
<td>$c$</td>
<td>0.048</td>
</tr>
</tbody>
</table>

Table 2-1: Nonlinear Fit Results ($\alpha \neq 1$)

II Features and Limitations of the FS-MS Model

The Frequency Share - Market Share Model represents the correlation between Frequency Share and Market Share. The higher the frequency, the higher the market share. Moreover, the relationship is not linear: an airline with a low frequency share that increases its service frequency by one (everything else remaining unchanged) will capture more extra market share than an airline with a high frequency share that increases its service frequency by one (everything else remaining unchanged).

The strength of the model is its simplicity. However, there are three assumptions that limit its utility: (1) the total market demand is fixed, (2) fares are not used as decision factors, and (3) the demand for travel does not depend on the time-of-day.

II.1 Total Market Demand Is Fixed

In Frequency Share - Market Share Models, it is implicitly assumed that the total demand for every single market is fixed no matter how high the total aggregated frequency over all the airlines offering service is. In other words, when service frequencies vary, the passengers are simply being redistributed among all the airlines offering service whereas the total number of passengers served over all the airlines remains unchanged. Moreover, if an airline is already attracting 100% of the market, the airline is not going to generate more travelers (e.g. travelers diverted from other modes) by increasing its frequency.
II.2 Fares

Frequency Share - Market Share Models do not have mechanism to account for the impact of fares on a traveler’s choice of itineraries. However, for some passengers, there is a real trade-off between fare and itinerary quality: for example, one may be willing to fly a connecting itinerary to get a fare that is $100 cheaper. Thus, the models are unable to react when airlines use fares as a means to attract market share without making any change to the schedule they offer.

II.3 Timing and Time-of-Day Demand Distribution

Frequency Share - Market Share Models do not have a mechanism to account for the demand for travel as a function of the time-of-day. Indeed, when traveling from BOS to SFO, more people want to depart at 12:30pm rather than at 11pm. Therefore, if two airlines A1 and A2 are competing in the BOS-SFO market and if A1 is offering two itineraries, one leaving at 12:30pm and one leaving at 11pm, while A2 is offering only one itinerary that leaves at 12:30pm, a Frequency Share - Market Share Model would say that A1 captures two thirds of the market. However, when booking their trip and thus considering the different departure times, one can argue that more than a third of the travelers will decide to travel with airline A2 if A2 offers enough seats. Timing is therefore a determining factor in the market share that is captured by an airline.

II.4 Conclusion

The extended Frequency Share - Market Share Model, which is the most developed model among the Frequency Share - Market Share Models, is designed based on the assumption that frequency and itinerary quality are the only determining factors; fares and timing are not included in the model. Indeed the extended Frequency Share - Market Share Model remains quite basic and has been presented here as a precedent to the Decision Window Model.
Decision Window Model

I Objective of the Decision Window Model

The Decision Window Model (DWM) offers a partial solution to the challenge continually faced by an airline and more specifically by its revenue management department. The DWM is a tool that, given an airline schedule, predicts how many travelers will want to take each of the itineraries offered.

It is based on the concept of a decision window, or the time window over which an individual traveler decides between competing itineraries. This concept builds upon the assumption that travelers base their decision process on time characteristics (day departure time, duration of airline flights and arrival time). Itinerary quality, service quality and airline preference influence the decision making process as well and are consequently incorporated into the DWM.

The Decision Window Model has three steps.

- **Step 1**: Define the individual traveler's decision window
  - Size of the window
  - Position of the window

- **Step 2**: Determine which itineraries/paths to consider
  - Itineraries in the window
  - Eliminate itineraries with non-competitive characteristics

- **Step 3**: Determine which itineraries is first choice preference
  - Trade-off between airline preference and itinerary quality
II  Definition of a Decision Window

II.1 Paths/Itineraries

Paths, or itineraries, are flights and combinations of flights that will take a traveler from the point of origin to their final destination.

Paths/itineraries can be of four different types: non-stop, one-stop, connecting and interline connecting (when the two flight legs are flown by two different airlines).

II.2 Decision Window

As Boeing has defined it, the decision window represents the time frame within which the traveler is willing to consider traveling. The decision window is bounded by the earliest departure time and the latest arrival time the traveler will consider.

A decision window has three main characteristics. (1) It is typically situated on the preferred day. (2) The window is wider than the perceived itinerary time. (3) Finally all departure and arrival times within the window are satisfactory to the traveler.

There are two parameters to be determined when defining the individual traveler’s decision window:

1. Size/Width of the window: The decision window is the sum of the Delta-T and the Schedule Tolerance (See definitions below).

2. Position of the window:

   • What day is the Decision Window located in? Demand is allocated to days based on the day-of-week demand distribution for the market considered.

   • At what hour in the day is the Decision Window positioned? Demand varies by hour, based on time-of-day demand.

II.3 Delta-T (or ΔT)

Delta-T (or ΔT) is the difference between the local arrival time and the local departure time.
The Delta-T of an itinerary is computed for a specific itinerary. For example, the Delta-T for a non-stop flight leaving BOS at 9:30 AM and arriving at SFO at 12:51 PM is 3 hours and 21 minutes.

The Delta-T of a market is the traveler's perception of the travel time in a given market; it is usually equal to the Delta-T of the itinerary corresponding to the best service in the market (smallest Delta-T in the market).

For itineraries and markets with time zone changes, Delta-T is different from the actual travel time. Indeed, in the above example, BOS-SFO has a Delta-T of 3 hours and 21 minutes whereas the total travel time is 6 hours and 21 minutes.

II.4 Schedule Tolerance

The schedule tolerance represents the amount of time flexibility a traveler has in planning a trip. As a matter of fact, even if a flight lasts 2 hours, a traveler may consider flights that leave after 8pm and arrive before noon.

There are multiple schedule tolerances for individuals within a given market. The distribution of schedule tolerances has been developed from survey results.

The decision window is the sum of the Delta-T and the schedule tolerance, as shown in figure 2-2. For example, for a traveler in BOS-SFO market (ΔT=3h21), the earliest departure is 7:00AM and the latest arrival is 12:00PM. The decision window size is 5 hours and the schedule tolerance is 1 hour and 39 minutes.

Some people have a lot of schedule flexibility, while others have very little. The distribution of all the individual decision windows within a market determines how many passengers find each itinerary satisfactory.
II.5 Coverage State

The Coverage State is a representation of which itineraries fall within passenger decision windows. For a given market and the set of itineraries associated with it, several coverage states can be computed for each combination of itineraries.

For example, in a market served by the itineraries I1, I2 and I3, there are eight different coverage states to be computed: (1) I1, I2 and I3 fall within the decision window, (2) I1, I2 and I3 don’t fall within the decision window, (3) I1 and I2 both fall within the decision window but I3 doesn’t, etc.

The results are the percentage of people in the market who have a particular set of itineraries within their window.
For example, when the coverage state for (1) is 10%, it means that 10% of the people in the market have all three itineraries within their decision window.

III Determination of Which Subset of Itineraries in a Schedule the Traveler Will Consider When Making a Decision

III.1 Which Itineraries Are Considered to Be in the Traveler’s Decision Window?

Given an individual decision window, there are two important rules to determine which itinerary fits in it.

1. In the Decision Window Model, only itineraries that fit completely in the decision window are considered for a traveler’s first choice itinerary preference.

2. In the Decision Window Model, only the best service for each airline is considered for the first choice itinerary preference. While itinerary quality is a dominant characteristic, it is only dominant within an airline.

Figure 2.3: Which Itineraries Are Considered?
III.2 What Are the Possible Scenarii?

Each traveler chooses among the itineraries offered by the airlines based on her individual decision window. There are three possible scenarii:

1. If there are no itineraries within the window, the traveler must re-plan the trip.
2. If there is only one itinerary within the window, the traveler chooses that itinerary.
3. If there are multiple itineraries within the window, the traveler must make a choice between the itineraries.

III.3 How Does Re-Planning Occur?

If a traveler cannot find a flight within her decision window he must re-plan her trip. Some people re-plan by considering other flights on the same day. Other travelers look at the same time-of-day period but on different days; they are referred to as day-of-week flexible travelers.

Timing is crucial. Indeed itineraries beginning at popular times will be within more travelers’ decision windows.

IV Determination of the First Choice Preference

Itinerary

Considering a traveler’s decision window, if there is only one itinerary within this window, the traveler chooses that itinerary. However, when determining preference between multiple itineraries within her window, a traveler faces a tradeoff between airline preference and itinerary quality.
IV.1 Tradeoff Between Airline Preference and Itinerary Quality

IV.1.1 Decision Orientation

Different travelers evaluate itineraries differently: schedule oriented people are more concerned with the schedule aspects of the flight whereas airline oriented people are more concerned about airline image when choosing itineraries. As shown in figure 2-4 below, decision orientation (schedule vs. airline oriented) varies by range of the trip measured in miles: the longer the travel distance, the higher the percentage of people who are airline oriented; the shorter the travel distance, the higher the percentage of people who are schedule oriented. Therefore the trade-off between airline image and itinerary quality varies with market.

Schedule oriented passengers look first for the best itinerary quality. They consider only itineraries with the highest itinerary quality in the market, such as non-stops. If there are multiple non-stops, then they consider airline.

Airline oriented passengers choose first the preferred airline, and then choose the best itinerary for that airline.

![Fraction of Schedule Oriented Passengers](image)

Figure 2-4: Airline vs. Schedule Oriented Passengers

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IV.1.2 Measure of Airline Integrated Image

Travelers evaluate airlines based on a number of factors. The Decision Window Model groups these factors into four areas.

1. Availability and Reliability, such as:
   - Number of cities served
   - Number of flights
   - On-time performance

2. Marketing Programs, such as:
   - Frequent flyer plan
   - Discount fare plan
   - Advertising

3. Service Quality, such as:
   - Reservation services
   - Pre-flight service
   - In-flight service
   - Food and beverage service
   - Baggage service

4. Passenger Environment, such as:
   - Seat comfort
   - Cabin spaciousness/décor
   - Flight cabin quietness
   - Carry-on storage
   - Types of airplanes flown

The four factors vary in importance depending on the range of the trip.

1. The importance of Availability and Reliability decreases when the range increases.

2. The importance of Marketing Programs is constant.

3. The importance of Service Quality increases when the range increases.
4. The importance of Passenger Environment increases when the range increases. The combination of these four areas forms a single image that a traveler has of a particular airline, which is called the airline integrated image.

IV.1.3 Determination of Itinerary Quality

Itinerary quality is measured by the number of stops and connects on an itinerary. The best itinerary quality is non-stop service, and has an Itinerary Quality Index of 1. As shown in table 2-2, itinerary quality is decreased by: Stops, connects, interline connects, other (excess time...). The indexes are used to discriminate low quality itinerary from high quality itinerary.

<table>
<thead>
<tr>
<th>Route</th>
<th>Itinerary Quality Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-stop</td>
<td>1</td>
</tr>
<tr>
<td>One-stop</td>
<td>2</td>
</tr>
<tr>
<td>One-connect</td>
<td>3</td>
</tr>
<tr>
<td>Interline Connect</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2-2: Itinerary Quality Index

IV.1.4 Airline Service Based Coefficients

The Airline Service Based Coefficients represent the result of the trade-off between airline image and itinerary quality. Both airline and schedule oriented people are represented in the coefficient. The table 2-3 demonstrates how the importance of the itinerary quality index decreases as the range increases. Indeed, for a range equal to 1000 miles, the Airline Service Based Coefficient varies from 100 to 0.14 when the itinerary quality index increases from 1 to 5. On the other hand, for a range equal to 6000 miles, the Airline Service Based Coefficient varies from 100 to only 59.23 when the itinerary quality index increases from 1 to
5. In other words, the longer the range, the smaller the difference between the Airline Service Based Coefficients of a good itinerary quality index (1) and a bad one (5).

<table>
<thead>
<tr>
<th>Airline Service Based Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Itinerary Quality Index</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

Table 2-3: Airline Service Based Coefficients

**IV.2 Determination of the First Choice Preference**

**Itinerary**

We will assume from now on that travelers appreciate equally all the airlines that are offering service. Consequently, the determination of the first choice preference itinerary is mainly based on itinerary quality.

However, the Decision Window Model is designed such that, within a window, path choice is determined after airline choice. This has important consequences on the probability that a given flight is selected. For example: a traveler is faced with a choice between three nonstop flights; he prefers airline A1 and airline A2 equally and is indifferent to the three flights in her window. This effect is shown graphically in figure 2-5. As shown in the figure, since the market share equation is between airlines, A1 gets half of the demand but each A1 flight only gets 25%.
IV.3 Example

Range: 1000 miles
Two airlines A1 and A2; Preference for Airline A1 = Preference for Airline A2
A1 offers one non-stop.
A2 offers one one-connect flight.

In this example, the range is 1000 miles therefore we know from the graph that the Fraction of Schedule Oriented People (FSOP) is 0.674. Schedule oriented people look first for the best itinerary quality: consequently, in this case, they will choose the non-stop itinerary.
offered by the airline A1. On the other hand, the Fraction of Airline Oriented People choose first the preferred airline; since the two airlines are equally preferred in this case and since the only two itineraries offered fit within one decision window only, the Fraction of Airline Oriented People is evenly allocated here among the two airlines (0.163 each).

<table>
<thead>
<tr>
<th></th>
<th>Choose Airline A1</th>
<th>Choose Airline A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule Oriented Passengers 67.4%</td>
<td>67.4%</td>
<td></td>
</tr>
<tr>
<td>Airline Oriented Passengers 32.6%</td>
<td>16.3%</td>
<td>16.3%</td>
</tr>
<tr>
<td>Total</td>
<td>83.7%</td>
<td>16.3%</td>
</tr>
</tbody>
</table>

Table 2-4: Example Results

There is another way to compute these probabilities. According to the Itinerary Quality Index table, A1 is offering an itinerary that has an Itinerary Quality Index equal to 1 and A2 is offering an itinerary that has an Itinerary Quality Index equal to 2. For a range of 1000 miles, the Airline Service Based Coefficients table gives the following coefficients: 100.00 for (A1,IQI=1) and 19.45 for (A2,IQI=2).

\[
\text{Probability (A1 is selected)} = \frac{\text{Coefficient (A1)}}{\text{Coefficient (A1)} + \text{Coefficient (A2)}}
\]

\[
\text{Probability (A1 is selected)} = \frac{100.00}{100.00 + 19.45}
\]

Probability (A1 is selected) = 83.7%
V Overview of the Decision Window Model

In figure 2-7, we present how the different blocks fit together. Using demand distribution data and schedule quality factors, the schedule is challenged by the passengers’ choice criteria and then evaluated to finally determine which itinerary passengers are willing to fly.

Figure 2-7: Overview of the Decision Window Model
VI Features and Limitations of the Decision Window Model

VI.1 Total Market Demand Is Fixed

Like the Frequency Share - Market Share Models, one underlying assumption in the Decision Window Model is that the total demand for every single market is fixed beforehand no matter how high the total aggregated frequency over all the airlines offering service is. This assumption is consistent with the notion of frequency saturation where, at some point, increasing service frequency satisfies the same travelers that were satisfied with another itinerary. As a matter of fact, if the added itinerary falls only within time windows for which some itineraries are already available, the increase in frequency won’t result in any increase in the number of passengers captured.

VI.2 Fares

Like the Frequency Share - Market Share Models, the Decision Window Model doesn’t take into account the impact of fares on travelers when they consider itineraries. For some passengers, there is a trade-off between fare and itinerary quality: for example, one may be willing to fly a connecting itinerary to get a fare $100 cheaper. The Decision Window Model is however assuming that frequency and itinerary quality are the only determining factors.

VI.3 Itineraries Quality

Short itineraries such as nonstop and direct itineraries are good. Itineraries with long travel time are less likely to fit within the traveler’s decision window. Itineraries with a low Itinerary Quality Index are less likely to be the first choice preference of a traveler.

VI.4 Range of Trip

The Decision Window Model takes into account the range of a trip when allocating demand among the airlines that are offering service on a particular market because range determines
the importance of different key factors. Indeed, decision orientation (schedule vs. airline) and thus the results of the trade-off between airline image and itinerary quality depend on the range of the trip. The longer the range, the more important airline service quality and passenger environment are. At longer range, a difference in itinerary quality is less important. Furthermore, the size and the position of the individual decision windows are closely related to the range of the trip through Delta-T (travel time and time zone difference if any) and thus through time-of-day demand distribution, which is a function of Delta-T.

**VI.5 Timing and Time-of-Day Demand Distribution**

Contrary to the Frequency Share - Market Share Models, the Decision Window Model does take into account that the demand for travel depends on time-of-day.

Let's come back to our previous example with the FS-MS model: when traveling from BOS to SFO, more people want to depart at 12:30pm rather than at 11pm. If two airlines A1 and A2 are competing in the BOS-SFO market and if A1 is offering two itineraries, one leaving at 10:30pm and one leaving at 11pm, while A2 is offering only one itinerary that leaves at 12:30pm, a Frequency Share - Market Share Model would say that A1 captures two thirds of the market because it doesn't take into account time-of-day demand distribution. On the other hand, the Decision Window Model is based on the consideration that timing also determines the market share and thus allocates 95.4% of the demand to airline A2.

Consequently, timing is a crucial parameter when designing a schedule with the purpose of maximizing the number of passengers captured.
VI.6 Frequency

VI.6.1 Higher Frequency Is Good

The Decision Window concept reinforces another key belief about the characteristics of airline markets. High frequency, i.e. a large number of itineraries at various times during the day, increases the likelihood that each traveler will find at least one itinerary within his Decision Window. Consequently, when an airline increases the frequency of its service on a given market, this should result in an increase in the number of passengers captured in this market.
VI.6.2 Frequency Saturation

An example of what is referred to as frequency saturation is illustrated in figure 2-9. In the figure, I1, I2 and I3 are already offered by the airline; itinerary I4 is added and therefore service frequency is increased. However, I4 falls only within one decision window DW2 that already contains itineraries I2 and I3. Given the definitions and the assumptions used as a basis for the Decision Window Model, the above increase in frequency doesn’t improve the service offered to the passengers because it doesn’t increase the likelihood that each traveler will find at least one itinerary within the decision window. Consequently, adding I4 to the schedule doesn’t result in any additional captured passenger for the airline.

The Frequency Share - Market Share models are based on the assumption that if an airline increases its service frequency, it will, as a result, capture more passengers: the market share captured by an airline is a strictly increasing function of the frequency share of this airline in
a competitive environment, i.e. when several airlines are competing within a single market. Therefore, in the previous example, when the itinerary 14 is added at a time where people are looking for travel options, the airline should see a strictly non-negative effect on its market share according to the Frequency Share - Market Share models.

The reason why the Frequency Share - Market Share models and the Decision Window Model have diverging results is that Frequency Share - Market Share models don’t take timing into consideration whereas the Decision Window Model does. The Decision Window Model is acknowledging the difference between adding a non-stop itinerary at 8am versus adding a non-stop itinerary at 8pm in a market where the only itinerary already offered is at 7:50pm.

VI.7 Conclusion

While still acknowledging that frequency and itinerary quality are two key factors for airlines aiming at attracting market share, the Decision Window Model goes beyond the Frequency Share - Market Share Models by also recognizing the importance of the range of the trips and of the timing of the itineraries. However, the Decision Window Model still does not provide a way to simulate the importance of fares in the market share evaluation process.

A model integrating the Decision Window Model into airline schedule planning would thus add a new dimension to the schedule design for an airline faced with trying to attract as many passengers to its itineraries as possible. Indeed, frequency, itinerary quality, and itinerary timing (departure and arrival time) would thus be the three key parameters that could be used to create competitive advantage.
Chapter 3

MIT Airline Scheduling Module (ASM)

I Methodology and Objectives

The ASM presented in this thesis is an automated tool that optimizes airline schedule design in a competitive environment. In other words, this tool provides a feasible schedule and maximizes the profit of a given airline using an incremental and recursive process, which allows to capture the changes in the total demand distribution among the competitors that any schedule decision by any airline inevitably would induce.

The purpose of the ASM is to relate within a single simulation module different factors that are determining both for the decision making process of the airline and for the decision making process of the potential travelers. As a matter of fact, an individual traveler who is deciding between competing itineraries bases his or her decision on several factors. Some of these factors can be directly referred to as temporal: departure time and flying time. Itinerary quality is also a decisive factor that may sometimes be translated into a time factor since non-stop flights are typically shorter than connecting flights; itinerary may also be differentiated using quality indexes that discriminate connecting flights from non-stop flights. Frequency is another time related critical factor since higher frequency brings a competitive advantage as long as the market is not saturated. Another type of factor is monetary: fares may have a determining role in the choice of the traveler who may trade-off timing considerations and fare.

That being said, the airline’s objective is to design a schedule that will generate the highest profit possible. The airline designs its schedule under fleet availability constraint or more generally speaking under cost constraint. Although profit is computed as the difference between revenues and costs, maximizing profit is more complex than simply maximizing revenues and minimizing costs. Indeed, revenues and costs are highly interrelated: for example, the market share that is captured by the airline depends directly on the number of
itineraries offered by the airline and consequently depends on the money spent by the airline to fly those itineraries.

To achieve the objectives of the ASM, we build upon the *Extended Schedule Design and Fleet Assignment Model (ESD-FAM)* by Lohatepanont and Barnhart (2002) and thus bring the integration of the airline scheduling process a step further by coupling it with the *Decision Window Model (DWM)*. Indeed, in the solution algorithm of ESD-FAM, we introduce a mechanism to represent the interaction between schedule quality (frequency of service, time-of-day distribution of departure times, travel time) and total unconstrained demand (market share) of the airline in market $m$ by using the DWM.

## II Assumptions

Since the ASM is based on the ESD-FAM and the DWM, we are making the same assumptions that have been previously listed in Chapter 2 about the ESD-FAM and the DWM.

It is thus assumed that the schedule is daily, which means that the same set of flights is flown everyday, and uses an incremental approach to schedule design.

It is also important to remember that, when an airline is designing its schedule for the next time period, it is assumed that its competitors are not making any change in their own schedule.

Finally, it is assumed that the effect of schedule changes on demand is limited to the total demand distribution among competitors while the total market demand remains constant. In other words, the addition of new flight legs to the schedule of an airline is not going to stimulate the demand and generate new passengers who did not want to travel before; the only effect is a capture effect from which the airline offering an increased level of service will benefit.
III Solution Approach

III.1 Feedback Loop

III.1.1 Initialization

The ASM combines the ESD-FAM and the DWM to represent the decision making process of the airlines with respect to the schedules that they fly. It is based on an iterative process; therefore, the first step for solving the ASM is to initialize the feedback loop.

Given:

- The total market size for each O&D market, and
- The schedules offered by all the competing airlines,

the total unconstrained demands for each O&D market (airline’s market share) are computed and allocated among the competing airlines using the DWM.

Given all the above and:

- The aircraft available to the airline in the future (possible scenarios: acquisition, retirement, no change), and
- The fares charged by all the competing airlines,

a list of candidate flights to be deleted from the schedule and a list of candidate flights to be newly scheduled with the corresponding fares have to be generated by the airline that is using the ASM in order to design its schedule for the next time period.

III.1.2 Set of Optional Flights

The set of optional flights refers to the set of all the flights that are candidates to deletion or addition. This set is the key input to the ASM. Indeed, the base schedule that is fed into the ASM includes both the set of mandatory flights and the set of optional flights. To establish the set of optional flights, the following questions have to be answered:

- What are the relevant markets and the departure times that the airline does/does not serve?
- How can one select candidate flights to be potentially removed from/added to the schedule?
This set has to be pre-selected based on time-of-day passenger loads and fares data, i.e. based on profitability. The pre-selection of candidates can be carried out pursuing the following three steps:

1st Step: Establish set of potential candidates to be added

After sorting O&D markets by total unconstrained demand and expected total revenue, we determine the O&D markets for which the total supply (i.e. considering all the competing airlines) does not fully satisfy the demand either because the total frequency of service is insufficient or because the time-of-day distribution of departure times does not cover the full range of the demand. Using the DWM, we then determine which are the relevant departure times that the airline, which is designing its schedule using the ASM, does not currently serve and that may be worth adding in the next time period. We assume that the fares for these new flight legs would be equal to the current fares for each O&D market.

2nd Step: Compute profit per flight leg

The profit on a flight leg basis is the difference between the operating costs incurred by flying the leg and the revenue generated by the passenger flown on the leg. Using passenger loads per flight leg and pro-rated fares, we compute the pro-rated revenue per flight leg for the current schedule. We also estimate the expected profit per flight leg for the potential candidates determined in the first step.

3rd Step: Greedy route creating algorithm

Given the set of flight legs currently flown and the set of potential candidates to add, the objective now is to construct routes that can be flown by a single aircraft on a daily route acknowledging that there is a trade-off between costs and revenue generated when operating that aircraft. Because the airline aims to maximize the utilization of an aircraft and thus profit from this asset, the idea is to determine which sequence of flight legs corresponds to the best, i.e. most profitable, route for every available aircraft.

The greedy route-creating algorithm can be described as follows:

1. Select and start in the morning with the "best" (most profitable) flight leg and then create "N1" routes using this flight leg and the best combination of flights that can be flown by one aircraft on a daily route.
2. Select and start in the morning with the second best flight and then create "N2" routes using this flight leg and the best combination of flights that can be flown by one aircraft on a daily route.

3. …

The candidates for addition should then be the flight legs that have been incorporated into the highly profitable routes generated by the route-creating algorithm and the candidates for deletion should be the flight legs that have been incorporated into the least profitable routes generated by the route-creating algorithm.

One big limitation of the model is that its tractability decreases when the number of the decision variables increases: the more optional flights, the less tractable the implementation of the model and the longer the computational time. Depending on the size of the network flown by the airline, one may want to limit the search for candidates to a smaller subset of flight legs, which are the most and the least profitable, and run the route-creating algorithm with this subset to restrict the number of routes created.

**III.2 Solution Algorithm**

The ASM takes as input data, such as the flights list and the corresponding fares for each competing airline and the total market sizes, as well as data specific to the airline that is designing its future schedule (referred to as airline $A$), such as the set of optional flights, and future fleet composition and size.

For each market to be potentially served by the airline $A$ in its base schedule, the total market shares for each competing airline are computed using the DWM. The DWM is also used to compute the unconstrained demand at the itinerary level, i.e. the unconstrained demand that the airline is going to capture on each itinerary serving a given market. Once those are known, the same process is used to compute the $\Delta D_p$’s, the demand correction terms for each itinerary when one of the optional flights is not flown. The demand correction terms are obtained for as many combinations of flight deletions as possible, assuming all flight legs (whether mandatory or optional) are initially included in the base schedule. The final step consists is running the LP solver for the ESD-FAM.
The output when running the LP solver for ESD-FAM during step (n-1) is the new base schedule to be used in step n. The new market shares, the new per itinerary demands and the new demand correction terms $\Delta D_p^q$'s are computed based on the new schedule; and the LP solver for ISD-FAM is then run another time. When the schedule obtained as output of step n is identical to its input schedule (i.e. schedule obtained as output of step (n-1)), the stopping criteria is met.

Convergence depends on the sensitivity of the model to the demand correction terms. If the model is very sensitive to these terms, it might take many iterations to estimate the correction terms correctly.

The solution algorithm is summarized in Figure 3-1.
Figure 3-1: Solution Approach for ASM
**IV Summary**

In this chapter, we presented the MIT Airline Scheduling Module (ASM), which combines the Decision Window Model (DWM) and the Extended Schedule Design and Fleet Assignment Model (ESD-FAM) within a feedback loop. The ability to solve problems using the ASM depends on the scale and complexity of these problems, and on the quality of the data. In the next chapter, we present a case study for a real airline, describe the solution process from data pre-processing to running the LP solver, discuss the results and finally illustrate how the airline can use the ASM to reach decisions that would provide them with a competitive advantage.
Chapter 4

A Case Study

1 Background and Assumptions

The case study presented in this thesis is based on data provided by a real airline whose competitive environment is limited to only another airline on its domestic network. By doing so, we take up the challenge of scaling up the ASM to a real airline while limiting the size of the inputs, decision variables, and constraints of the model. Indeed, the ASM is very sensitive to the size of the airline network. The larger the network, the higher the number of itineraries because the higher the number of possible combinations of flight legs, and consequently the higher the possibilities of change in the schedule. This results in a larger set of optional flights, a larger set of decision variables, a more complex objective function and a higher number of constraints. Essentially, the larger the network, the less tractable the implementation of the model and the longer the computational time.

1.1 System Map

The geographical network, i.e. the set of destinations served by the airline, consists of five airports. Only two airports (A1 and A3) are connected to all the other airports with direct service thus playing the role of hubs. Airport A1 is the only international gateway, which means that the only flight legs that may carry domestic as well as international passengers are flight legs into A1 or out of A1.

Table 4-1 provides the distance between the airports and figure 4-1 illustrates the system map.
Table 4-1: Distances Between Airports

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<th>O&amp;D</th>
<th>Distance (Miles)</th>
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<td>A1A3</td>
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<td>A2A1</td>
<td>298</td>
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<td>A2A3</td>
<td>189</td>
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<td>A2A4</td>
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<td>635</td>
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<tr>
<td>A5A3</td>
<td>216</td>
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### 1.2 Schedule

The specific details of the paths are presented in Table 4-2. As shown in the table, the schedule consists of 85 nonstop flights and 115 itineraries, from which 28 are one-stop itineraries and 2 are two-stop itineraries.

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<th>To</th>
<th>Total</th>
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<td>A5</td>
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**Total Number of Flights** 85

<table>
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<th>Directional O&amp;D</th>
<th>From</th>
<th>Via</th>
<th>To</th>
<th>Total</th>
</tr>
</thead>
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<td>A3</td>
<td>A5</td>
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</table>

**Total Number of Itineraries** 115

Table 4-2: Schedule Summary
1.3 Fleet

The available fleet consists of ten aircraft. Nine of the ten have the same fleet type with a capacity of 136 seats. The tenth aircraft has a higher capacity of 195 seats and has so far only been used by the airline for round trip nonstop service between the two hubs A1 and A3. For the sake of simplicity, and because it may only lead to a slight underestimation of the potential revenue (since some passengers might be spilled unnecessarily), we are assume that there is one single fleet type with a seat capacity equal to 136.

1.4 Time-Line Flight Network

At the core of the fleet assignment problem is the flight network, which is used to maintain the balance of the fleet or each fleet if there are two or more. We use the time-line flight network with node consolidation.

The time-line flight network consists of a set of nodes associated with each station and arcs that represent flight legs, aircraft on the ground, and overnighting aircraft [Talluri, 1996]. Each node corresponds to an arrival or a departure of a flight. The location and time of a departure node is the origin airport and the departure time of the flight; the location and time of an arrival node is the destination airport and the ready time (time at which the aircraft is ready to take off again and fly the next leg) of the flight. All nodes are sorted chronologically at each station for each fleet's flight network. There are four types of arcs:

- Flight arc, which start and end nodes in a fleet network denote a flight in the schedule.
- Maintenance arc, which represents a maintenance opportunity in a maintenance station.
- Ground arc, which connects the successive nodes in one station.
- Wrap-around arc, which connects the last event in the evening and the first event in the next morning at one station and thus represents aircraft overnight.

The count time is a time arbitrarily chosen in the flight network to count the number of aircraft used in the fleet assignment solution.

In this case study, we used node consolidation to decrease the size of the network to 103 nodes, 85 flight arcs, 98 ground arcs, and 5 wrap-around arcs. Node consolidation consists of grouping nodes to form islands. An island begins with a set of flight legs all flying into
the station and ends with a set of flight legs all flying out of the station. The two figures below, 4-2 and 4-3, illustrate the node consolidation process through which the network size is decreased from ten nodes down to two islands.

**Figure 4-2: Time-Line Flight Network**

**Figure 4-3: Node Consolidation**

### 1.5 Assumption

In this case study, the recapture rates $b'_r$'s are set to be equal to 0 except for $r$ equal to the null itinerary in which case $b''$ is equal to 1 for all itineraries $p$. The null itinerary is a fictitious "empty" itinerary with a fare equal to 0. In other words, when an itinerary $p$ is capacitated, it is assumed that passengers can only be spilled to the null itinerary i.e. that the revenue is lost.

This assumption is made because the real recapture rates are unknown and because arbitrarily choosing the above values (0 and 1) leads to a more tractable problem as the number of decision variables is greatly decreased. However such an assumption is rather conservative as it may cause an underestimation of revenue while costs are still accurately...
computed. Indeed spilled passengers are spilled when the itinerary is capacitated, which means that some revenue is lost while the operating costs have still to be borne by the airline. Moreover, once the results are obtained, we can look at the number of spilled passengers, the corresponding capacitated itineraries and the set of itineraries serving the same O&D market but that are not capacitated. A sensitivity analysis can thus be done to estimate the revenue that could have potentially been recaptured looking at different scenarios.

II Formulation

II.1 Objective Function

Given the assumptions previously explained in this chapter, we present here the particular formulation for the Extended Schedule Design and Fleet Assignment Model used for the case study. Note that: $\zeta_q = 1 - Z_q$. The objective function is to minimize the sum of operating costs, spilled revenue, and changes in revenue due to cancellations.

$$
\text{Min} \sum_{i \in L} c_i f_i + \sum_{p \in P} \text{fare}_p \cdot t_p^{\text{null}} + \sum_{q \in Q} \left( \text{fare}_q D_q - \sum_{p \in P, p \neq q} \text{fare}_p \Delta D_q^p \right) \zeta_q
$$

II.2 Constraints

Subject to:

\[ f_i = 1 \quad \forall i \in L^F \]
\[ f_i \leq 1 \quad \forall i \in L^O \]
\[ y_{o,t} + \sum_{i \in I(o,t)} f_i - y_{o,t} - \sum_{i \in D(o,t)} f_i = 0 \quad \forall o,t \]
\[ \sum_{o \in O} y_{o,t} + \sum_{i \in I} f_i \leq N \]
\[ -\sum_{q \in Q} \sum_{p \in P} \delta_q^p \Delta D_q^p \zeta_q + f_i \cdot SEATS + \sum_{p \in P} \delta^p t_p^{\text{null}} \geq Q_i \quad \forall i \in L \]
\[ -\sum_{q \in Q} \Delta D_q^p \zeta_q + \sum_{p \in P} t_p' \leq D_p \quad \forall p \in P \]
\[ \zeta_q + f_i \geq 1 \quad \forall i \in L(q) \]
\[ \zeta_q + \sum_{i \in I(q)} f_i \leq N_q \quad \forall q \in PO \]
The 1st set of constraints is the set of cover constraints for mandatory flights ensuring that every mandatory flight is assigned to a fleet type. The 2nd set of constraints is the set of cover constraints for optional flights allowing the model to choose whether or not to fly flight $i$ in the resulting schedule; if flight $i$ is selected, a fleet type has to be assigned to it.

The 3rd set of constraints ensures the conservation of aircraft flow.

The 4th set of constraints is the set of count constraints ensuring that only available aircraft are used.

The 5th set of constraints is the set of capacity constraints ensuring that the number of passengers on each flight $i$ does not exceed its capacity.

The 6th set of constraints is the set of demand constraints ensuring that the model does not spill more passengers than demand for the itinerary.

The 7th and 8th set of constraints are itinerary status constraints that control the $\{0,1\}$ variable, $\zeta_q$, for itinerary $q$. 

$$f_i \in \{0,1\}, \quad \zeta_q \in \{0,1\}$$

$$y_{o,s} \geq 0, \quad t_p' \geq 0$$
III O&D Passengers' Data Processing

III.1 Available Raw Passengers' Data

Because, we only had limited data, we had to derive some of the data required for the model. Specifically, we were given:

(a) The set of flight legs (i.e. flight numbers) serving each directional sector for any day of the week (i.e. Mondays, Tuesdays, Wednesdays, Thursdays, Fridays, Saturdays and Sundays) during a given month. Further, we were given the exact number of passengers (loads) traveling on each of the flight legs for any day of the week.

Example:

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<th>Sector</th>
<th>Airport1-Airport2</th>
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<td>Period</td>
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<td>76</td>
<td>76</td>
<td>76</td>
<td>76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4-3: Flight Leg Loads Per Day of the Week

(b) The schedule and the set of itineraries offered for every directional O&D market served by the airline on a specific date e.g. MM DD, YYYY.
(c) The exact number of passengers (loads) traveling on each path for the entire month.

Example:

O&D market: A1A3


<table>
<thead>
<tr>
<th>True Origin</th>
<th>True Destination</th>
<th>From</th>
<th>To</th>
<th>Directional O&amp;D</th>
<th>Directional Sector</th>
<th>One-way Passengers</th>
</tr>
</thead>
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<td>A1</td>
<td>A3</td>
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<td>A1A3</td>
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<td>A2</td>
<td>A1A3</td>
<td>A1A2</td>
<td>1,000</td>
</tr>
<tr>
<td>A1</td>
<td>A5</td>
<td>A1</td>
<td>A5</td>
<td>A1A5</td>
<td>A5A3</td>
<td>50</td>
</tr>
<tr>
<td>A1</td>
<td>A5</td>
<td>A5</td>
<td>A3</td>
<td>A1A3</td>
<td>A1A3</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 4-4: Example of Passenger Loads Distribution Among Different Possible Paths

### III.2 Data Processing

The approach here is to use the break down in (a) to figure out the number of passengers in (c) traveling on a given day of the week.

Let’s define $P^d_f$, number of passengers on flight leg $f \in F^d_S$ serving sector $S$ on day of the week $d$:

$$P^d_f = \frac{P^D_f}{N^m_D}$$

Where:

$D \in \{\text{Mondays, Tuesdays, Wednesdays, Thursdays, Fridays, Saturdays, Sundays}\}$, month $m$

d $\in \{\text{a Monday, a Tuesday, a Wednesday, a Thursday, a Friday, a Saturday, a Sunday}\}$

$N^m_D$: Number of occurrences for $D$ during month $m$.

$P^D_f$: Sum of passengers on flight leg $f$ over $D$ in month $m$. 
III.2.1 1st Step: \( \text{Ratio}^d_s \)

We calculate \( \text{Ratio}^d_s \), the percentage of passengers per month who travel on a specific day of the week in a given month for a given directional sector using the following expression:

\[
\text{Ratio}^d_s = \frac{\sum_{f \in F^d_s} P^d_f}{\sum_{f \in F^m_s} P^m_f} = \frac{P^d_s}{P^m_s}
\]

Where:

\( S \in \{A1A2, A1A3, A1A4, A1A5, \ldots A5A4\} \) = Set of directional sectors

\( d \in \{\text{Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday}\} \) = Set of days of the week.

\( F^d_s \): Set of flight legs serving the directional sector \( S \) on day of the week \( d \).

\( F^m_s \): Set of flight legs serving the directional sector \( S \) during month \( m \).

\( P^d_f \): Number of passengers on flight leg \( f \in F^d_s \) on day of the week \( d \).

Hence, \( \sum_{f \in F^d_s} P^d_f = P^d_s \): Total number of passengers traveling on sector \( S \) on day of the week \( d \).

\( P^m_f \): Number of passengers on flight leg \( f \in F^m_s \).

Hence, \( \sum_{f \in F^m_s} P^m_f = P^m_s \): Total number of passengers traveling on sector \( S \) during month \( m \).

Passengers are either international passengers or domestic passengers; therefore:

\( P^d_s = DmstP^d_s + IntlP^d_s \), for the directional sector \( S \) on day of the week \( d \).

\( P^m_s = DmstP^m_s + IntlP^m_s \), for the directional sector \( S \) during month \( m \).
III.2.2 2nd Step: Number of domestic vs. international passengers on each sector per month

We know the number of passengers on each path per month. Therefore:

- $Dmst_P^m_S$: The number of domestic passengers traveling during a month $m$ on a given directional sector $S$ is equal to the number of passengers who both are traveling during a month $m$ on this sector $S$ and have a domestic directional O&D market.

- $Intl_P^m_S$: Subsequently the difference between the total number of passengers and the number of domestic passengers who are traveling during a month $m$ on a given directional sector $S$ corresponds to the number of international passengers who are flying during a month $m$ on this particular directional domestic sector $S$ as part of an international itinerary.

$$Intl_P^m_S = P^m_S - Dmst_P^m_S$$

III.2.3 3rd Step: Number of domestic vs. international passengers on each sector per day of the week

We assume that $Ratio^d_S$, which was computed using the total number of passengers (i.e. domestic and international passengers), is still applicable separately to both the subset of domestic passengers and the subset of international passengers. Therefore we can scale the monthly data obtained during the second step down to daily data using $Ratio^d_S$:

- $Dmst_P^d_S$: The number of domestic passengers traveling on a day of the week $d$ on a given directional sector $S$ is equal to the product of the number of domestic passengers traveling during a month $m$ on sector $S$ and $Ratio^d_S$.

$$Dmst_P^d_S = Ratio^d_S \cdot Dmst_P^m_S$$

- $Intl_P^d_S$: The number of international passengers traveling on a day of the week $d$ on a given directional sector $S$ is equal to the product of the number of international passengers traveling during a month $m$ on sector $S$ and $Ratio^d_S$.
\[ IntlP_S^d = Ratio_S^d \cdot IntlP_S^m \]

III.2.4 4th Step: Number of domestic vs. international passengers on each flight leg per day of the week

We assume that the ratio of international passengers versus domestic passengers is a constant on every flight leg. Therefore, for each directional sector \( S \) on the day of the week \( d \), we can compute the number of domestic passengers on each flight leg on each day of the week using the ratio:

\[ \frac{DmstP_S^d}{DmstP_S^d + IntlP_S^d} = \frac{DmstP_S^d}{P^d} . \]

- \( DmstP_f^d \): The number of domestic passengers traveling on a day of the week \( d \) on a given flight leg \( f, f \in F_S^d \), serving the sector \( S \) is equal to the product of the number of passengers traveling on a day of the week \( d \) on flight leg \( f \) by the ratio \( \frac{DmstP_S^d}{P_S^d} \).

\[ DmstP_f^d = \frac{DmstP_S^d}{P_S^d} \cdot P_f^d \]

- \( IntlP_f^d \): The number of international passengers traveling on a day of the week \( d \) on a given flight leg \( f, f \in F_S^d \), serving the sector \( S \) is equal to the product of the number of passengers traveling on a day of the week \( d \) on flight leg \( f \) by the ratio \( \frac{IntlP_S^d}{P_S^d} \).

\[ IntlP_f^d = \frac{IntlP_S^d}{P_S^d} \cdot P_f^d \]

III.2.5 5th Step: Number of passengers on each itinerary per day of the week

Given the number of domestic passengers on each flight leg per day of the week and given the schedule for Wednesdays and the itineraries offered, we can solve an assignment problem to compute the number of domestic passengers on each of the 115 itineraries for
Wednesdays, and more particularly for the date MM DD, YYYY (a Wednesday), using the Excel SOLVER.

There are 41 flights that are used only by 41 distinct nonstop itineraries. For these 41 itineraries, the number of passengers is equal to the load on the corresponding flight leg.

Consequently, there are still 74 unknown loads $DmstP_i^d$ for the remaining itineraries and we need 74 independent equations.

### III.2.5.1 Solution

The problem to solve is:

Find $DmstP_i^d$ for all itineraries $i$ flown on a day of the week $d$, such that:

1. $DmstP_f^d = \sum_{i \in I_f^d} DmstP_i^d$, For all flights $f$ on a day of the week $d$.
2. $DmstP_p^d = \sum_{i \in I_p^d} DmstP_i^d$, For all paths $p$ on a day of the week $d$.

### III.2.5.2 First Set of Equations

Each flight leg $f$ is used by several itineraries $i \in I_f^d$ on each day of the week $d$. $DmstP_f^d$ is known and $DmstP_i^d$ is unknown.

There are 44 independent equations:

$$DmstP_f^d = \sum_{i \in I_f^d} DmstP_i^d$$

### III.2.5.3 Second Set of Equations

On the one hand, a path $p$ is associated to a set of sectors $S_p^m$ that are flown for a given month $m$. A nonstop path is associated to one sector; a one-stop path is associated to a set of two sectors, etc.
For each path $p$, we know $DmstP^m_p$, the number of domestic passengers traveling on this path for a month $m$. We also know $DmstP^m_s$, the number of domestic passengers traveling on each sector $s \in S^m_p$ as part of their trip on path $p$ for a month $m$.

Therefore, for each path $p$ and each sector $s \in S^m_p$, we can compute the ratio $\frac{DmstP^m_p}{DmstP^m_s}$, which is the percentage of domestic passengers on the sector $S$ flying an itinerary of type $p$.

We assume that, for a given path $p$, the monthly ratio is representative of the distribution of passengers among sectors $s \in S^m_p$, in other words that the daily ratio for the day of the week $d$ between passengers on path $p$ and passengers on sector $s \in S^m_p$ is equal to the monthly ratio:

$$\frac{DmstP^d_p}{DmstP^d_s} = \frac{DmstP^m_p}{DmstP^m_s}, \forall p, \forall s \in S^m_p$$

Finally, we assume as an approximation that $DmstP^d_p$, the number of domestic passengers traveling on each path $p$ for a day of the week $d$, is equal to the average of the number of domestic passengers traveling on the day of the week $d$ on each sector $s \in S^m_p$. $|S^m_p| = |S^d_p|$ is the number of sectors $S$ using path $p$ for a month $m$ or for a day of the week $d$. Note that

$Ratio^d_S = \frac{DmstP^d_p}{DmstP^m_s}$. Consequently:

$$DmstP^d_p = \frac{\sum_{s \in S^d_p} (DmstP^m_p \cdot Ratio^d_S)}{|S^m_p|}$$

On the other hand, for a given day of the week $d$, for each path $p$, there is a set of itineraries $I^d_p$ serving that path. The number of (domestic) passengers on path $p$ on day of the week $d$ is equal to the sum of the passengers traveling on each itinerary $i \in I^d_p$:

$$DmstP^d_p = \sum_{i \in I^d_p} DmstP^d_i$$
On Wednesday MM DD, YYYY, there are 32 paths, which correspond to 32 new independent equations.

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</tbody>
</table>

Table 4-5: Number of Daily Itineraries Sorted by Type of Path
IV Costs, Revenue, and Profit Data Processing

IV.1 Flight Operating Costs

The function used to compute operating costs has two components: a fixed cost, which is represented by the landing and navigation charges, and a variable cost, which is a function of the block hours flown.

In other words, for each directional sector $S$, we know:

- Total number of block hours flown during month $m$
- Number of landings during month $m$
- Cost per block hour
- Total landing and navigation charges during month $m$

We can determine:

- $h_s$: Monthly average number of block hour per flight on sector $S$
- $c_s$: Cost per block hour on sector $S$
- $l_s$: Monthly average landing and navigation charges per flight on sector $S$

For each flight $f$ serving directional sector $S$, we can thus compute the operating cost:

$$\text{Cost}_f = l_s + c_s \cdot h_s$$
IV.2 Pro-rated Flight Revenue and Profit

IV.2.1 Domestic vs. International Passengers

Ideally, the network we are considering would be closed: all passengers would be so-called “domestic passengers” and would only fly from one airport included in the network to another airport included in the network, possibly through a third airport also included in the network. However, in this case study, the network passenger flow includes both domestic and international passengers. Consequently, we need to compute the revenue from international passengers, who are flying flight leg $f$ as part of their international itinerary, in order to compute the actual profit on each flight leg $f$. Indeed, if we were computing the profit for every flight leg only using domestic revenue and total operating costs, we wouldn’t take into account the fact that these operating costs are also incurred while serving international passengers traveling on a domestic sector.

Because international passengers are given priority over domestic passengers by revenue management, one approach to deal with international passengers could be to artificially decrease the seat capacity on domestic flights flown by international passengers. However, since the Airline Schedule Module is solving the fleet assignment problem at the same time as it is generating the schedule, we don’t know in advance which aircraft is going to fly which flight leg. We don’t even know which flight legs are going to be flown. In this case, we wouldn’t be able to handle international passengers who would like to travel on flight legs that are not selected by the schedule generator.

We are thus taking an alternative approach, in which the international travelers are added to the number of passengers on the corresponding domestic itineraries between their origin/destination and the airport $A1$ (the only international gateway). That is to say, we treat them as simply "more passengers on those itineraries." We assume that they contribute the same fare as the other passengers on that itinerary, i.e. we assume that the prorated fare for international passenger on the domestic part (i.e. the domestic flight leg $f$) of their trip is equal to the domestic fare for the nonstop itinerary corresponding to flight leg $f$. This is an optimistic assumption.
Therefore, let us define:

- \( \overline{DmstP_f^d} \): Modified number of domestic passengers traveling on a day of the week \( d \) on a given flight leg \( f, f \in F_S^d \), serving the sector \( S \) to take into account international passengers on the corresponding domestic itineraries between their origin/destination and \( A1 \) (the only international gateway).

\[
\overline{DmstP_f^d} = DmstP_f^d + IntlP_f^d, \quad \text{if } f \text{ serves a sector } S \text{ involving } A1 \\
\overline{DmstP_f^d} = DmstP_f^d, \quad \text{otherwise}
\]

- \( \overline{DmstP_i^d} \): Modified number of domestic passengers traveling on a day of the week \( d \) on a given itinerary \( i, i \in I_f^d \) to take into account international passengers on the corresponding domestic itineraries between their origin/destination and \( A1 \) (the only international gateway). We assume that all the international passengers traveling on flight leg \( f \) on day of the week \( d \) are assigned to the only nonstop itinerary \( i, i \in I_f^d \).

\[
\overline{DmstP_i^d} = DmstP_i^d + IntlP_i^d, \quad \text{if } i \text{ is a nonstop itinerary involving } A1, \text{i.e. } i = \{f\} \\
\overline{DmstP_i^d} = DmstP_i^d, \quad \text{otherwise}
\]

**IV.2.2 Pro-rated Flight Revenue**

Each flight leg \( f \in F_S^d \) is used by several itineraries \( i \in I_f^d \) on a day of the week \( d \). In the above sections, we have computed \( \overline{DmstP_f^d} \), modified number of domestic passengers traveling on a day of the week \( d \) on a given itinerary \( i, i \in I_f^d \). Furthermore, we also know from the airline’s data \( \text{fare}_i \), the average fare paid by passengers traveling on itinerary \( i \in I_f^d \).

We are using distance pro-rated revenue, given the fact that each flight leg has a fixed distance in kilometers.

For example, if the itinerary \( i \) uses two flight legs \( f1 \) and \( f2 \), then the revenue allocated to flight leg \( f1 \) due to itinerary \( i \) would be:
\[
\text{Rev}_i' = \frac{\text{length}_1}{\text{length}_1 + \text{length}_2} \cdot \text{fare}_i \cdot \text{DmstPd}_i
\]

And the revenue allocated to flight leg 2 itinerary \(i\) would be:

\[
\text{Rev}_i' = \frac{\text{length}_2}{\text{length}_1 + \text{length}_2} \cdot \text{fare}_i \cdot \text{DmstPd}_i
\]

Consequently, for a given flight leg \(f, f \in F_S^d\), serving the sector \(S\), we can compute the pro-rated flight revenue generated by domestic passengers by summing the revenue allocated to flight leg \(f\) over all the itineraries \(i, i \in I_f^d\).

\[
\text{Revenue}_f = \sum_{i \in I_f^d} \text{Rev}_i'
\]

![Figure 4-4: Pro-Rated Flight Revenue Allocation](image)

For example, for a small network with two hub airports (H and G) and three spoke cities (A1, A2, and A3) where the passengers can only fly either nonstop or one-stop through one of the hubs, the revenue allocated to flight leg \(f_{A1 \rightarrow H}\) is given by:

\[
\text{Revenue}_{f_{A1 \rightarrow H}} = \text{Rev}_{f_{A1 \rightarrow H}}^{A1 \rightarrow H} + \text{Rev}_{f_{A1 \rightarrow H}}^{A1 \rightarrow G} + \text{Rev}_{f_{A1 \rightarrow H}}^{H \rightarrow G} + \text{Rev}_{f_{A1 \rightarrow H}}^{G \rightarrow H} + \text{Rev}_{f_{A1 \rightarrow H}}^{G \rightarrow A2}
\]
IV.2.3 **Pro-rated Flight Profit**

For each flight leg $f$, we have computed in the previous sections both the flight operating costs and the prorated flight revenue. Consequently, the prorated flight profit is the difference between costs and revenue:

$$\text{Profit}_f = \text{Revenue}_f - \text{Cost}_f$$
V Results and Interpretation

V.1 Problem and Solver Parameters

Below, we use the ASM to evaluate here the current schedule flown by the airline. In other words, no flight leg is mandatory and every flight leg is optional. By doing so, we can assess the performance of the current schedule from a pure by profit-maximizing point of view. Nevertheless, it’s rather common that an airline has to fly some specific routes no matter how profitable they are for other reasons (political, historical and so forth) but we are focusing here only on the financial viability of the schedule.

We solve the mixed integer problem (MIP) for the case study using CPLEX on OPL studio. The table below presents a summary of the runs (with, among other information, solving time and number of iterations) done for different values of \(N\), the number of aircraft available, varying from ten to one. There are 418 variables and 10279 constraints. Solving time, number of nodes and number of iterations reach a peak for \(N\) equal to 6.

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<td>650086.75</td>
<td>661543.46</td>
<td>682560.03</td>
<td>763930.99</td>
<td>761706.51</td>
<td>820589.69</td>
<td>880801.26</td>
</tr>
<tr>
<td>Bound</td>
<td>646586.52</td>
<td>646633.87</td>
<td>647302.06</td>
<td>650023.12</td>
<td>661477.33</td>
<td>682492.54</td>
<td>763910.54</td>
<td>761642.01</td>
<td>820513.95</td>
<td>860447.75</td>
</tr>
</tbody>
</table>

Table 4-6: Solver Parameters for Different Runs

V.2 Aircraft Utilization

Because an airline is always trying to maximize the utilization of its fleet, the ultimate goal is to offset costs with sufficient revenue so that flights are profitable. The available fleet is usually a fixed input when the airline is designing its schedule because change in the fleet mix takes some time. Moreover, there are always some fixed costs associated with the acquisition or the lease of each aircraft. We are focusing here on the operating costs because
these costs depend mostly on the decision made by the airline regarding its schedule and its fleet assignment. Therefore, the ultimate objective is to determine whether or not it would actually be profitable for the airline to fly less aircraft.

We run the model for different values of \( N \), the number of aircraft available, varying from ten to one. Table 4-7 summarizes the results: optimal value of the objective function (total and break down between operating costs, spilled revenue and lost revenue due to cancellations).

<table>
<thead>
<tr>
<th>( N )</th>
<th>Objective Function</th>
<th>Operating Costs</th>
<th>Spilled Revenue</th>
<th>Lost Revenue</th>
<th>Total Lost Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>$646,649</td>
<td>$591,636</td>
<td>$121,432</td>
<td>$98,170</td>
<td>$219,602</td>
</tr>
<tr>
<td>9</td>
<td>$646,697</td>
<td>$591,636</td>
<td>$121,478</td>
<td>$98,170</td>
<td>$219,649</td>
</tr>
<tr>
<td>8</td>
<td>$647,366</td>
<td>$591,636</td>
<td>$113,627</td>
<td>$99,636</td>
<td>$213,263</td>
</tr>
<tr>
<td>7</td>
<td>$650,087</td>
<td>$591,636</td>
<td>$116,304</td>
<td>$109,892</td>
<td>$215,940</td>
</tr>
<tr>
<td>6</td>
<td>$661,543</td>
<td>$519,485</td>
<td>$144,441</td>
<td>$115,753</td>
<td>$254,334</td>
</tr>
<tr>
<td>5</td>
<td>$682,560</td>
<td>$447,334</td>
<td>$207,005</td>
<td>$130,406</td>
<td>$322,758</td>
</tr>
<tr>
<td>4</td>
<td>$712,758</td>
<td>$360,753</td>
<td>$238,885</td>
<td>$140,862</td>
<td>$369,090</td>
</tr>
<tr>
<td>3</td>
<td>$763,931</td>
<td>$274,173</td>
<td>$319,411</td>
<td>$153,849</td>
<td>$460,074</td>
</tr>
<tr>
<td>2</td>
<td>$820,590</td>
<td>$144,301</td>
<td>$446,839</td>
<td>$156,780</td>
<td>$602,488</td>
</tr>
<tr>
<td>1</td>
<td>$880,801</td>
<td>$115,441</td>
<td>$553,941</td>
<td></td>
<td>$710,721</td>
</tr>
</tbody>
</table>

Table 4-7: Optimal Solution for Different Numbers of Aircraft

The results indicate that the number of flights that should be flown is constant for values of \( N \) between 7 and 10, and decreases as the number of aircraft available decreases for values of \( N \) below 7. Interestingly, the detailed data for values of \( N \) between 7 and 10 show that, while both the spilled revenue and the revenue lost due to cancellation fluctuate, the optimal value of the objective function is nearly constant. The figures 4-5 and 4-6 allow illustrate what happens. This suggests that seven aircraft may be sufficient to fly the schedule instead of ten. Therefore, the airline could either retire the three extra aircraft or use the extra capacity to fly new routes or increase service in currently underserved routes to make more profit.

68 itineraries are flown when \( N \) is equal to seven while only 67 itineraries are flown when \( N \) is equal to ten. This can be easily explained: having more aircraft gives the airline more flexibility in the fleet assignment. Indeed, with ten aircraft, the airline can afford to have an aircraft sitting on the ground waiting for a later flight leg that lots of passengers would like to fly; whereas, with only seven aircraft, the airline may assign its aircraft to earlier less
profitable flight legs to send the aircraft to another station on time and insure that other later profitable flights can be flown.

Figure 4-5: Optimal Solution Value vs. Number of Utilized Aircraft

Figure 4-6: Optimal Set of Decision Variables vs. Number of Utilized Aircraft
V.3 Frequency Saturation

The optimal solution for this case study indicates that only 41 flight legs out of 85 and only 68 itineraries out of 115 should be flown. Table 4-8 summarizes the results per directional O&D market. It thus implies that the airline should reduce the frequency of service for every O&D market it is currently serving. In some cases, it is even recommended that the O&D market should not be served anymore, which might raise policy issues, especially regarding access for small markets as it will be discussed in the next chapter.

<table>
<thead>
<tr>
<th>Directional O&amp;D Market</th>
<th>Cancelled</th>
<th>Flown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1A2</td>
<td>8</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>A1A3</td>
<td>5</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>A1A4</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>A1A5</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>A2A1</td>
<td>7</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>A2A3</td>
<td>4</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>A2A4</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>A2A5</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>A3A1</td>
<td>6</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>A3A2</td>
<td>3</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>A3A4</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A3A5</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>A4A1</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>A4A2</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>A4A3</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A5A1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>A5A2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A5A3</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>48</td>
<td>67</td>
<td>115</td>
</tr>
</tbody>
</table>

Table 4-8: Optimal Solution – Frequencies for Each O&D Market

Airlines usually follow a route expansion strategy, and thus predominantly focus on adding frequencies to previous developed destinations, because they are adhering to the rationale that such a strategy would be to attract a bigger market share, especially more business class travelers. The obvious limitation of this strategy is that the higher the frequency, the higher the operating costs. Consequently, without denying the fact that higher frequency is good, one of the reasons why the optimal solution implies an overall reduction in frequency of service is certainly that, beyond a certain frequency, the revenue generated when adding frequency does not offset the extra operating costs. This tradeoff is indeed embedded in the ASM thanks to the objective function of the ESD-FAM. Note that this reasoning is
particularly appealing in the case of the small markets (e.g. A3A5 and A5A3) where the optimal solution indicates that the markets should not be served anymore because the expected revenue is simply too low.

Pushing the reasoning a step further, the overall reduction in frequency of service might also be explained by the frequency saturation. This concept, which has been introduced in the ASM through the Decision Window Model, takes into account a further limitation of the route expansion strategy: the demand for travel is spread across the day and adding frequency may not be improving the supply if the departure times are concentrated within only one time window. Consequently, the optimal solution is minimizing overlap in routes and frequencies by taking the redundant itineraries off the schedule, which results in a decrease in the frequency of service. This reasoning may be more adapted to the big markets (e.g. A1A2 and A1A3) whose current frequency of service is very high, even excessive to some extent.

V.4 International Passengers

In this case study, we treat the international travelers simply as more passengers on the corresponding domestic itineraries between their origin/destination and the airport A1 (the only international gateway). We assume that they contribute the same fare as the other passengers on that itinerary, i.e. we assume that the prorated fare for international passenger on the domestic part (i.e. the domestic flight leg \( f \)) of their trip is equal to the domestic fare for the nonstop itinerary corresponding to flight leg \( f \). This is an optimistic assumption, which tends to slightly overestimate the expected revenue.

However, this approach does not take into account the fact that international passengers have different decision windows than domestic passengers. Indeed, their travel time is not limited to the flying time corresponding to the domestic flight leg of their itineraries and it may even be far longer. If it is correct that some international passengers have a shifted decision window, then it might make sense to schedule flight legs that were not attractive when considering the time-of-day domestic demand distribution but that might be attractive when considering the time-of-day international demand distribution. Therefore, for the biggest O&D markets, especially A1A2 and A1A3, the decision to decrease frequency may
need to be revised to accommodate the international passengers willing to travel on the deleted flight legs.
Chapter 5

Issues of Access for Small Markets

I Introduction

This chapter supplements the profit maximizing optimization methodology (which has been developed in chapter 3 and illustrated by a case study in chapter 4) by discussing policy implications, particularly in the context of access for small markets. Indeed, optimization methods often lead to extreme schedule decisions such as eliminating service to markets, often small markets, that are not financially profitable for the airlines. This result is of grave concern to government policy makers as rural access to markets, goods and services is a politically charged subject. The issue is therefore to understand what is likely to happen in small communities if the government doesn’t respond in some way and how much subsidy, if any, would it be necessary to encourage airlines to maintain service in these markets. Our approach is based on economic policy and cost-benefit analysis and is illustrated in the context of the country (referred to as country C) and the airline studied in chapter 4.

II Air Transport Policy Framework

II.1 Transportation System

The social, economic and cultural development of a country is typically highly intertwined with the development of its transportation system. In country C, the evolution of the transportation system has been characterized not only by the country’s remoteness from many of its trading partners, but also by its relatively low population density. International air and telecommunication channels have helped overcome the country’s isolation, but there is still a heavy reliance on sea transport for overseas trade. Comprehensive railway and road networks have been established over difficult terrain and, taking into account the size of the population, the capital cost has been high. In recent years deregulation has brought major changes in the transport sector. The sector had been protected by legislation and by being
entirely government-owned but is now on a more commercial footing. The fundamental shift away from government owned and operated transport systems to a more market based, private sector approach to the delivery of transport services represents a major policy change and had fundamental and far-reaching impacts on the national transport system, and especially in the national air transport system [National Ministry of Transport].

II.2 Air Transportation

Country C is one of the most aviation-oriented nations in the world: there is one pilot for every 430 people and one aircraft for every 1,170 people. During the 1998/99 years the airlines carried more than 4.7 million passengers on domestic services and 2.7 million arrived on international air carriers.

As in most countries, the airline industry in country C is characterized by high capital costs (e.g. for aircraft and ground support equipment), combined with relatively inflexible operating costs (labor, fuel, insurance, and infrastructure). In most areas of operating costs carriers are price takers and have little or no influence over price. This is particularly true for services such as airports, security and air navigation, which are generally mandated by regulation and are single sourced or monopoly service providers.

On the revenue or market side, the overall size of the market has continued to grow over the last ten years. In general, this growth has mirrored the growth in GDP. However, the airline industry tends to be very cyclical and earnings tend to fluctuate in ranges greater than the changes in GDP. A major reason for these demand characteristics is that the demand for air services is primarily derived. Generally speaking, air services are an intermediate product and not the end product. Therefore, it is greatly influenced by such factors as changes in the business climate or consumer preferences for leisure activities. The reverse of this relationship is also true. Changes in the price of air services can have a significant impact on the viability of other sectors such as tourism and the business convention market.

It is thus very difficult for the airline to save cost. They have to focus on capturing high revenue and thus they cannot afford serving unprofitable markets as the margin on profitable markets is limited by the height of the operating costs. Consequently, they tend to serve only promising markets involving cities where people and businesses are concentrated.
II.3 Challenges

Deregulation had a positive effect for the airline industry and, more generally, for the travelers. However, it has created some significant challenges, which must be tackled if the country wants to continue to enjoy these benefits in the future. Some of the key issues that have appeared recently are as follows:

- The need to guarantee an environment that fosters competition;
- The need to develop an industry policy that clearly recognizes the need for an adequate return to investors and shareholders;
- The need to establish policies that ensure that critical common industry infrastructure such as air navigation, airports and security are efficient, cost effective and priced compliant with accepted international standards;
- The need to continue to improve and modernize the safety, security, access and environmental regulatory frameworks in a manner which does not excessively restrain the industry’s growth; and
- The need to ensure that small regional markets receive the best possible service.

In this thesis, we focus the discussion on the last issue.

III Issues of Access for Small Markets

III.1 Supply and Demand Interactions

The integrated model of air transportation service demand and supply shown in figure 5-1 has been developed to describe intercontinental air passengers’ services. However, it still provides us with a good representation of the economic issues faced by airlines on the domestic market. “In view of the available transportation services, and their associated price, frequency and trip convenience, consumers then decide whether or not to purchase the services. Reasonably, the current and projected states of the economy will have an impact on consumers’ decision, given a specified supply of air transportation services. The
level of aggregate demand is in turn considered by air carriers in planning their future services.” [Fan, 1999]

Figure 5-1: Integrated Model for Air Transportation Service Demand and Supply [Fan, 1999]

In the previous chapters of this thesis, we clearly adopted a profit-maximizing approach in accordance to the above economic model. In this chapter, the focus shifts from the interaction of air carriers and consumers back to the role of the government as a policy decision maker, especially regarding issues of access to small regional markets.
III.2 Small Regional Markets

Country C’s geography presents a huge challenge: How can one make sure that people living in smaller centers and rural areas have access to essential air services? The purely economic approach of market defined services does not always lead to an acceptable solution from a policy point of view (because it is not in the best interest in the long term from a social and political standpoint) when the market may be too small to generate sufficient revenues to offset the cost of the service. Moreover, the issue is made more complex because air transport services are related to a variety of other requirements such as public safety and local economic development. Given these issues, a clear framework to guide policy makers is crucial.

III.3 Role of the Government

There are several ways in which the government might intervene in situations such as this. Although some argue that the government should not intervene at all and that one should let the market rule, other argue that, to the contrary, the government should interfere by setting mandatory standards and rules. Finally, refusing these two extremes, some argue that the government should develop market-based regulation. In this case, one possible framework would incorporate the following principles:

- Market forces should be the primary determining factors of air service.
- Cautious, cost-efficient and non-market distorting support of critical common infrastructure is a legitimate role for governments in small regional markets.
- Governments are responsible for public safety and should continue to provide the support necessary to deliver this function.
- Other objectives such as regional development should be managed outside this framework.
- Any intervention must be subject to careful consultation with all the stakeholders.
IV Regions Community Profile

In chapter 4, we presented a case study involving five airports A1, A2, A3, A4 and A5 that represent the set of airports to which the airline is offering domestic service. To apply this framework it is first necessary to understand the social, economic and political interests at stake and evaluate the implications of comprehensive air service. Relevant data about the regions associated with each airport are presented below. Note that airports A4 and A5 are actually serving the same region.

IV.1 Population

<table>
<thead>
<tr>
<th>Population (at the 2001 Census)</th>
<th>Change Since 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td></td>
</tr>
<tr>
<td>3,737,277</td>
<td>118,974</td>
</tr>
<tr>
<td>Region A1</td>
<td></td>
</tr>
<tr>
<td>1,158,891</td>
<td>90,234 = +8.4%</td>
</tr>
<tr>
<td>Region A2</td>
<td></td>
</tr>
<tr>
<td>423,765</td>
<td>9,717 = +2.3%</td>
</tr>
<tr>
<td>Region A3</td>
<td></td>
</tr>
<tr>
<td>481,431</td>
<td>13,389 = +2.9%</td>
</tr>
<tr>
<td>Region A4 &amp; A5</td>
<td></td>
</tr>
<tr>
<td>181,539</td>
<td>-3,543 = -1.9%</td>
</tr>
</tbody>
</table>

Table 5-1: Population at the 2001 Census

IV.2 Business

<table>
<thead>
<tr>
<th>Business Locations in 2002 (Geographic units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
</tr>
<tr>
<td>309,749</td>
</tr>
<tr>
<td>Region A1</td>
</tr>
<tr>
<td>108,789 = 35.12%</td>
</tr>
<tr>
<td>Region A2</td>
</tr>
<tr>
<td>36,994 = 11.94%</td>
</tr>
<tr>
<td>Region A3</td>
</tr>
<tr>
<td>37,123 = 11.98%</td>
</tr>
<tr>
<td>Region A4 &amp; A5</td>
</tr>
<tr>
<td>14,228 = 4.59%</td>
</tr>
</tbody>
</table>

Table 5-2: Business Locations in 2002
A geographic unit used in the context of business surveys refers to a separate operating unit engaged in one, or predominately one, kind of economic activity from a single physical location or base.

**IV.3 Income**

<table>
<thead>
<tr>
<th>Country</th>
<th>Median Income (at the 2001 Census)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$18,500</td>
</tr>
<tr>
<td>Region A1</td>
<td>$21,100</td>
</tr>
<tr>
<td>Region A2</td>
<td>$22,400</td>
</tr>
<tr>
<td>Region A3</td>
<td>$17,600</td>
</tr>
<tr>
<td>Region A4 &amp; A5</td>
<td>$15,700</td>
</tr>
</tbody>
</table>

Table 5-3: Median Income at the 2001 Census

**IV.4 Average Annual Household Spending**

<table>
<thead>
<tr>
<th>Transportation</th>
<th>Food</th>
<th>Housing</th>
<th>Housing Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>$7,358</td>
<td>$7,004</td>
<td>$10,159</td>
</tr>
<tr>
<td>Region A1</td>
<td>$8,066</td>
<td>$7,957</td>
<td>$13,566</td>
</tr>
<tr>
<td>Region A2</td>
<td>$8,570</td>
<td>$7,375</td>
<td>$10,234</td>
</tr>
<tr>
<td>Region A3</td>
<td>$6,188</td>
<td>$6,242</td>
<td>$8,543</td>
</tr>
<tr>
<td>Region A4 &amp; A5</td>
<td>$5,916</td>
<td>$6,309</td>
<td>$8,573</td>
</tr>
</tbody>
</table>

Table 5-4: Average Annual Household Spending at the 2001 Census

**IV.5 Implications**

Given the data presented in tables 5-1 and 5-2, we expect high level of traffic between region A1 and regions A2 and A3 but low level of traffic between regions A4 and A5 and any of other regions. Indeed, previous work has shown that there are huge travel needs from/to wherever people and businesses are concentrated. The data presented in tables 5-3 and 5-4
further support the expectation of high level of traffic between region $A1$ and region $A2$. Indeed, people in these two regions are wealthier and spend more than the average population; such a situation creates a need for mobility and exchanges between the two regions.

In other words, the above tables clearly demonstrate the economic and social differences among the different regions served by the airline. Region $A1$ is the most dynamic, populated, growing and wealthy region of all, followed closely by region $A2$. Region $A3$ comes then and region A4&A5 is the least attractive one.

V Alternatives

V.1 Alternative Mode of Transportation

Rail transportation is the alternative mode of transportation that represents the biggest competition to air transportation within country C. The national railway company is owned by a private consortium. The consortium plays a key role in the increasingly competitive transport market of the country, operating rail, trucking and shipping services throughout its national network. In the 1998/99 financial year 12.9 million tons of freight was carried. Urban commuter services in $A1$ and $A2$ provide more than 10 million passenger trips a year. One possible recommendation would be that the Government support the development of the rail in markets neglected by the air service. This is a reasonable option in markets like $A1A2$ and $A3A4$ for which the cities are relatively close to one another.

V.2 Essential Air Service

Under a so-called essential air service program (in reference to the program administered by the U.S. Department of Transportation) the government would determine the minimum level of service required at each eligible community by specifying a hub through which the community is linked to the national network, a minimum number of round trips and available seats that must be provided to that hub, certain characteristics of the aircraft to be used, and the maximum permissible number of intermediate stops to the hub.
The concentrated structure of the air transportation industry in country C makes it difficult to regulate in terms of an essential air service program. The responsibility of complying with essential services regulations presently lies with the airlines offering domestic service. Only two airlines comprise the entire air travel market. The concentration of compliance costs on these airlines and the diffuse benefits to the scattered rural communities imply a classic Olsonian collective action problem [Olson, 1982]. Airlines have fairly homogeneous interests and can more easily mobilize opposition to essential services while the general public’s interest is underrepresented.

A recommendation would be for the government to offer subsidies for a number of air routes if they meet certain criteria. This practice may be a viable means of ensuring adequate air services to remote and sparse areas of population. The list of criteria has to be carefully establish by the government so at to be in accordance with the particular social, economic and political interests of the country. The extent to which routes should be subsidized depends on the amount that would be necessary for the airline to counterbalance the loss in profit if it was to offer service to these non-profitable routes. It also should be based on a careful estimation of the benefits associated to the provision of air transportation service to small regional markets.
Chapter 6

Conclusion and Future Research Directions

I Summary

In this thesis, we bring the integration of the airline scheduling process a step further by building upon (coupling) the Extended Schedule Design and Fleet Assignment Model (ESD-FAM) by Lohatepanont and Barnhart (2002) and the Decision Window Model (DWM) to create the Airline Scheduling Module (ASM), an automated tool that optimizes airline schedule design in a competitive environment. We applied the ASM to the schedule of a real airline in the case study in chapter 4. The results emphasize the importance of an adequate use of resources, the interactions between frequency and market shares, and the existence of frequency saturation. However, the purely economic approach of market defined services does not always lead to an acceptable solution from a policy point of view when the market may be too small to generate sufficient revenues to offset the cost of the service. Therefore, in the last chapter, we discuss different policy recommendations (such as supporting of an alternative mode of transportation and developing an essential air service program) that might be put in place to address the issue of access for small markets.

II Future Work

In this thesis, we conduct computational experiments using one set of data. Additional computational experimentation should be performed to evaluate further the potential benefits of the integrated approach of the Airline Scheduling Module.

The model in this thesis does not consider simultaneous changes of schedule by competing airlines. The ASM is used so far to determine the changes in the schedule of only one airline that is aware of the competitive environment. In other words, the model takes into account the changes in the allocation of the total demand within all the competing airlines assuming that only one airline is able to modify its schedule for the next time period. One possible extension is to use the ASM within a game theoretic simulation to study the non-cooperative
gaming behaviors of all the airlines offering service. A proposed method would consist of running simultaneously the ASM for competing airlines so as to simulate the competitive responses of each airline competitor seeking to maximize profit. A model of airline hub competition may be developed and calibrated using historical data.

The model in this thesis does not explicitly incorporate the fare effects. However, the ASM is sensitive to fare, especially the fares of the optional flights that are candidate to be added to the network. Additional research extension is to study the sensitivity to fare of the results obtained with the ASM model. Eventually the model could be modified to incorporate fare effects; given that it is possible to calibrate the model using historical data.

Another future research direction would be to use the MIT Extensible Air Network Simulation (MEANS) to calibrate the whole NAS Strategic Simulator. MEANS was initially designed to support the exploration, development and evaluation of Air Traffic Management (ATM) concepts for Collaborative Decision-Making (CDM), in particular, and for Traffic Flow Management (TFM) in general. Since then, the capabilities of MEANS have been expanded to allow for the evaluation of airline scheduling concepts, and the reliability and robustness of airline schedules. The architecture of MEANS emphasizes flexibility, modularity, and the ability to easily simulate uncertainty and other probabilistic phenomena. MEANS is an event-based simulation. It tracks aircraft through the entire nation and the emphasis is placed on ground-based effects. Arrival and departure rates at airports are constrained, which produces delays that propagate throughout the system. The simulation also tracks every passenger in the NAS.
References


