THE PROCESSES OF AIRLINE OPERATIONAL CONTROL

by

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ABSTRACT

The airline industry has undergone many drastic changes in the way operations are conducted since the Airline Deregulation Act of 1978. The Federal Aviation Administration of the Department of Transportation, however, has not fully kept up with these changes. This has created tension between the airlines and the FAA, who, responsible for providing air traffic control and management, is using decades old technology and procedures to handle modern day problems.

This thesis details the process of building and implementing an airline schedule. This is based on interviews with several major US airlines. Particular attention is paid to the day to day running of the airline at the Airline Operations Control Center.

Several areas are identified where the FAA can provide better ATC service to the airlines, and to the traveling public. These areas include more lenient rules for swapping ground delay program slots, including slot sale, and new tools to make more efficient use of the national air space.

Thesis Supervisor: Professor Robert W. Simpson
Title: Director, MIT Flight Transportation Laboratory

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I would like to thank the students of the Flight Transportation Lab: Tom, for helping me keep my perspective through all this; Mike, for showing me just how quickly a thesis can be done; Edmund, for sharing the experience of the frantic last week of editing with me; and Robert, for making lab a fun place to come to.

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Chapter 1 Introduction

1.1 Motivation for Research

In the United States air transportation, there are two entities that affect daily operations, the Federal Aviation Administration (FAA) of the Department of Transportation (DOT) and the airlines. The FAA provides Air Traffic Control at all major airports, and throughout the National Air Space. The airlines provide air transportation service to the public. The FAA is a government agency. The airlines are publicly held corporations.[1] Since deregulation, the way the airlines do business has changed greatly. The way the FAA administers the National Air Space (NAS) has not changed substantially during this period.

It is the purpose of this study to detail the way airlines operate. In particular, the Airline Operations Control Center (AOCC), the section of the airline responsible for day to day operations, was investigated and analyzed. Areas where better cooperation between FAA and the AOCCs could be instituted were identified and defined.

In this study, we traveled to American Airlines and United Airlines to see the workings of their Airline Operations Control Centers. We also visited the Boston AARTC to investigate the processes used by the FAA to perform both air traffic control (ATC) and traffic flow management (TFM).

Chapter 2 of this thesis details the process or airline schedule development. Chapter 3 details the Airline Operations Control. Chapter 4 examines operational problems and current airline solutions. Chapter 5

[1]Some small regional carriers are privately held.

explores areas where the FAA can work with the airlines to increase the efficiency of air transportation operations in the United States.

1.2 Evolution of the Hub and Spoke Network

Airline regulation dates back to 1938 with the creation of the Civil Aeronautics Authority and its successor, the Civil Aeronautics Board. The regulatory boards established routes, set fares, and limited the number of airlines that could compete on these routes.

With the Airline Deregulation Act in 1978, the airlines were given much more commercial freedom to compete. This freedom allowed new carriers to emerge, to set their own fares, and caused much restructuring of airline's patterns of service. The freedoms in fares have led to the multiple fare structures which allow vacationers to travel for less than half of what the time conscious business traveler pays.

The change in market entry and exit rules altered the way airlines schedule service. Prior to deregulation, it was quite common for passengers to change airlines (interlining) in order to reach a destination because the origin city and destination city were not served by the same airline. With deregulation, each airline was able to expand to serve more cities, and it accomplished this by offering a network pattern called *hub and spoke*. In this pattern, flights came in from several cities to a centrally located hub airport. At the hub, the passengers switched planes on the same airline and continued their trip out to the final destination.

Hub and spoke networks allowed several advantages to the airlines. These included: a rapid means of expanding the number of OD markets served by one carrier; more services could be offered for each flight; ease of operations by having central sites for planning and maintenance. The net result of this was to improve the level of service and competitiveness of the airlines who used hub and spoke. It also brought the disadvantages of the high cost of hub operations, the congestion and delay due to the lack of capacity at hub airports, and major disruptions to the airline service when operations at a hub airport could not be conducted as scheduled. This has changed the way airlines operate. This study will attempt to explain the methods the airlines currently use successfully conducting airline service.

Chapter 2 Airline Schedule Generation

2.1 Introduction

Every month, dozens of schedules will need to be generated in order to keep an airline flying. Some of these schedules are published months in advance, some are "tweaked" every hour of every day. They all, however, work together toward one goal, providing reliable, predictable, and desirable service for the public.

The basis of airline marketing is the *Passenger Schedule.* This schedule contains all the information the public needs to make its travel decisions, namely: flight origin, flight destination, flight departure time, flight arrival time, and aircraft type. Directly in support of this schedule are the *Schedule of Crew Trips* and the *Schedule of Aircraft Rotations.* These two operational schedules describe the activity of the major airline resources: aircraft and crews. These three schedules are grouped together as *Airline System Schedules* and are generated centrally for the entire airline.

With the System Schedules generated, a second group of schedules, called the *Station Schedules,* are generated which deal with the resources at the individual stations. These resources include gates, refueling equipment, baggage handling equipment, tractors, and all ground personnel. These schedules are usually generated by operating managers at each airline station, and are updated repeatedly as needed.

The System Schedules, particularly the Passenger Schedule, are generated as much as six months in advance of operations and are used in selling services and allowing passenger reservations. The Station Schedules are constructed closer to operations, with gates and ground operating schedules generated perhaps just the month before they go into effect.

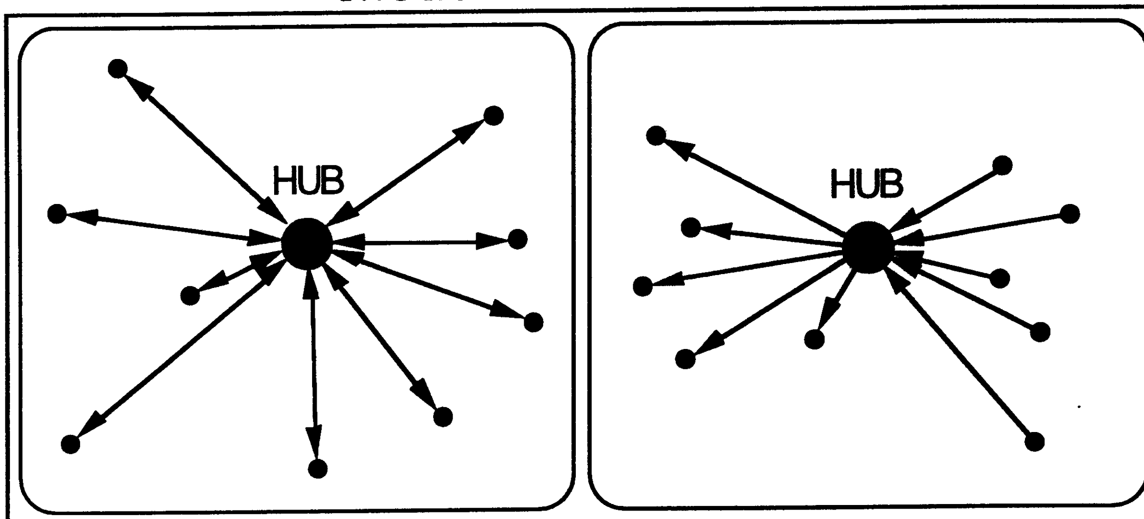
2.2 Hub and Spoke Networks

Since deregulation was introduced in 1977, hub and spoke network structures have permeated all major airlines in the United States where now 95% or more of all airline flights are going either into or out of a hub airport and major airlines have several such hub stations. These hub and spoke networks present the passenger with more options for air travel, while allowing the airline much more flexibility in both scheduling and operations. With as little as one connection, a passenger has access to most points within an airline's network.

A simple hub and spoke network is based on a centrally located *hub* airport surrounded by a group of secondary airports called *outliers* or *spoke stations*. There are two general modes for hub and spoke operations. In an omni-directional hub, flights come from all directions into the hub (see Figure 2-1A) and the same aircraft may then return to the original spoke station. This allows for $n*(n-1)$ possible connections, with n representing the number of inbound flights. The second major mode is a directional hub, where flights come in from one direction and travel out in the same direction (see Figure 2-1B). Directional hubs normally take the form of eastbound/westbound or northbound/southbound. In a directional hub, n aircraft serve n^2 connection markets.

Flights inbound to a hub are all scheduled to arrive within a small window of time called an *arrival bank*. While each aircraft is on the ground, passengers and baggage have sufficient time to make their connection. Then, the aircraft depart within another small window call the *departure bank*.

TWO HUB AND SPOKE MODES



A. Omni-Directional Hub **B. East - West Directional Hub**

Figure 2-1

One very important decision concerning connections at a hub, is the decision of which aircraft links arrival and departure flights. Every aircraft in the arrival bank will be assigned to a flight in the departure bank. The connected flights are said to provide "*through service*", because passengers would not need to change aircraft to continue flying. Deciding on which markets will be served with these through flights can have an impact on revenue, since other airlines may only be offering "*connecting*" service in the market. Flight listings, such as the OAG and ABC guides, list the through flights with the non-stop flights, and list all connecting flights separately. This, combined with the general passenger preference to not have to walk through the terminal makes a through flight a more attractive.

2.3 Connecting Complex

The key to implementing the hub and spoke network is to coordinate activities at the hub airport. This coordination of arrivals and departures is called a *connecting complex* (see Figure 2-2). The arriving flights are scheduled to all reach the hub airport within a period of time of between 15 and 60 minutes. These arrivals, as many as 60 in total, are referred to as an *arrival bank*. At the end of the connecting complex, the same aircraft will

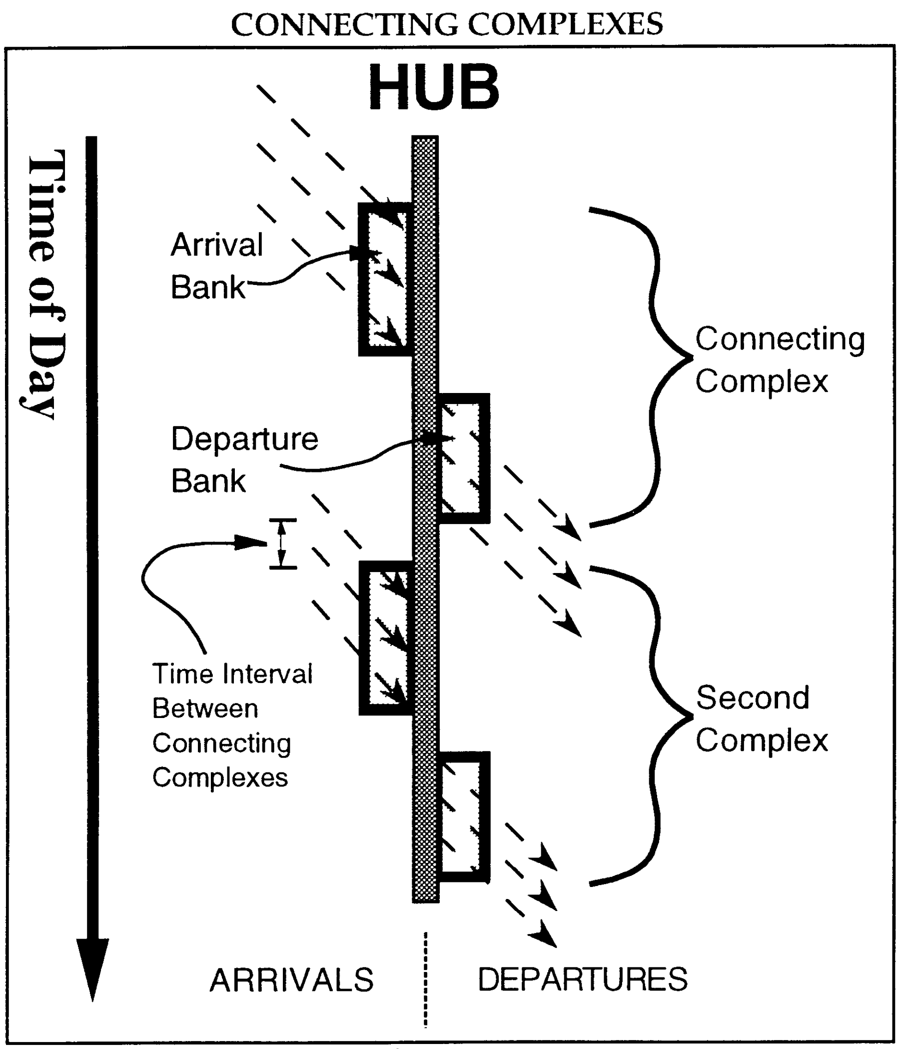


Figure 2-2

depart the hub airport in a similarly short period of time. This is referred to as the *departure bank.*

Major Hubs, such as Dallas-Ft. Worth for American Airlines, Chicago for United, and Atlanta for Delta, will have as many as a dozen connecting complexes a day. Because of this, the time between complexes becomes very small, and, in fact, complexes will overlap as early departures free up gates which can be used by early arrivals of the next complex. This increases the gate utilization. Lesser hubs will generally space out the complexes enough to put time between successive complexes.

Smooth operation of the complexes becomes essential for the airline. This is particularly true during the time the aircraft are on the ground. There are several activities that must be accomplished during this short period of time. These include passenger connections, baggage and cargo connections, crew transfers, and aircraft handling to prepare for the next flight.

2.3.1 Minimum Connection Times - Baggage, Cabin Crew, Cockpit Crew, Passenger

In assembling connecting complexes, one critical decision is how much time to put between the end of the arrival bank and the beginning of the departure bank, known as the *bank interval.* This determines the minimum time passengers, baggage, and crews will be permitted to make connections between the last arrival and the first departure. Likewise, determining what order flights will be scheduled to arrive and depart plays a role in determining the ease or difficulty of all connections, particularly the crew connections.

Passengers connecting within the complex must de-plane their arrival aircraft, proceed through the terminal to their departure gate, usually nearby, and board their departure aircraft. The minimum time for this activity will differ for each airport and each complex. Through experience the airlines have learned these *minimum passenger connection times,* which generally are 20 to 30 minutes. The arrival and departure banks will be separated chronologically by the minimum passenger connect time to allow all passengers to make their connections (see Figure 2-3). Through proper scheduling of the gates to minimize walking distances, minimum passenger connection times can be reduced. Less organized carriers may schedule as much as an hour or more for passenger connections.

SINGLE COMPLEX

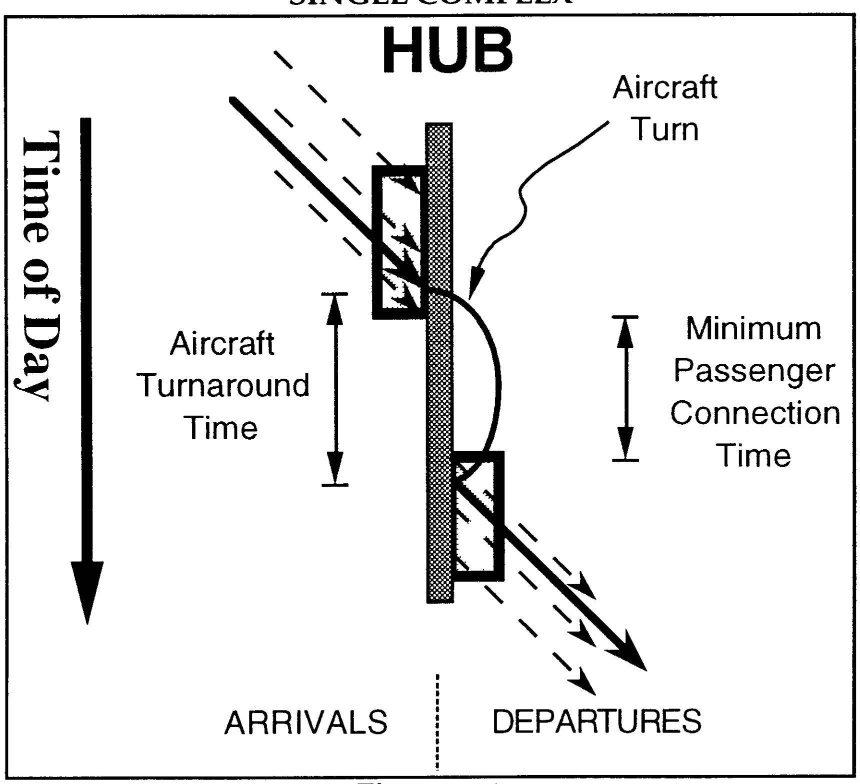


Figure 2-3

While passengers transfer through the terminal, baggage and cargo will be transferring on the apron area of the airport. The process of transferring baggage and cargo at the hub airport during a complex is preplanned to minimize the required time, the *minimum baggage connect time.* At a spoke airport, all baggage and cargo are sorted, then may be loaded in a manner which facilitates the transfers at the hub. Because departure flights from a hub usually represent the final segment of most passengers travel, no prior baggage sorting is necessary before hub departures. If planned properly, the minimum baggage connect time will be less than the minimum passenger connect time.

When crews reach the hub airport, one of three things can be scheduled to happen: the crew can stay onboard and fly out on the same aircraft; the crew can end their duty period; or the crew can make a connection and depart on another aircraft. When remaining onboard, there is no additional time requirement for the airline. When ending a duty period, the crew coming on duty can be ready to board the aircraft as soon as the old crew deplanes, again with little or no additional time requirement for the airline. When connecting to another flight however, the crew is faced with waiting for the passengers to deplane, then deplaning and crossing the terminal, followed by boarding their new aircraft, and performing all necessary check-in procedures on the new aircraft. This requires significantly more time than either other option, and this may keep an aircraft out of service longer, and can lower the total aircraft utilization. Consequently, airlines will always try to keep crews together with the aircraft as long as possible to save both time and cost.

Keeping the crews with the aircraft also minimize the logistics, because three of the airline resources (the aircraft, cabin crew, and cockpit crew) are traveling together. However, both types of crews have different requirements governing their work activities. It is, therefore, not always possible to keep them together when a flight arrives at a hub.

When connecting complexes are planned out, it is necessary for the airline to consider all connection times in deciding when each aircraft will arrive and depart. The minimum crew connection time is the potentially the most important, as it dictates how much time must be put between the arrival aircraft and the departure of that aircraft when crew connections occur.

2.3.2 Minimum Aircraft Turn Time

The entire process of bringing the aircraft to the gate, unloading and reloading passengers and baggage, servicing, refueling, recatering, and cleaning the aircraft, and then leaving the gate as a departure is known as an *aircraft turn*. There is a *minimum turn time* for aircraft which may depend on the length of haul of the departing trip. Longer flights will need more fuel, food, and water to be loaded prior to departure. Aircraft can be overfueled at the spoke airport to reduce the turn time required.

The duration of flights making up the complex can vary greatly in length. For example, during one United Airlines connecting complex at Chicago's O'Hare International Airport, arrival flight times vary from 1 hour 17 minutes to 4 hours 16 minutes. There is also a network of very short commuter flights run by an affiliated commuter airline. These flights, scheduled to correspond to United's connecting complex schedule, are under an hour in duration. Because of these differences in flight duration, there will always be slack in the airline's schedule at the spoke airports, where aircraft may have to wait on the ground for a departure that will arrive at the hub airport during the arrival bank.

An advantage of an airline which is running a large multiple hub network, is that all aircraft are not involved in a single connecting complex.[2] This allows the airline to send flights into another hub airport, instead of having them sit on the ground awaiting a return to its original hub. Even with the increases in utilization that this allows, there will always be slack ground time at the spoke stations to get the arrival times planned at the hub.

2.3.3 Minimum Gate Buffer Times

Every aircraft in a connecting complex is scheduled to be *on* a gate for a period of time called the *gate occupancy time* or *scheduled turn time.* There is a *gate buffer time* added to the scheduled departure off a gate as a limit on its earliest usage by the next arrival. The buffer lowers the probability that late departures and early arrivals will overlap. At hub airports, the gate occupancy times become much more important as the airport activity level rises.

As more complexes are conducted at a hub, the time between successive complexes becomes smaller. At the major hubs, where as many as a dozen or more complexes are run each day, the time interval between complexes (see Figure 2-2) can become negative. This means that arrivals from one complex will reach the hub airport before all the departures from the previous connecting complex have departed. This limits the gate assignment.

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[2]Some small airlines, such as Icelandair involve all aircraft in their connecting complexes. This causes shorter Iceland-Europe flights to have to sit on the ground waiting for the North America-Iceland flights to reach Iceland.

There are two buffers around overlapping complexes. The first buffer is the time scheduled between the first departure of the departure bank, and the first arrival of the succeeding arrival bank. (See Figure 2-4 below) The second buffer is at the end of the overlap period, defined as the scheduled time difference between the last departure and the last arrival.

OVERLAPPING COMPLEXES

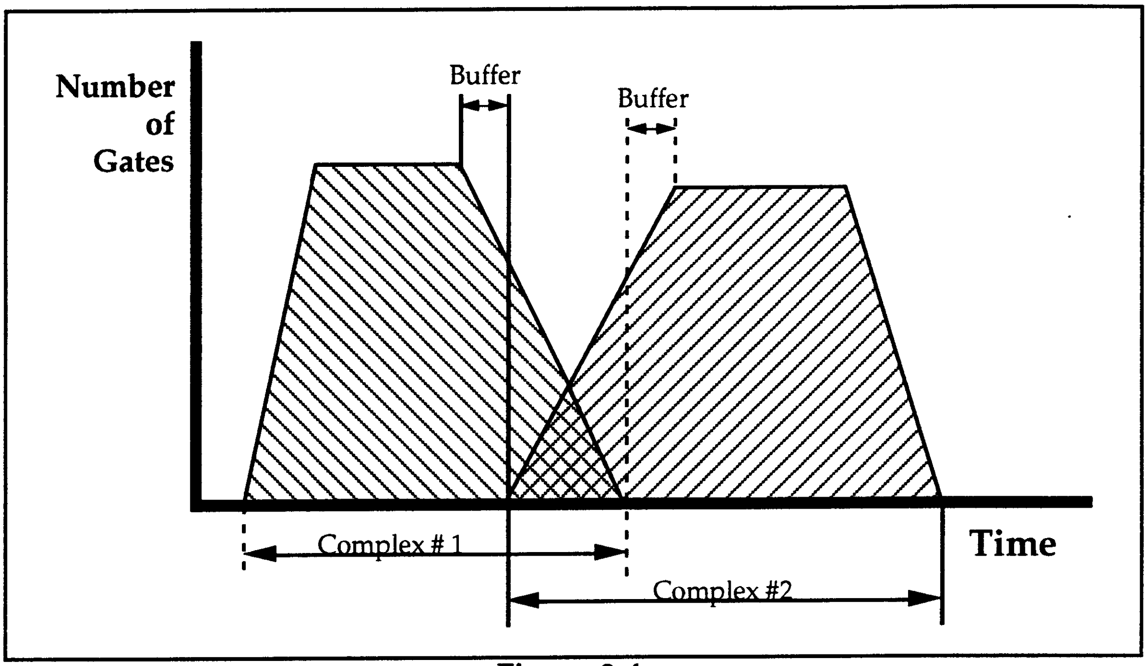


Figure 2-4

Shrinking the minimum gate buffer times allows for higher gate utilization rates and more operations can be conducted. However, this also increases the risk of a time deviation causing irregular gate operations (see chapter 4). Each airline makes tradeoffs to determine what minimum gate buffer time they will use at each hub, depending on flight duration and other factors.

Early arrivals, or late departures can cause conflicts for gate occupancy. When such a conflict arises, it becomes necessary for an aircraft to use a different gate. It may also be possible to move a departure delayed due to traffic flow management by the FAA off the gate onto the apron or elsewhere on the airfield, making the gate available for an arrival.

2.4 The Three Airline System Schedules

There are three Airline System Schedules: the published Passenger Schedule, and the two Resource Schedules; a Schedule of Crew Trips, and a Schedule of Aircraft Rotations. These schedules, generated centrally for the entire airline, are considered the primary schedules for the airlines. These System Schedules define all airline operations, and must be completed in advance to allow the stations to generate the Station Schedules.

The Passenger Schedule is the listing of all services offered by the airline. It is the plan that the airline will attempt to follow throughout the schedule period, since it is a commitment to its passengers. It represents the output of the airline which determines its revenues in competition with the scheduled services of other airlines.

The Passenger Schedule is presented to the traveler in several forms. There is the printed airline timetable, listings in comprehensive flight guides such as the OAG and ABC guides, and listings on Computer Reservations Systems (CRS*s*). The last has become the most popular, and is used by most travel agents. All three forms of the schedule, however, contain the same basic information (i.e. the set of all services available to travel from an origin to a destination airport).

The Schedule of Crew Trips (also known as the Crew Schedule) is the plan for air crew activities during the schedule period. Each crew member, both cockpit and cabin, is assigned to fly a series of trips starting and ending at a crew base on specific days during the schedule period. Each trip will contain a sequence of flight legs, and any required overnighting, or deadheading between flights. This schedule determines one of the major elements of operating cost in executing the Passenger Schedule. It is important to make good utilization of the crews based at the various crew bases throughout the system.

The Crew Schedule is usually generated without individual crew member assignments. Then, after the *generic* schedule is completed, crew members *bid* on individual monthly assignments. The bidding is based on seniority within the airline and type of aircraft for which crew members are qualified.

The FAA sets limits on the maximum flight hours flown by air crews during any day, week, and month, as well as limits on the maximum *daily duty hours*. Daily duty hours refers to the hours between reporting for duty and the last flight of the day. There are minimum rest times required between duty periods based on the lengths of the duty periods. Union agreements with the airline further restrict the possibilities for both the cockpit and the cabin crews. In generating the Schedule of Crew Trips, all these restrictions must be taken into account. The result is a schedule in which, if executed as planned, any crew member is *legal* to make his or her trips.

The Schedule of Aircraft Rotations (also referred to as the Aircraft Schedule) is the plan for all aircraft movements during the schedule period. Sequences of flight legs from the Passenger Schedule are assigned to specific aircraft within the airline's fleet. The aircraft are assigned to fly repeating patterns of flight legs called *rotations* which start and end at a maintenance base. Aircraft have periodic maintenance and inspection requirements after various numbers of flight hours. The rotations must account for all maintenance and inspection requirements, and bring the aircraft to one of many appropriate maintenance facilities for each maintenance check within the specified number of flight hours.

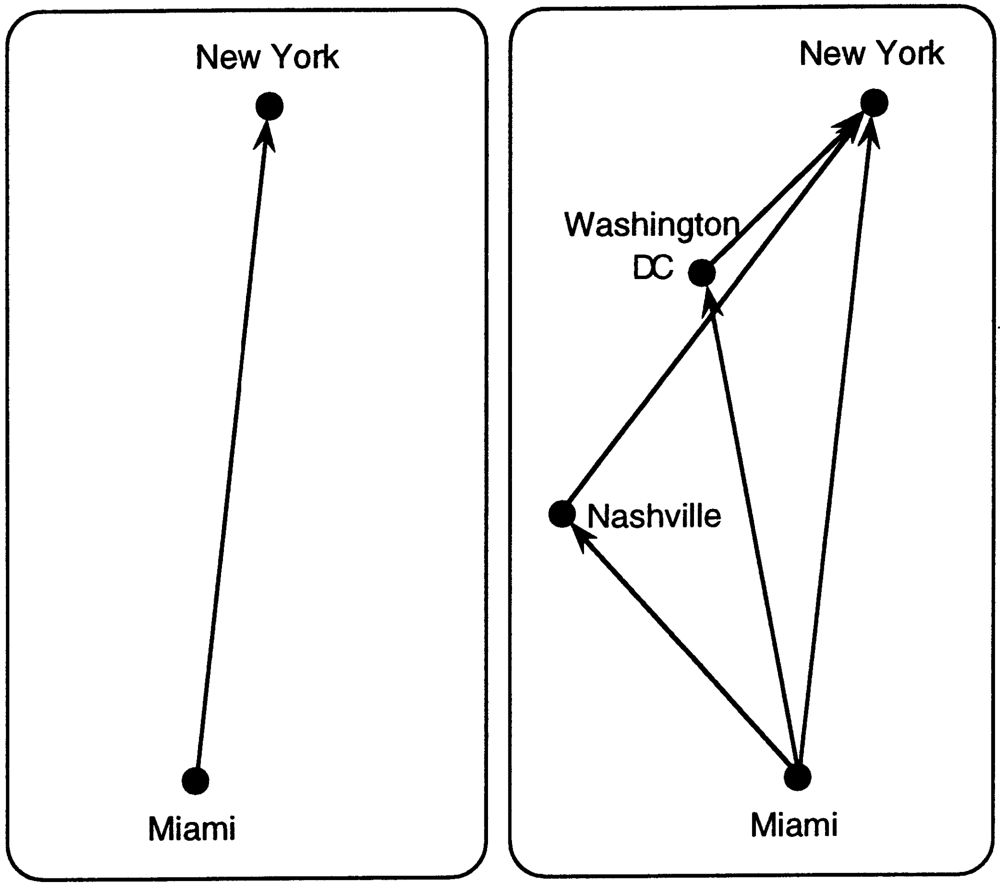
This is the second major element of operating cost in executing the Passenger Schedule. It is important to achieve good utilization of both aircraft and maintenance resources.

2.5 Published Passenger Schedule

The Published Passenger Schedule is the airline's cyclic plan for the schedule period. The schedule period is the planning horizon for airline services. In the United States, schedule periods are generally one month. Foreign carriers may schedule seasonally or semi-annually. Domestic airline schedules have a daily cycle with some weekend exceptions. International schedules have a weekly cycle. To the customer, the Passenger Schedule is the set of *flights* which may be selected for travel between cities.

To the airline the Passenger Schedule is a set of flights and flight legs. It is important to note the difference between a flight leg and a flight. A flight leg is an operational term, and is synonymous with a single *operation* or a *flight segment*. Namely, a flight leg from A to B is a departure from A flying non-stop to B at a specific time. For example, Figure 2-5A represents a flight leg from Miami to New York. A flight, on the other hand, is a marketing term. It may consist of only one flight leg, but more generally, a flight is a particular sequence of flight legs flown by the same aircraft so that passengers do not have to deplane at any intermediate stops. More than one flight routing can exist between any two cities. For example, Figure 2-5B shows three distinct flight routings between Miami and New York. Airline operations personnel view the transportation network in terms of flight legs. Passengers and airline marketing personnel, on the other hand, see the transportation network as made up of flights.

FLIGHT LEG VS. FLIGHT



A. One Flight Leg
Miami - New York

B. Three Unique Flights
Miami - New York

Figure 2-5

A simple hub and spoke network, as shown in Figure 2-6, would have just one central hub (in this case, Chicago). Chicago is one of the world's largest and busiest hubs, due to its central location in the United States. Most remaining city in the network are spoke cities. Chicago is a directional hub serving as a connection point between the east and west coast cities in the

United States. But simple hub and spoke networks for an airline seldom exist. Most US airlines have a network which consists of multiple hub and spoke patterns.

PURE HUB AND SPOKE NETWORK

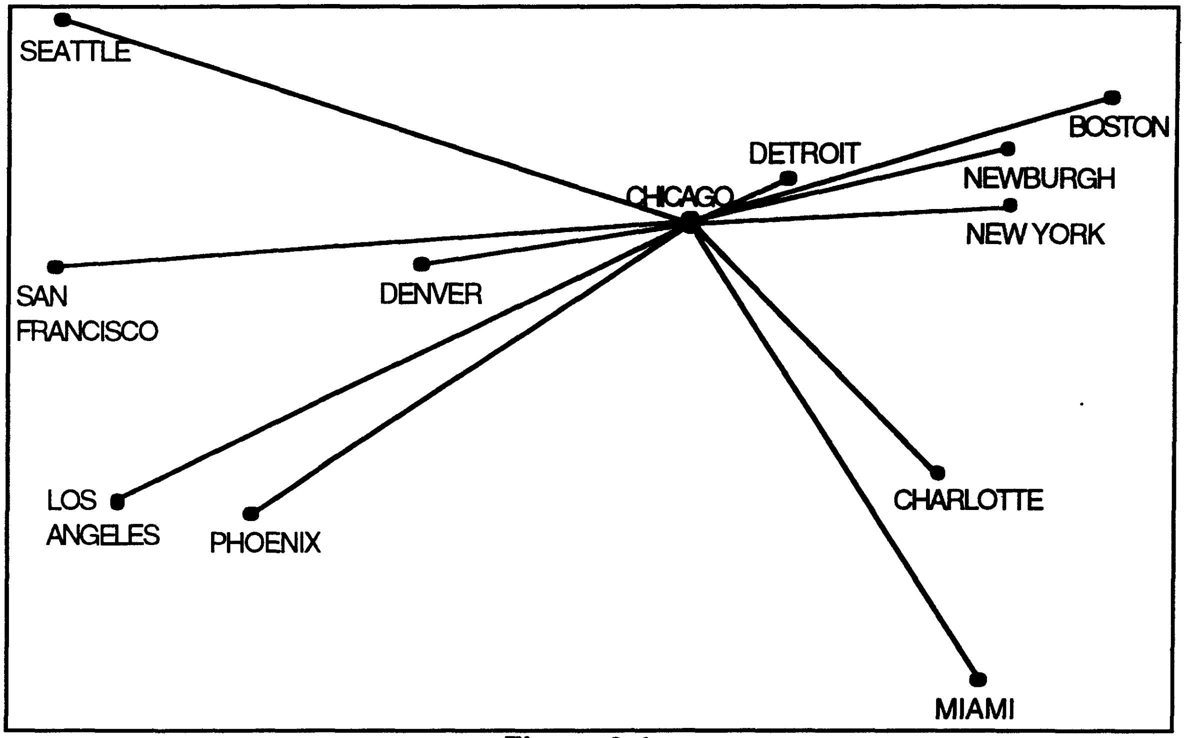


Figure 2-6

Figure 2-7 shows such a sample network. Here, two major hubs exist, with flights designated by solid lines. Chicago is the northern hub, with extensive service to the northeast. Dallas, the southern hub, provides east - west travel between southern cities. There are also "*regional hubs*", such as Denver, New York, and Charlotte. These offer connecting service for cities in their region. For example, New York acts as a hub for service in the northeast and along the east coast. There are also non-stop flights in major business markets which bypass all the hubs, such as New York to Los Angeles, San Francisco, or Seattle, as shown by the dashed lines in Figure 2-7.

Additionally, most major airlines are affiliated with regional and commuter carriers. These smaller carriers operate less dense short haul routes feeding additional passengers into various airports using smaller turboprop aircraft. A spoke station for the major carrier may be a hub airport for the regional carrier. We shall call these "*local hub*" patterns.

MIXED NETWORK

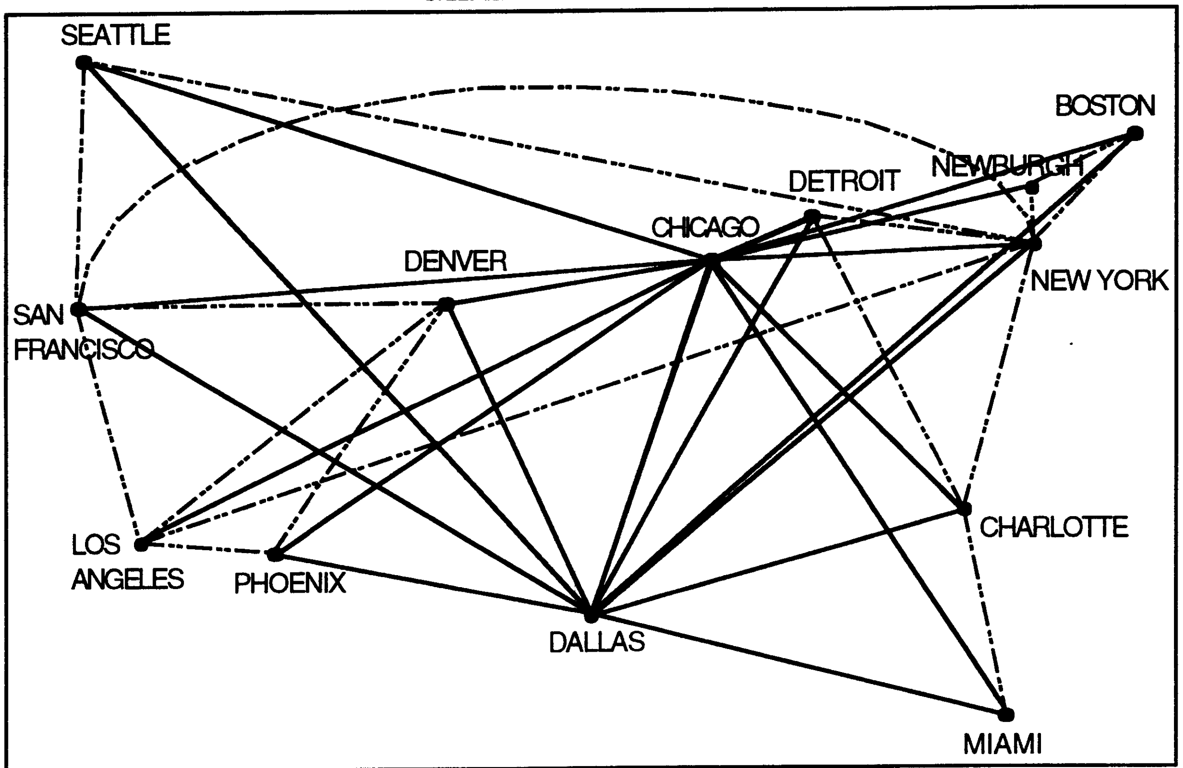


Figure 2-7

2.6 Resource Schedule of Crew Trips

The Schedule of Crew Trips is the assignment of two of the airline's resources to specific flights. These resources are the pilots (also referred to as cockpit crews) and the flight attendants (also referred to as cabin crews). The crews are stationed at several crew bases within the airline network, usually at hub stations.

The two groups are always scheduled separately since they have different work restrictions. Flight attendants may be qualified to work on more than one type of aircraft during a schedule period, whereas pilots are generally only qualified on one aircraft type at a time. The number of flight attendants is dictated by both the size of the aircraft and the passenger load expected on various flight legs. The number of cabin crew actually assigned to a flight may differ on each flight leg. The number of pilots is fixed for each aircraft type There are different FAA and union rules governing the work restrictions for pilots and cabin crew, and this results in feasible or legal trips which are different for the two types of crew. Though the two Crew Schedules are generated separately, they contain the same elements and form. Therefore, we will refer to the Crew Schedule as being the combination of these two schedules.

Once the Passenger Schedule for individual types of aircraft have been created, the Schedule of Crew Trips can be assembled. In the USA, the Schedule of Crew Trips consists of monthly bidlines. A bidline is a sequential listing of all trips that an individual crew member will be taking during the month. Though each individual crew member will have his or her own bidline, the monthly assignment usually means that crew members will stay together, as either a cockpit or cabin crew, for most or all of the month. The complete set of bidlines is generated so that every flight will have the necessary number of each type of crew member.

A crew trip is the planned set of activities for a crew member while away from his or her crew base. (see Figure 2-8) Because of the nature of airline networks and the restrictions on crew work, it is not always possible to return a crew member to his or her crew base each day. Duration of crew trips tend to be 1 to 3 days for domestic crews, and up to a week or more for international crews. As we can see in Figure 2-8, the total number of flight hours is always less than the total number of duty hours for a crew member.

Each crew trip is designed to allow crew members to meet both FAA and union agreements on rest time as well as duty and flight time.

SAMPLE CREW TRIP

```
Trip T1
     - Report to Crew Base at Station A at 0600
     - Depart A 0700, Flight 111 to B arriving 0900  (2 flight hours)
     - Depart B 0945, Flight 222 to C arriving 1215  (2.5 flight hours)
     - Disembark at C, for lunch (2 hours)
     - Depart C 1415, Flight 333 to D arriving 1630  (2.25 flight hours)
     - Off duty at D 1700  (Daily duty hours: 11, flight hours: 6.75)
     - Overnight at D
     - Report to Station D at 0515
     - Depart D 0615, Flight 444 to B arriving 0800  (1.75 flight hours)
     - Depart B 0900, Flight 555 to E arriving 1130  (2.5 flight hours)
     - Disembark at D, for lunch (2 hours)
     - Depart E 1330, Flight 777 to A arriving 1615  (2.75 flight hours)
     - Off Duty at A 1645  (Daily duty hours: 11.5, flight hours: 7)
Total trip flying hours = 13.75
Total trip time away from base (TAFB) = 34.75
Total duty hours = 22.5
```

Figure 2-8

As agreements between airlines and unions have evolved, the crew salary structure has evolved into one based on four different elements. These elements are: base pay, paid every month regardless of flying hours and based on seniority; flight pay, based on actual hours of flying; duty time guarantees; and finally, trip guarantees based on the TAFB (Time Away From Base).

The last two elements have caused the US airlines and air crew unions to adopt a system of *pay and credits*. Base pay for all crews, and flight pay for all flights are fixed amounts for each schedule period and independent of how the schedule is built. The guarantees, however, are very closely related to the structure of the Crew Schedule. Duty time guarantees promise a minimum amount of flying time, usually four hours, whenever a crew member is called into duty. If this minimum is not met, the crew member gets paid for four flight hours and is credited with the four hours for the month. This unflown credit may lead to overtime rates of pay for hours flown over the monthly limit set by the union agreement. Credit hours do not apply to FAA monthly restrictions. Trip guarantees promise that a fraction of the TAFB (e.g. 1/4 for American Airlines) will be flight time. If the trip does not meet the TAFB guarantee, the crew member is given pay and credit for the full guaranteed flight time. Guarantees are the union's way of pressuring the airline to make efficient use of their time. Inefficient use of crew time during a duty period or a trip will cause the airline to incur additional cost in the form of the pay and credits. This additional cost can be as high as 20% of normal crew costs at a major US airline. Such pay rules do not apply to other airlines outside of the USA.

From a crew scheduling point of view, the fixed portion of the crew cost does not need to be considered. Therefore, in optimizing the crew schedule, only pay and credit costs need to be considered. This reduces the complexity of the problem slightly, and provides the airline with a metric to use in comparing new schedule efficiency.

Once the crew trips have been created for the schedule period, the process of building the bidlines can begin. The crew trips are strung together with sufficient rest time between trips to meet all FAA and union requirements. Likewise, the trips are spaced appropriately to comply with FAA limitations on total flight hours of 30 in seven consecutive days, and 100 in a calendar month. The bidlines may also meet union agreements for such factors as number of weekend days at home or number of times per month that a crew member will have at least two successive days at home. The bidlines must further ensure the requisite number of crews for all scheduled flights, a process known as *covering the schedule.* A sample set of bidlines is presented in Figure 2-9. The same crew trips are repeated many times over the course of the month. Furthermore, the same crew trip will be flown simultaneously by multiple crews , each staggered by one day. This allows the flight legs that the first crew flew on the first day to be flown by the second crew on the second day, and so forth.

SAMPLE BIDLINES

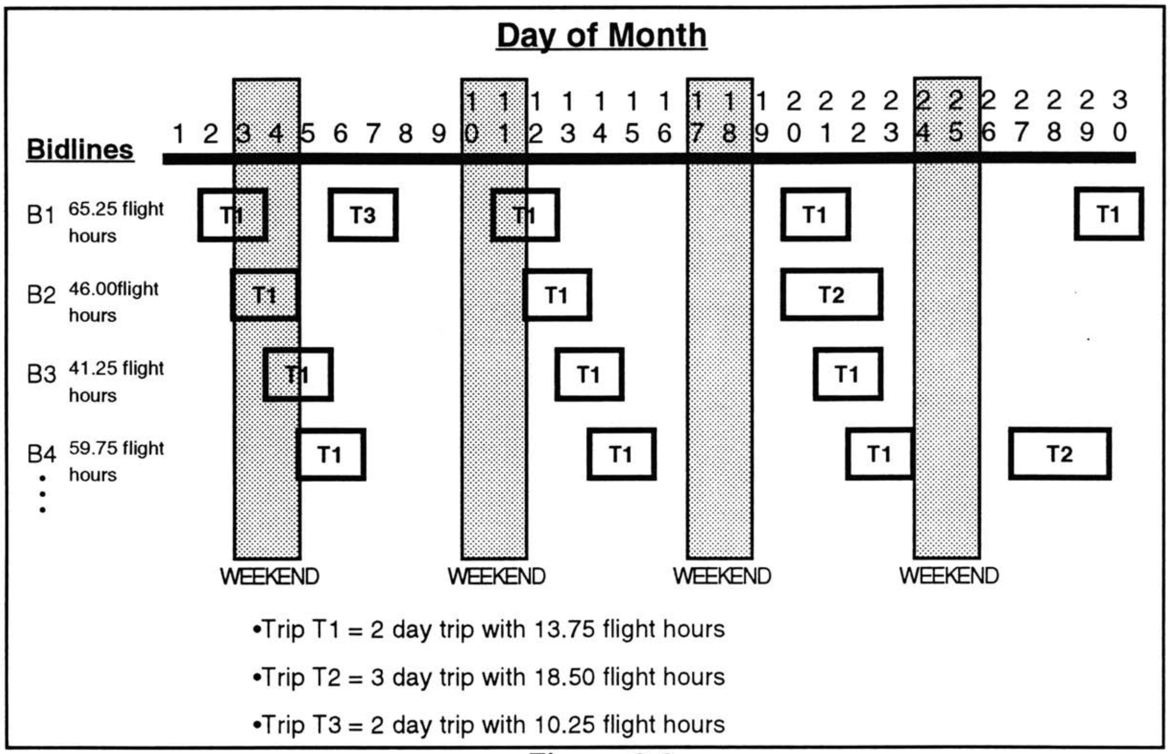


Figure 2-9

In generating cockpit crew trips, the FAA limits the amount of duty time that a cockpit crew member is available to fly. FAR 121.471 states:

> No domestic carrier may schedule any flight crew member and no flight crew member may accept an assignment for flight time in scheduled air transportation or in other commercial flying if the crew member's total flight time in all commercial flying exceed -
>
> (1) 1,000 hours in any calendar year;
>
> (2) 100 hours in any calendar month;
>
> (3) 30 hours in any 7 consecutive days;
>
> (4) 8 hours between required rest periods.[3]

---

[3]The 8 flight hours between rest periods rule is to limit the number of flying hours in a daily duty period.

These restrictions are to assure that a flight crew member is not overly stressed or tired from too many successive hours of flying in one year, month, week, or day. The FAA also stipulates exact rules for rest periods between flight periods in FAR 121.471:

> No domestic air carrier may schedule a flight crew member and no flight crew member may accept an assignment for flight time during any 24 hours preceding the scheduled completion of any flight segment without a scheduled rest period during that 24 hours of at least the following -
>
> (1) 9 consecutive hours of rest for less than 8 hours of scheduled flight time.
>
> (2) 10 consecutive hours of rest for 8 or more but less than 9 hours of scheduled flight time.
>
> (3) 11 consecutive hours of rest for 9 or more hours of scheduled flight time.

Once the generic schedule of bidlines is finalized, individual crew members are *assigned*. In the United States, the assignment of crews is carried out through the process of *bidding* based on seniority. Crew members bid by selecting their top three (or more) choices for the month. Thus, for a given aircraft type, the most senior crew member will get to fly his or her preferred bidline, the next senior crew member can select a bidline exclusive of the first selection, etc. More junior crew members will fly whatever bidlines remain, and develop a personal bidding strategy based on repeated experiences to make their bids effective.

It is necessary for the airline to maintain a number of reserve crews available at each base. These crews are used to fill in during irregular operations (see Chapter 4) and give the airline a capability to maintain the Passenger Schedule when crews get sick, need training, are late in getting back from a trip, or are still finishing last month's schedule. Reserve crews come in two general forms. The normal type of reserve crew is an *on-call* crew which, on specified days of the month, must make themselves available to be at the crew base within a pre-specified amount of time, usually one or two hours.

If the airline foresees the need, reserve crews can be called in for *standby duty* at the crew base or hub station, becoming the second form of reserve crew. Standby crews may also become associated with the *hot spare* aircraft. Standby crews become eligible for normal flight pay, and pay and credit rules for reporting to duty, where on-call crews only receive base pay. Very junior crew members on a given type of aircraft will end up with the reserve bidlines, containing many scheduled on-call periods, and have to wait until they are called in to fly. Such crews must maintain a minimal amount of flying during the year to remain qualified on their aircraft type. If there were no irregular operations, such considerations might cause the airline to cancel planned trips by regular crew members (who is paid as though the trip had been flown) to allow the spare crews to get flying time.

2.7 Resource Schedule of Aircraft Rotations

An aircraft rotation is directly analogous to a crew member's trip. Where the crew trip takes the crew member from his or her crew base, through the system and then back to the same crew base, the rotation takes the aircraft from a maintenance base, through the system, and then back to the a maintenance base capable of servicing that aircraft type.

The monthly Schedule of Aircraft Rotations is very similar to the monthly Schedule of Crew Trips. It is the assignment of an airline resource, in this case a specific aircraft, to specific flights within the Passenger Schedule. All aircraft have an identifying number on their tail, and airlines generally refer to specific aircraft as *tail numbers*. This schedule produces flight rotations for each aircraft, or tail number, in the airline's fleet, since each aircraft's maintenance requirements are different.

If we look at Figure 2-10, we see a sample rotation. This is a three day rotation originating at Dallas. On the first day of flying, the aircraft overnights in Chicago. On the second day, the line of flying (LOF) causes it to overnight in Denver. At the end of the third day, it has returned to Dallas where maintenance activities can be done to prepare the aircraft for a repetition of this rotation, or perhaps another rotation out of this base for that aircraft type. An aircraft might continue to fly these rotations until it is required to enter heavy maintenance, or the schedule period ends; but there is also unplanned maintenance for unexpected failures of aircraft systems, as well as unplanned aircraft switching. It is very unusual for an aircraft to actually fly its planned rotations for the month due to these unexpected events.

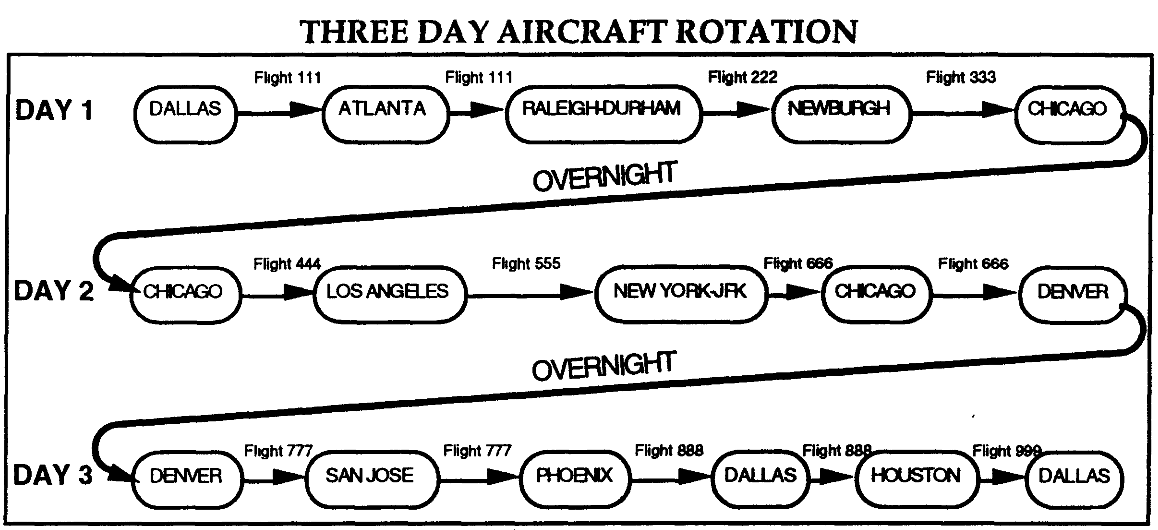


Figure 2-10

Rotations are flown by groups of aircraft, one for each LOF in the rotation. For example, the rotation in Figure 2-10 has three LOFs and would be flown by three different aircraft of the same type simultaneously, with each aircraft's *individual* rotation being staggered by one day. Thus, on every day, there would be one aircraft to start the line of flying at Dallas, one at Chicago, and one at Denver.

Each airline is responsible for providing the FAA with a detailed plan of periodic scheduled maintenance for each aircraft type in its fleet. The maintenance is generally broken down into several packages ranging from light maintenance which can be performed overnight, to heavy maintenance which may take the aircraft out of service for 4 weeks. The required time between maintenance checks is based on flight hours. Light maintenance stops are performed frequently while heavy maintenance is performed very infrequently. The package can be redesigned from time to time to suit changes in schedule patterns. If the basic scheduled maintenance package is repeated every 50 flying hours, the aircraft rotations must have a total flying time of no more than 50 hours, and preferably, exactly 50 hours to avoid performing excessive maintenance. Any failure of equipment will cause a deviation of the aircraft from its planned rotations as it is routed to the nearest maintenance base which can repair it. This is accomplished by switching aircraft of the same type which are on the ground at a station at the same time, normally during a connecting complex at a hub airport (see Chapter 4).

The Schedule of Rotations is created by Aircraft Routers. These airline schedulers are normally associated with the Maintenance Operations Control Center (MOCC). They build lines of flying into rotations that will bring the aircraft to the appropriate maintenance base close to, but within the required time for all scheduled maintenance. Daily maintenance can usually be completed in a stop of a few hours, and are normally scheduled during overnight stops at every station.

For domestic US airlines, the Schedule of Rotations is the most flexible of the three System Schedules. This is due to the common situation of having several aircraft of the same type overnighting at one station. The Aircraft Router has a large degree of freedom in assigning different tail numbers to each LOF at the start of each day. One of the factors in such switching is to match the next evening's maintenance workload to the capabilities of every maintenance station and the availability of replacement spare parts for the unexpected maintenance. This switching can also be executed by Aircraft Routers throughout the day to control the maintenance workload at each station that night. They must inform each station of such desired switches and this may result in different gate assignments.

2.8 The Station Schedules

The Station Schedules describe the activities of station resources for any station of the airline. Of the various Station Schedules, the most important is gate scheduling which has become critical in the post deregulation years, as hub and spoke networks expanded through the US carriers. Connecting complexes involve a large amount of activity during a short duration of time. Hence, efficient gate scheduling is necessary in order to orchestrate such an operation.

The process of gate scheduling is hampered by gate restrictions. Airline gates come in varying sizes, and not all gates can accommodate all aircraft types. Gate availability can also be affected by the occupancy of surrounding gates, since a large aircraft on one gate may block off access to other gates. All of these issues must be considered by the gate schedulers ahead of time, and as the aircraft actually arrive to assure the smooth operation of the connecting complex.

Scheduling of baggage handlers and other ground personnel is also very important to an airline. Again, the importance is heightened at a hub during connecting complex operations. Both the number of personnel who will be on duty, and the procedure for transferring baggage and cargo must be carefully planned out.

Other Station Schedules cover resources such as fuel and fuel service equipment, catering, and ground support staff such as gate agents and ramp handlers. These services are typically generated by the local station at each airport, and are often re-scheduled throughout the day for late/early arrivals as the *operational schedule* is updated (see Chapter 4).

2.9 The Four Phases of Airline Schedule Development

The process of Airline System Schedule development will be unique to each airline. Each airline will have its own organization names and time frames for these activities. However, we can generalize the process by separating it into four distinct phases. All airlines implement these four phases, using their own nomenclature to do so. The four phases are Service Planning, Schedule Generation, Resource Assignment, and Execution Scheduling.[4]

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[4]Simpson, Robert W. Briefing on Computerized Airline Scheduling. 1989. unpublished

2.9.1 Airline Scheduling Groups

The four phases follow a sequential path, building until the airline schedule is generated, and continuing through implementation. (See Figure 2-11). We need to define three groups within the airline that take part in schedule generation: Marketing, Scheduling, and Operations.

2.9.1.1 The Marketing Group

Alexander Wells defines Marketing as:

> ...that broad area of business activity that directs the flow of services provided by the carrier to the customer in order to satisfy customers' needs and wants and to achieve company objectives.[5]

The Marketing group, therefore, is the group within the airline management structure that is responsible for determining a set of scheduled services which the passenger will select.

The Marketing group will exist as a part of management within the airline's headquarters. The group is responsible for not only developing the service plan, but for also developing new marketing initiatives and determining the fare levels and any promotional activities.

[5]Wells, Alexander T. Air Transportation: A Management Perspective. Wadsworth Publishing Company. Belmont, California. 1984. p. 290

THE FOUR PHASES OF SCHEDULE DEVELOPMENT

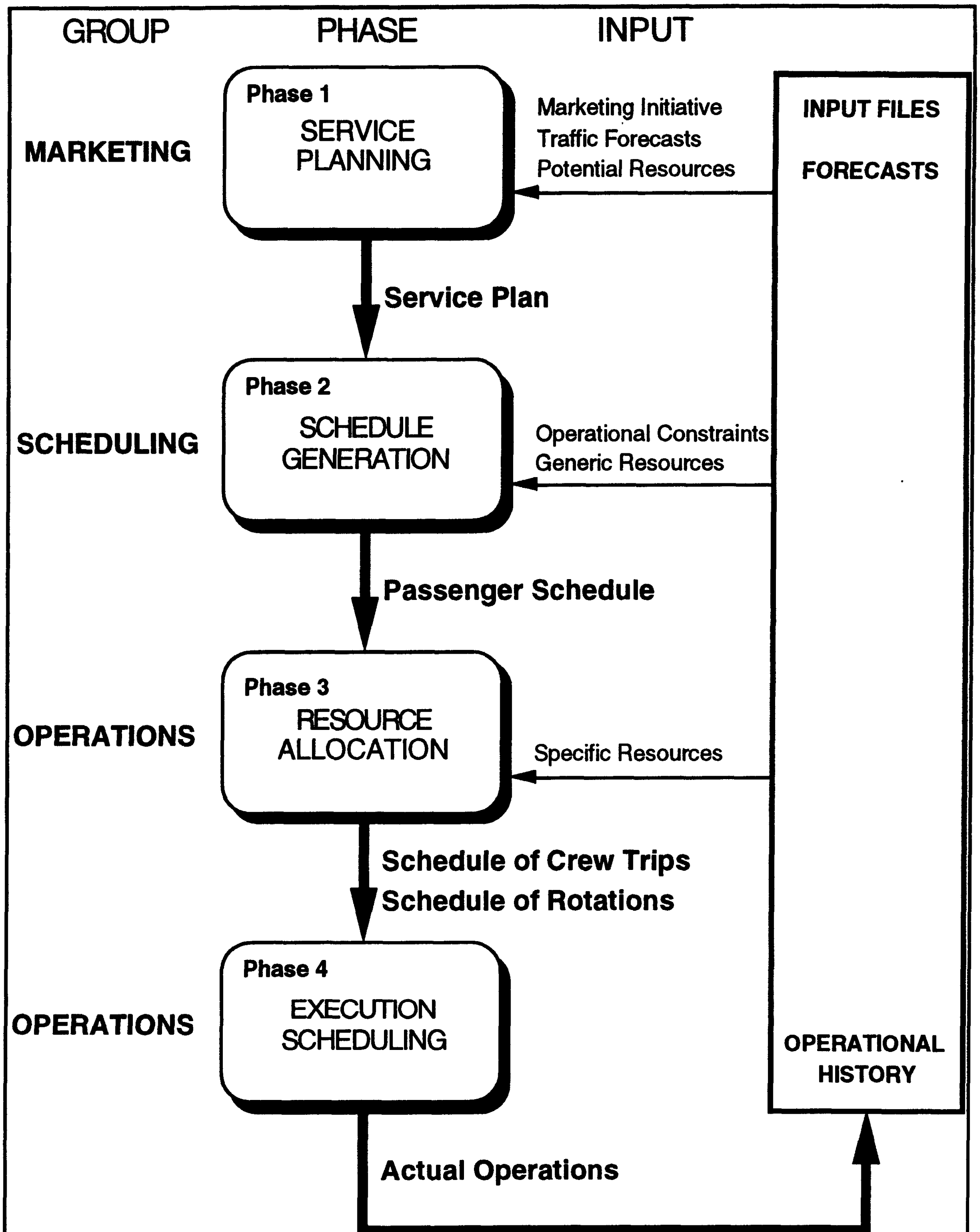

Figure 2-11[6]

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[6]Simpson, Robert W. Briefing on Computerized Airline Scheduling. 1989. unpublished

2.9.1.2 The Scheduling Group

There are three elements of the Scheduling group. The generation of the Passenger Schedule is the responsibility of what we will call the Service Scheduling group, which is usually located at the airline headquarters, perhaps within the Marketing Group. The unassigned version of the Schedule of Crew Trips is the responsibility of the Crew Scheduling group. This group is usually located at the Airline Operations Control Center (AOCC). Finally, the unassigned rotations are developed by the Aircraft Routers who are generally within the Maintenance Operations Control (MOCC) center.

The schedule generation phase is worked through shortly before the beginning of the schedule period. By this time, Scheduling has full information about what resources are expected to be available in terms of numbers of crews, aircraft, and gates. This allows Scheduling to produce generic schedules where the actual resources can be assigned later in the assignment phase.

2.9.1.3 The Operations Group

The Operations group is composed of the sections of the Airline Operations Control center, the Maintenance Operations Control center, and the many Station Operations Control centers. The Resource Assignment phase is conducted by Crew Operations within the SOCC and the Aircraft Routers within the MOCC.

The assignment of crews to the bidlines is conducted through a bidding process. Once the bids are completed, Crew Operations assigns crew members for the many bidlines that the airline will be operating. The Crew Trackers within Crew Operations will monitor the crew members as they move through the airline network, and will call in reserve crews as needed (see Chapter 3).

The Aircraft Routers take the generic Schedule of Aircraft Rotations and may assign the specific aircraft tail numbers to it for the complete month, even though they know that there will be many revisions of this plan on every day of the month due to schedule deviations and unplanned maintenance.

2.9.2 Service Planning

The process of schedule generation begins with the service planning phase. The goal of service planning is the production of the *Service Plan,* which is a set of services that the airline will be offering in each market. The level of detail will vary from airline to airline, but generally, it will be a complete schedule for a full cycle period. A cycle period is one day in domestic service (daily schedule) and one week in international service, (weekly schedule). Tentative flight times may be specified, or simply time windows, with whatever level of accuracy the airline chooses for this phase. Depending on the airline, specific aircraft types (i.e. 747-400, DC10-30, etc.) may be specified, or simply aircraft classes (wide-body, narrow-body, long range, etc.).

The marketing group considers several factors in creating the service plan. These factors include marketing initiatives, expected competitive services, traffic forecasts, current schedules and a list of potential resources.

Marketing initiatives are decisions and plans made by upper management and involve changes in service for the purpose of entering new markets. For instance, an airline looking to enter a new market may offer more flights at lower fares or special promotional fares to introduce their service.

Traffic forecasts generally come in two forms. Forecasts of the total market, and forecasts of the airline's market share. These are based on the size and demographic breakdown of the market (e.g. percentage of business travelers), economic and population growth, and on the airline's planned level of service for the market. With these forecasts, the airline can attempt to estimate the contribution to profitability of different combinations of service in all markets, and for all flights.

The new service plan is often based directly on the current schedule, with only small changes being made to improve revenues and costs, or to accommodate the acquisition of new aircraft. The current airline schedule produces actual traffic and revenue data which seems acceptable, and these small changes are thought to move it closer to being optimal.

The service plan is based on listings of potential resources, as opposed to a list of current resources. This allows the airline to consider service plans for times in the future. New aircraft may be available. Old aircraft may be sold. The airline may be considering changing its fleet. Further, the actual availability of aircraft may be affected by maintenance, both scheduled and unscheduled. Likewise, the size of the crews and their dispersion through the network of crew bases may change. Finally, as new routes are considered, potential gate availability must be considered as well.

2.9.3 Schedule Generation

The production of the Passenger Schedule is the sole domain of the Scheduling group. Presented with a service plan, a list of generic resources, and a set of operating constraints, the Scheduling group generates the detailed optimal schedule that the airline will present to the travelers, and that the Operations group will work to maintain against all irregularities.

The service plan presents a general outline for market services for the airline during the scheduling period. The Passenger Schedule includes the exact departure and arrival times and turns the service plan into a schedule of feasible flight legs that the airline will operate over the course of the schedule period. All constraints the airline is operating under are taken into account, including actual resources.

There are many operational constraints that the Schedulers must consider in making the Passenger Schedule feasible. The network must exhibit balanced circulation flow. At every station, the number of aircraft of each type that flows in must equal the number that flows out The network must also exhibit circulation, meaning that all flows repeat each cycle. There are many solution techniques available, but these constraints must always be met. The size of each aircraft fleet made available for the schedule is a major restriction on operations. There will be spare aircraft for maintenance, training, and hot-spare positions.

The number of available crew members, and the training of the crew members becomes a constraint on available operations, though the airlines generally maintain excess crews, giving them on-call spare duty and only pay their base pay for when they are not needed to fly.

At each airport, the number of available gates is constrained. This limits the number of concurrent operations that can be accommodated at this facility. Maintenance requirements may also provide several constraints for Scheduling.

With all constraints met, the Passenger Schedule is generated. Once this schedule has been created, the Scheduling group can create the bidlines and rotations that make up the Schedule of Crew Trips and the Schedule of Aircraft Rotations. These bidlines and rotations are generic, in that no crew member or aircraft tail number is assigned to them. Both of these tasks fall under the Scheduling group because many of the same solution techniques and tools are used in generating the schedules.

2.9.4 Resource Allocation

The Scheduling group turns over the Passenger Schedule, along with the crew bidlines and the aircraft rotations to the Operations group. Operations then begins the process of assigning the specific resources to the respective schedules.

Crews are presented with the available bidlines, and given a limited time to propose their bids. Crews are limited to only the bidlines for which they qualify. This limits cockpit crews to only aircraft they are current on, and limits cabin crews to aircraft for which they are trained and certified. Further limitations may exist in international operations, where some cabin crew members may be required by the airline to be fluent in the appropriate foreign languages. Operations then assigns the bidlines in the order of seniority of the individual crew members.

Aircraft are assigned to the appropriate rotations for the new schedule based on their position at the end of the previous schedule period. Operations attempts to find the least cost way of transferring aircraft from these positions to the locations they need to occupy at the beginning of the new schedule. The assignment to new rotations is usually very flexible in the hub and spoke pattern of service making this process easier.

Gate scheduling is accomplished in this phase by the Station Operations Control Centers (SOCCs). Individual gates are assigned to flights with appropriate constraints on occupancy. These constraints include considerations for occupancy of adjacent gates as well as the scheduled order of arrivals and departures. It is also common for gate scheduling to be performed over a much shorter planning horizon.

2.9.5 Execution Rescheduling

Execution rescheduling is a two-fold process. First, it involves the maintenance of the operational version of the System Schedules (see Chapter 4 for a detailed description of operational versions of schedules.). These schedules have actual departures and arrival times based on daily winds as well as any schedule deviations that have occurred.

The second process is what is normally called *rescheduling*. This is the process by which the Airline Operations Controllers (see Chapter 3) respond to irregular operations by taking steps to bring the airline back toward the original Passenger Schedule with the least disruption to travelers.

Chapter 3 Airline Operations Control

3.1 Introduction

Airline operations are handled in two phases, strategic and tactical. Strategic operations is concerned with scheduling and planning. This branch of the Operations group generates the Schedule of Aircraft Rotations and the Schedule of Crew Trips. These activities constitute Phase 3 of the scheduling process (see Chapter 2). These schedules are generally updated either on a monthly or seasonal basis.

The tactical side of the Operations group is responsible for the fourth phase of schedule generation, Execution Scheduling. Execution Scheduling is the process of executing the airline schedules on a daily basis. This involves three activities: executing the pre-planned schedules, updating the schedules for minor operational deviations, and *rescheduling* for irregular operations. This fourth phase of Schedule Generation is also known as Operational Control. The processes of Operational Control are handled jointly by three groups: the Airline Operational Control center (AOCC), the Maintenance Operations Control center (MOCC), and the Station Operations Control centers (SOCC).

The AOCC is responsible for flight dispatch and schedule tracking, tasks that can be easily centralized. This makes it convenient to locate the AOCC at the airline's headquarters, which, in turn, is normally located at one of the airline's major hubs. The SOCC handles specific station tasks, such as gate scheduling and passenger handling. An SOCC is located at each major airport the airline services. Finally, all aircraft maintenance issues are handled at the airline's MOCC. The MOCC is situated at the airline's major maintenance facility.

It is important to note that all airlines may not organize themselves nor use the generic names for organizations and processes as presented here. Tasks may be split up differently between the centralized AOCC, and the de-centralized SOCCs, sometimes referred to as stations. However, every airline has the same duties to fulfill, and groups will be assigned within the airline to perform these duties.

3.2 Airline Operations Control Groups and Functions

The Airline Operations Control center is a centralized grouping of key activities that compose what is often referred to in a nebulous sense as Operations. The AOCC takes on many names amongst the different airlines, usually something akin to Flight Operations or System Operations Control. The AOCC came into being at the airlines because of advances in communications and computerization, which allowed centralized control, and because of the efficiencies gained by having the operational areas of the airline represented within talking distance of each other.

The AOCC is organized into three functional groups, each with distinct responsibilities. The Airline Operations Controllers are responsible for maintaining the *operational versions of all the system schedules* (See chapter 4) and for the management of irregular operations. The *Flight Dispatch* group is responsible for flight planning, flight dispatch and enroute flight following. And finally, the *Crew Operations* group is responsible for tracking crew members as they move through the airline route network, for maintaining up to date status for all crew members, and for calling in reserve crew members as needed.

These three groups are usually located together in the Airline Operations Control center. Some airlines may, however, locate their Flight Dispatchers at the Station Operations Control centers, physically putting the Dispatchers in the regions they cover.

The Flight Dispatch process encompasses broad operational responsibility. In many cases, separate groups will exist which support the Dispatchers. It is normal to see a separate Meteorology group and a Load Control group, even though their function is primarily associated with Flight Dispatch.

3.2.1 Airline Operations Controllers

The Airline Operations Controllers are the center of the AOC process. They are the one group within the AOCC with the responsibility and authority to resolve the problems that develop during the course of both regular and irregular operations. Airline Operations Controllers receive inputs from every part of the airline during operations (see Figure 3-1). From these inputs, the Controllers construct the updated, or revised versions of the airline system schedules. We will refer to these revised versions as the *Operational Schedules* (see Chapter 4). If the information shows that the airline is suffering irregular operations, (see Chapter 4) the Controllers are responsible for devising a new schedule plan to handle the irregular operations, and return the airline to the normal schedules.

The goal of returning the airline to its normal schedule can be viewed differently by each individual airline. American Airlines views it as their responsibility to have the airline back on schedule by the beginning of the next day. To this end, American will cancel flights and either transfer passenger to remaining flights, or reroute passengers on other carriers. At the opposite extreme, United Airlines views its responsibility as flying as many of its scheduled flights as possible. Therefore, United accepts irregular operations carrying over into the following day. In all recovery situations, the output of the Controllers is the Operational Schedule (see Figure 3-1). The Operational Schedule is the plan that the airline will enact to breach the gap between their current situation and normal scheduled operations.

SOC Information Flow Diagram

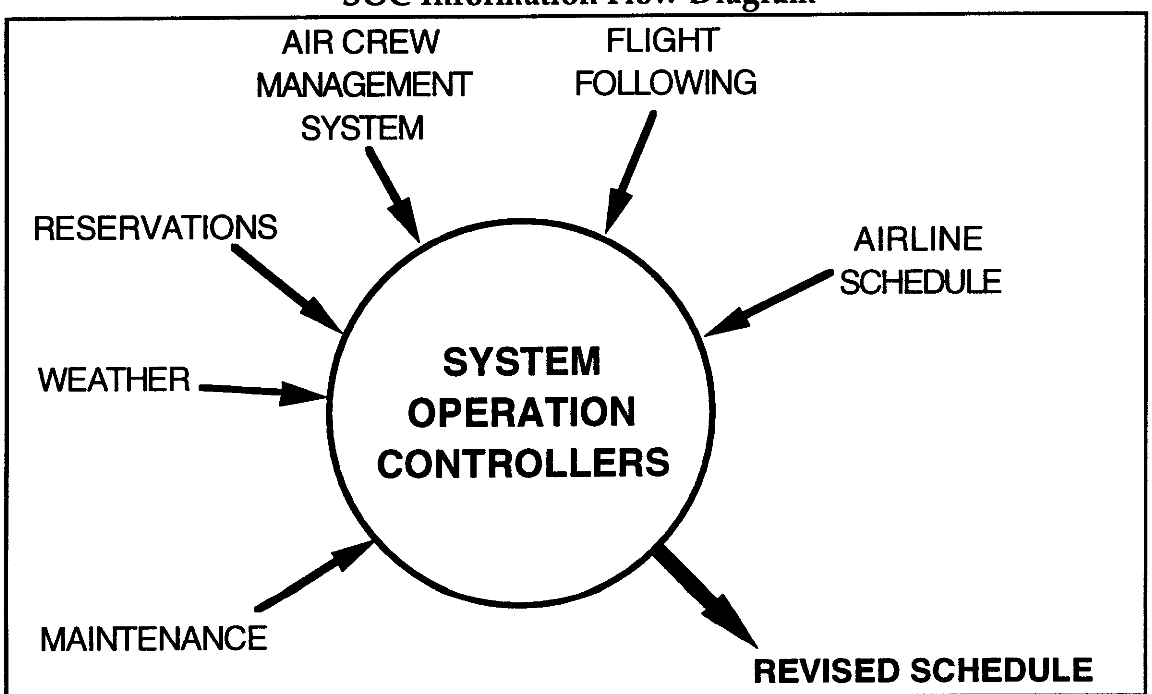

Figure 3-1

3.2.2 Flight Planning and Dispatch

Flight Dispatchers are licensed personnel responsible for the safety and operational control of each flight before takeoff and during flight. By law, this responsibility is shared equally between the Dispatcher and the aircraft's captain. Every airline operating in the USA is required to provide its own Certified Flight Dispatchers, and cannot contract this activity outside of the airline. Under United States regulations for airline operators, the Dispatcher has the authority and responsibility to delay or cancel flights under circumstances which raise doubts about its safety. The Dispatcher's duties include generating flight plans, monitoring aircraft load and fuel restrictions, monitoring crew and facility restrictions, and tracking the safe progress of each flight.

The Flight Dispatch group is generally arranged into domestic and international operations. They are further sub-divided into geographic regions. An individual Dispatcher is usually simultaneously responsible for several flights simultaneously. As the level of computerization has increased, the scope of responsibility of the individual Dispatcher has increased.

The Dispatcher's responsibilities can be broken down into flight planning, flight dispatch, and flight following. Flight planning is done in advance of take off, and includes computing and filing of the flight plan, and calculating fuel requirements. Flight dispatch covers the collection of load information, the calculation of takeoff and landing performance, and the monitoring of the availability of all necessary flight resources. Flight following is the process of tracking a flight's progress and acting as intermediary between the pilots and the ATC system during any problems.

The generation of flight plans has changed dramatically in the last few years. Originally, flight plans were standardized along pre-determined *optimal* routings between major cities. Though small airlines may still use standardized (or as they are sometimes known, *canned*) flight plans exclusively, the major US carriers generate flight plans on an individual basis every day. These are calculated for the purpose of minimizing fuel consumption given current weather estimates from both the National Weather Service, and the airline's own Meteorology department. Once generated, the Dispatcher is responsible for submitting the flight plan to the FAA approximately 75 minutes prior to departure. In practice, the flight plan can actually can be submitted as late as 30 minutes prior to departure. At this point, an estimate of the actual flying time for each trip is available. The duration of flights can vary from day to day with a standard deviation from a few minutes for short haul trips to up to 30 minutes or more for long haul trips. This situation creates a window for actual flight departure times desired to achieve an on-time arrival.

Between certain busy airports, there are ATC-preferred routings. These were established to organize the arrival flow of aircraft, and ease the burden on the ATC controllers during busy periods. The ATC network expects all flights between these cities to take whichever preferred routing is in effect. However, during slack times, the Dispatchers may submit non-preferred routings to Air Traffic Control, when they represent a fuel savings. All non-preferred routings have to be approved by each Air Route Traffic Control Center (ARTCC) through which the flight will travel, especially at busy times of day.

Prior to departure, a copy of the flight plan must be sent from the Dispatcher to the pilot at the departure airport. The flight cannot proceed without the acceptance of the flight plan by the pilot. There are several factors that can contribute to the pilot not accepting the generated flight plan. These factors include the takeoff weight, the takeoff conditions, the fuel load, enroute weather, and expected delays and possible diversion from the destination airport. In rejecting a flight plan, the pilot may interact directly with the Dispatcher to request that additional flight plans be generated.

The fuel requirement must be determined prior to the departure time as part of the flight plan. For any aircraft, the amount of fuel burned, and consequently the fuel cost, is directly proportional to both the distance traveled, and the weight of the aircraft. Carrying excess fuel can add significantly to the fuel consumption on long haul trips. Therefore, airlines try to minimize the amount of onboard fuel with each flight. This optimal fuel load is computed based on weather forecasts for wind along the flight path. All flights have alternate landing sites, in case of delays or bad weather, and reserve fuel is carried to allow the aircraft to fly to its alternate sites. The pilot must sign for his approval of both the flight plan and the fuel load. This allows the pilot to request the carriage of still more reserve fuel and exercise his judgment on the fuel requirement for that day's trip.

Additional pre-flight considerations are the aircraft's takeoff weight limits, which are determined by several factors, most importantly the length of the takeoff runway and the aircraft's takeoff performance. On a long haul trip which requires a high fuel load, passenger or cargo payloads may be reduced by the takeoff runways available given the wind and temperature conditions at the airport. A change in weather conditions just before departure may change the current runway configuration at the airport and, therefore, change the available takeoff load that the aircraft can carry. This causes a trade off between making a non-stop trip and reducing the passenger and cargo loads. Takeoff weight limits are more of a concern with long flights, primarily international, where the aircraft's takeoff performance limits are approached.

Every flight leg uses of three main resources: the aircraft, the flight crew, and the cabin crew. Minor resources include the gate, the jetway, the cargo loading and unloading equipment, the buses which might be needed for a remote gate, etc. The minor resources are the domain of the SOCC, and the major ones are the responsibility of the AOCC. As discussed in Chapter 2, each of these resources follows a separate schedule of activities. The aircraft follow the Schedule of Aircraft Rotations, monitored by the MOCC. The crews each follow separate schedules within the Schedule of Crew Trips, monitored by the Crew Operations group. Flight Dispatch must monitor the progress of each resource to assemble the flight. When the Dispatcher realizes that deviations to the scheduled activities are sufficient to cause his flight to be delayed, thereby creating irregular operations, he passes this information on to the AOC Controllers. The Controllers have the option of swapping resources, delaying the flight, or substituting a spare resource for the delayed one.

During flight, the responsibility of the Flight Dispatch group is flight following. This task requires the Dispatcher to *follow,* or monitor, the flight's progress from its origin until it reaches its destination. With new satellite communications technology, Dispatchers may be able to remain in constant contact with aircraft, allowing them to exercise control of flights enroute, as well as keep track of remaining fuel. Flight Dispatch is also responsible for monitoring the weather into which the aircraft will travel. Therefore, the Dispatcher may be required to update the flight plan to avoid inclement weather, such as thunderstorms. Many US airlines have contact with the aircraft through an ARINC data link, which allows for communications to be sent via a hard copy printout. These data links will allow an updated flight plan, revising the airspeed or altitudes for the remaining portions of the trip, to be delivered right to the pilot for his acceptance. To further the US domestic airlines in their dispatch role, the FAA has provided the airlines with Aircraft Situational Display (ASD) data. This combines radar data from throughout the national airspace, allowing for a real time visual update of every aircraft's position. This can be displayed in conjunction with weather information to allow the Dispatcher to 'visualize' aircraft positions and possible weather and ATC impacts along current flight plans.

3.2.2.1 Load Control

The Load Control group supports the Flight Dispatch group by maintaining both passenger and cargo manifests, and therefore a reasonably accurate estimate of aircraft load and its location onboard, and consequently an estimate of the aircraft's overall weight and center of gravity at time of departure. Passenger and cargo manifests are required by the FAA to be available for legal reasons in the event of an accident.

3.2.2.2 Meteorology

To support the Flight Dispatch group with accurate weather forecasts, airlines subscribe to a variety of weather sources, including the National Weather Service and one or more private weather sources. More importantly, they also maintain their own Meteorology department. The primary mission of the Meteorology group is forecasting of weather particularly of interest to the airline. This includes thunderstorms, precipitation, and winds, both along routes and at destination airports. They may alert Flight Dispatchers and Airline Operations Controllers of expected weather problems which have a significant operational impact.

Fuel costs represent approximately 12% of the total operating costs to an airline.[7] Optimization of flight plans to minimize fuel burn can be important to airline's costs. Flight plan optimization has been a common practice for long haul trans-Pacific and trans-Atlantic flights. Domestic markets, however, historically have had standardized routings and flight plans between cities. Airlines are now using optimization technology on domestic routes, and are petitioning Air Traffic Control to allow them to fly "*user-preferred*" flight plans. Both United and American calculate each flight plan on a daily basis to take advantage of current weather conditions. American currently has nearly half of their requests for *user-preferred* routings on domestic flights approved by ATC at a savings which they estimate to be over $500,000 annually.[8] United, with it's long trans-Pacific routes, estimates that optimal flight planning is worth up to $6,000,000 a year to the airline. The value of flight planning has become important enough that many small carriers and cargo airlines have begun contracting their flight planning out to the larger airlines such as American. It is difficult to verify the savings that such techniques are supposed to achieve.

Most irregular operations that the airlines face are caused by weather related problems. The airport closure (due to snow, bad visibility, equipment failure) is the worst case and will usually make the evening news. However, significantly less severe weather can still disrupt the operations of an airline. Even light precipitation or fog can cause visibility problems that will force the airport to initiate Instrument Flight Rules (IFR conditions) and begin

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[7]From Delta Air Lines, Inc. Quarterly Report for the Third Quarter, Fiscal Year 1993.
[8]American Airlines Systems Operations Control Center.

Instrument Landings. Not every runway is equipped with Instrument Landing Systems (ILS). Further, Visual Flight Rules (VFR) operations allow for close parallel landings which cannot be done under IFR. Thus, a reduction in ceiling and visibility will reduce the number of runways that are available for use, and correspondingly, will cut down the airport's landing capacity, otherwise known as the *airport acceptance rate*. Changes in the wind can also impact operations. Runways are not operated by the FAA with crosswinds greater than 15 knots, or tailwinds greater than 10 knots. This can lead to a change in the available runway configuration, which can again lower capacity.

3.2.3 Crew Operations

Crew Operations is composed of three separate responsibilities: crew scheduling, crew following and crew rescheduling. These three tasks are done for both the flight and cabin crews. Crew Operations begins with the Crew Schedule generated by the Crew Schedulers. The schedule is generated to keep active crews within FAR and union restrictions during regular operations. Crew Operations will keep track of available reserve crews, and their locations and may call in the reserve crews to execute one or more flights before returning them to their base. Under normal operations, Crew Operations simply update the status of each crew member in terms of flying times for the current month, week, and day as well as currency on various qualifications for automatic landings, over water routes, etc.

Under irregular operations, Crew Operations is responsible for keeping track of which crew members are still legal to fly and when they will become illegal. Crew Operations also support the Airline Operations Controllers in trying to return the airline to its normal schedule with the least cost. This involves monitoring the costs associated with different options for how crews can be used. These costs are driven by the various union arrangements at which the individual airlines have arrived. Most contracts call for a minimum number of hours of flight pay for a reserve crew which gets called in, regardless of the number of hours they actually fly. Likewise, there are added costs of housing crews when away from their home bases, and costs for *deadheading* the crews back to their bases

3.3 Maintenance Operations Control

The Aircraft Routers start with the aircraft schedule planned at the beginning of the schedule period. Then, just as Crew Operations follow crew members, the Routers follow aircraft. That way, when an irregular situation arises, and aircraft are not flying their pre-planned rotations, the Routers can give the Airline Operations Controllers advice on what aircraft are available and assist in interchanging aircraft between flights and rotations.

Airlines also maintain *hot spares* at hub stations to assist in overcoming irregularities. Being a hot spare may just be a stop on the aircraft's scheduled rotation and, therefore, the actual aircraft serving as a hot spare may change throughout the day. The two largest domestic airlines, American and United, each maintain approximately 10 spares (out of over 600 aircraft in the case of American Airlines), covering the range of aircraft types flown, and located at maintenance bases and hubs. The actual number and location of spare operational aircraft may change with each new schedule.

3.4 Station Operations Control (SOC)

The analogous organization to the AOCC on the airport level is the Station Operations Control Center (SOCC). An SOCC is located at every airport in the airline's network, though the size and responsibility will depend on the presence the airline has at the airport. The SOCC has three major functions: gate scheduling, passenger handling, and ground facility services. In the hub and spoke framework that US major carriers utilize, the SOCC at the hub airports are of vital importance. American Airlines begins everyday with a conference call in which every hub's SOCC reports how its operations the previous day had gone, and what it is expecting for the current day. This includes irregular operations, a review of the effectiveness of rescheduling, and upcoming weather problems.

Gate scheduling has become a very import aspect of effective operations at a hub airport. (see Chapter 2) Some airlines are beginning to put gate scheduling under the Scheduling group, instead of the SOCC because of its importance. Either done at the SOCC, or in the Scheduling group at headquarters, the SOCC is responsible for implementing the gate schedule.

At a hub airport, a major airline will control many gates, perhaps over 50 at the largest hub airports. Once deviations or irregular operations begin, the SOCC is responsible for modifying and rescheduling the gates as needed. As aircraft begin to arrive out of sequence, problems arise in the order that aircraft get on their gates. With limited apron space, it becomes necessary for the SOCC to reassign the gates for each aircraft so that the connecting complex can be operated.

The SOCC is responsible for all passenger handling. This includes any lounges for first class and club members, gate agents, and check-in facilities.

The SOCC is also responsible for taking care of the passengers when weather or breakdowns force the airline to strand passengers at the airport, or a flight is diverted to another airport, not its original destination. In many of these cases the SOCC will have to procure transportation, food, and lodgings for the passengers.

SOCC INFORMATION FLOW CHART

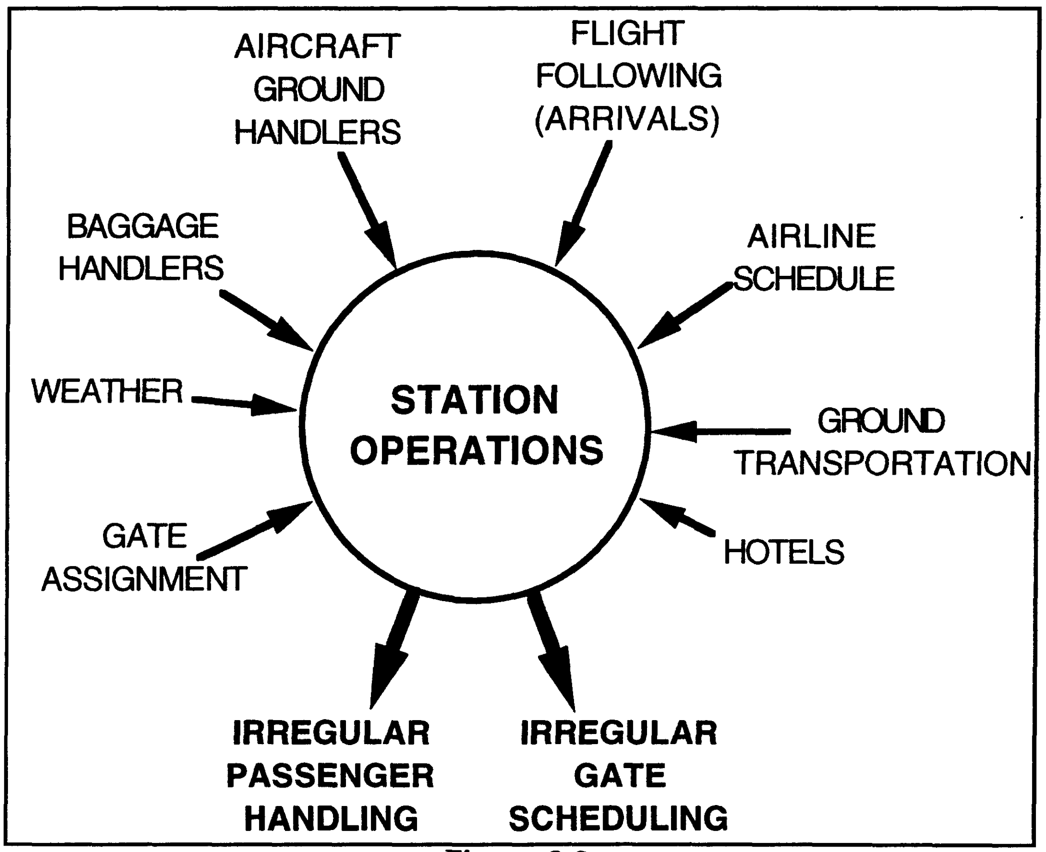

Figure 3-2

Beyond scheduling gates, the SOCC is responsible for the operation of all ground support services. This includes generating the minor schedules for their stations. This includes fuel and fuel service equipment, catering, and support staff such as gate agents, ground crew personnel, and baggage handling personnel. At the hub airport, the SOCC will also generate the schedules for the handling of baggage, the refueling, and taxiing of aircraft. As with the Airline Operations Controllers, the Station Operations people have authority to make decisions regarding operations on the ground at their airport. Again, it is useful to examine the information flow with which the Station Operations personnel are involved (see Figure 3-2).

Chapter 4 Analysis of Operational Problems

4.1 Definition of Operational Deviations

As any frequent traveler can attest, there are few things more unpleasant than reaching the airport, only to find your flight has been delayed or canceled. The individual passenger only sees the impact on his or her personal travel time and the inconvenience that represents. The airline, however, faces the potential for subsequent network-wide effects whenever this occurs. This is due to the tight scheduling that is created as more and more complexes are squeezed into hub airports, and is further compounded by the differences within the three Airline System Schedules, for passengers, crews and aircraft. Passengers will only take note of a disturbance in the Passenger Schedule, for instance a delayed flight, and even then only when the delay is excessive. In fact, even a small perturbation to any of the three schedules has the potential to become a rescheduling problem for an airline.

Any change to the Airline System Schedules we will call *operational deviations*. It becomes important to distinguish between deviations that do not cause problems from deviations that cause problems; or more specifically, cause rescheduling. Deviations that do not cause problems we will call *time deviations*, and deviations that lead to rerouting we will call *irregular operations*.

Time deviations are defined here as any change from the exact times in any of the three System Schedules. Specifically, these deviations are small changes to the arrival or departure times of individual flights. Normally, we only see delays, but it is important to note that early arrivals can occur, in some cases due to favorable tail winds, and are also time deviations. What distinguishes time deviations from irregular operations is that time deviations will not necessitate rescheduling. All passengers, crews, and aircraft will continue to fly their originally planned flights.

Irregular operations are defined as deviations that do lead to rerouting of activities in any of the three System Schedules. In the Passenger Schedule this covers flight delays large enough to cause missed connections or canceled flights. In the Crew Schedule this includes any instance where a crew member deviates from his or her scheduled order of flights. Finally, in the Schedule of Aircraft Rotations, any aircraft deviating from its planned rotation constitutes irregular operations as well. We will examine irregular operations in relation to the effects they have on each of the three System Schedules.

Time deviations do not negatively impact the airline, but simply represent day to day variations in the achieved times of various activities. Time deviations are tracked in the *operational versions* of the System Schedules. (See section 4.2) Irregular operations, in comparison, compel the airline to adopt changes to one or more of the System Schedules. During irregular operations the airline is in the Execution Scheduling phase or, as it is also called, the Rescheduling phase of schedule generation as described in section 2.7.

4.1.1 Handling Operational Deviations by AOC

The primary goal of the AOCC is to make the Operational Passenger Schedule conform to the published schedule. The Passenger Schedule represents the promise by the airline to its customers. It is the only part of the airline that the customer cares about. Maintaining a high level of on-time performance usually leads to higher customer satisfaction and more future business with the airline. Furthermore, any cancellation or missed connection potentially represents a loss of that revenue.

One of the biggest problems facing the AOCC in its attempt to keep the Passenger Schedule intact is *cascading effects* from operational deviations. Cascading effects describe one operational deviation directly causing subsequent deviations, because a resource, be it a crew member or an aircraft, was not in the proper place at the specified time to begin the next flight. Cascading effects tend to propagate quickly between the three System Schedules. Until the deviation can be corrected by AOC, **any** operational deviation in the Passenger Schedule may cascade to subsequent flights in the Passenger Schedule, and possibly to other schedules as well.

The AOCC has several methods to attempt to bring the Passenger Schedule back into order. These include absorbing scheduled slack, reducing actual aircraft turn times, adjusting flight speeds, substituting aircraft and crews, and flight cancellations

Airline schedules always contain an amount of *slackness* in them. This slack time in the schedule comes about from three factors. First, aircraft commonly must sit on the ground at spoke airports so that their arrival times will be closely coordinated with the rest of the arrival bank at the hub airport. Second, wind speeds on any flight leg will vary from day to day. Airline Schedulers normally plan their seasonal schedule with block times that account for approximately 95% of all wind conditions. Block time represents the time it takes a flight to leave the gate, fly to the next airport, and reach its gate there. Finally, Schedulers add an a buffer to achieve any desired level of on-time performance. Thus, there usually is slackness in the block times that is also available to reduce delay.

Beyond the slack that exists in the schedule, the AOCC may be able to reduce the aircraft turn time at the spoke station. Spoke stations are less busy than hub stations, allowing the SOCC to muster extra resources to achieve an actual turn time which is substantially less than the usual minimum turn time whenever an aircraft is late. Turn times of 15 minutes or less can be done for typical domestic aircraft, if needed to restore the Passenger Schedule, as compared to the usual 30 minute minimum turn time used for schedule planning. The time savings is gained by using extra baggage handlers, extra refueling equipment, and eliminating cabin cleaning. Further time savings can come from not completely sorting the baggage before loading. These options are not normally available at the hub airport, due to the high utilization rates for equipment and personnel.

Transport aircraft have a range of possible cruise speeds. Normally, airlines will schedule flights based on aircraft flying at their *best economic speed*. This speed minimizes the economic costs of the flight, which are made up of fuel costs and time costs. Time costs are defined differently by the various airlines, but generally cover some of the crew costs as well as a portion of the maintenance costs. This best economic speed will always be lower than the top speed for the aircraft. By utilizing this range of speeds, the AOCC has another tool to use in restoring the Passenger Schedule. *Speed ups*, as this tool is called, have a more substantial effect on longer flights. Speed ups represent additional operating costs due to increased fuel burn, but may avoid significantly higher costs in repairing the time deviations and avoiding additional irregular operations and interrupted trip expenses for passengers.

During hub operations, up to 60 aircraft are on the ground. This creates opportunities to eliminate delay by swapping departures. An aircraft delayed in arrival can be swapped with an aircraft having a later departure time. The planned departure for the delayed aircraft will be on time with a new aircraft, and the delayed aircraft can operate the later departure, reducing total system delay by the difference in the departure times. Though this may lead to problems which cascade into the aircraft and Crew Schedules, it corrects the Passenger Schedule. Because this is the only aspect that the passengers care about, airlines will often incur such irregular operations in order to restore the Passenger Schedule quickly and thus preserve the customers' good will.

The final tool for repairing the Passenger Schedule is to cancel flights. By strategically eliminating certain flights, the airline can better serve most of its passengers and aggregate passengers onto its remaining flights , and those of other airlines. While this seems to be a drastic option, it often minimizes both lost revenue and the loss of good will from unhappy customers. Normally, cancellations are only used during periods of massive irregular operations, where passengers may understand and accept the resulting disruptions.

4.1.2 Operational Deviations in the Passenger Schedule

Weather is the most common cause of deviations, and are often wide spread, impacting multiple flights at more than one airport. Consequently, this can be the most devastating cause of irregular operations. We can examine weather related deviations in two groups, severe weather that can close an airport for an extended period of time and less severe weather that only causes delays, while operations continue at a reduced rate.

Severe weather may force all airlines to cease operations at an airport. This is due to a combination of problems with visibility, winds, and surface conditions on the runways. This generally occurs during severe snow or thunderstorms, and in some occasions, with heavy fog. Sometimes an airport can be closed to landings while departures are able to continue at a reduced rate. When inbound flights are severely delayed by ATC, it may mean the cancellation of some flights at the airport, but flights that are not canceled are severely delayed which also causes cascading effects into schedules at other airports and subsequent flights.

When an airport unexpectedly closes to arriving flights, the AOCC needs to worry about aircraft that are already airborne enroute to that airport. Airborne flights may not be able to complete their trips by holding awaiting landing, and, consequently, will have to be diverted to other airports; or if caught early enough, returned to their departure airport. The latter may leave the airline more options for attempting to fix schedules, because the passengers and aircraft are returned to an operational airline station. Diverted flights, however, can be the worst form of irregular operations. Diversions to an airport where the airline does not have a station will leave the airline with aircraft, passengers, and crew members all at a wrong location with fewer options for recovery. This instantly cascades into all three System Schedules. The airline is further hindered by current US air traffic flow management policies, which do not allow the airlines to return diverted planes back into service with high priority once the impacted airport reopens. By diverting to another airport, the flight loses its arrival priority, and must file a new flight plan to get the diverted aircraft back to its original destination. This new flight plan is not considered by the ground delay programs of ATC (see 4.4 below) until all previously scheduled flights are handled.

Less severe weather will lower an airport's operating rates. This comes about from either high winds or low visibility. Airports can only operate runways that have crosswinds, or tailwinds, below 15 mph. Therefore, a wind strengthening, or wind direction shift can force an airport to operate a new runway configuration that has a reduced operating rate. If the ceiling and visibility are lowered, an airport can be forced to operate under more restrictive flight rules. Lower ceiling and visibility often eliminate visual approaches which have a higher landing rate. Poor visibility may eliminate the operation of close parallel runways, again reducing the landing rate compared to good weather operations.

Because spoke airports do not have many flights, weather related deviations do not impact a large portion of the airline. However, weather problems at hubs simultaneously impact many flights and can lead to wide spread irregular operations across much of the network. Tight scheduling along with the large number of flights in a complex lead to both more severe delays at the impacted hub as well delay traveling throughout the remainder of the network. Fortunately, the large number of flights at a hub airport may also allow more recovery actions by the AOCC.

Operational deviations can be caused by problems associated with an airline's ground support services. These services, present at each station, provide support for handling and moving cargo, passengers, and aircraft. We will group deviations from any of these services together under the name *ground deviations*. These can include problems with baggage handling, passenger handling, and equipment failures.

At a spoke station, the majority of passengers are not connecting, and therefore, all baggage can be unloaded directly to the baggage claim area, and all the baggage being loaded comes from a small check-in area. Thus, baggage handling at a spoke is uncomplicated and, together with the longer ground times, means baggage problems are infrequent.

However, at the hub airport, the story is very different. The majority of passengers arriving at a hub are connecting to flights departing within the hour. Just as the passengers need to physically move from one gate to another, their luggage must make the connection as well. While the complex is on the ground, the baggage must undergo unloading, sorting, transferring, presorting for loading, and loading. This must all be completed in a very short time, particularly for the last flights to arrive during the arrival bank and the first flights out during the departure bank. The problem is further complicated by having complexes of up to 60 aircraft all undergoing the same processes. Not only can equipment failures cause deviations, but improper presorting of baggage, errors in the planning of baggage delivery, as well as problems with moving baggage across the apron area can contribute to deviations.

Passenger handling facilities face the same time constraints in a connecting complex. Care has to be taken so that passengers have enough time to move between their arriving and departing gates, as well as go through additional departure processing. Many major airlines attempt to schedule the gates to minimize passenger walking distance. However, any problems arising with processing the passengers and issuing seat assignments can lead to deviations. Standby passengers, perhaps diverted by a cancellation, are a common situation and lead to slowed gate operations and delayed gate departures.

This problem can be further compounded by the process of *over-booking*. To help deal with the problem of passenger no-shows, the airlines have begun a process of selling more seats than are available on the plane in the expectation that they should still be able to serve all passengers once the no-shows occur. But, occasionally, more passengers show up than there are seats available. This puts the gate agents in a situation where they have to determine the actual passengers who will be boarding, and find a way in which to deny the excess passengers. Forcing a ticketed passenger to not board, called a *denied boarding*, has three negative repercussions for the airline. First, it is reported as a negative statistic about the airline. Second, the airline can be required to pay the passenger a penalty of up to twice the fare for the denied ticket. And third, a paying passenger who is denied boarding is very likely to build up a negative image of the airline from his or her personal experience. Rather than forcing a passenger off the plane, the other option in an over-sold situation is to offer to compensate a passenger for *surrendering* his or her ticket. Surrendering involves a passenger volunteering to give up his or her ticket, and compensation is usually a seat on a later flight, along with a flight credit or free ticket for future travel. Most airlines will attempt to entice passengers to surrender their tickets in an incentive auction, but it is very time consuming and delays the process of boarding the aircraft.

Further ground deviations can be caused by failures of the many physical facilities the airline has at each station. These problems include damage to both ground and terminal equipment as well as failure of computerized boarding systems at the station.

Equipment failures can include the baggage checking and loading equipment, the jetway, the tractors, and the computerized boarding systems.

Physical equipment can cause delays, but only in the area in which it is used, and not necessarily for all flights. Depending on how integrated the airlines computerized boarding system is, losing all or part of the computer can conceivably arrest the airline's ability to conduct operations. These boarding systems keep track of all ticketed passengers, seat availability and fares for future sales, information about baggage transfer, and gate allocation. The loss of any of these systems can slow down the rate of operations, leading to delays.

Gate scheduling is also a potential sources of deviations. Gates come in many sizes and shapes, and not every gate is capable of handling every type of aircraft. Under certain circumstances, an aircraft may land on time, but because another aircraft is occupying its planned gate, and no other gate is available to accommodate it, the aircraft is unable to unload passengers and baggage without a delay.

Still another source of ground deviations is the variation in *taxi times*. Taxi time refers to the time between when an aircraft pulls away from the gate, and the time it takes off, or between landing on the runway and arrival at the gate. These times normally vary from one day to the next, based on runway configuration which changes distances traveled to and from the gates. Taxi time variation of over 10 minutes is not uncommon.

Congestion on the surface of the airport will also lead to delays. After pushback from the gate, an aircraft joins a queue for the end of the takeoff runway. With takeoffs spaced approximately two minutes apart, the length of the queue can have a big effect on taxi times. Only four airports in the United States (JFK and LaGuardia in New York, National in Washington DC., and O'Hare in Chicago) currently limit the particular times at which airlines can schedule operations. And even those four only limit arrivals and departures within specified one hour time windows. Therefore, conflicting departure and arrival schedules between the airlines can cause taxiway congestion thereby causing ground deviations.

The final cause of operational deviations from the Passenger Schedule originate with the Air Traffic Control (ATC) system. Within the United States, air traffic control is carried out by segregated organizational entities. Operations within the airport terminal area are controlled by an two ATC facilities at the airport called TRACON and TOWER. TRACON controllers handle the aircraft during the hold for landing and on final approach as well as during climb after takeoff. The TOWER controllers handle landings, takeoffs, and taxiing aircraft. All enroute traffic is controlled by regional ARTCC*s* which handle aircraft in regions roughly 500 nm in size. These facilities are central facilities where ATC controllers provide safe separation between aircraft in a tactical manner, usually using radar surveillance. Within each ARTCC is a Traffic Management Unit (TMU) which is another set of ATC managers who are concerned with matching traffic flow rates to ATC capacity rates. The TMU*s* have five tools at the disposal for controlling traffic flow. These are:

1. DSP*s* /ESP*s* - Delay/Enroute Spacing Programs
2. Ground stops
3. Internal ground delay programs
4. EDCT*s* - Estimated Departure Clearance Times
5. Arrival Metering

The ESP*s* are the most common form of flow control. Flow Managers from the various regional centers negotiate with the Terminal Area controllers in the TRACON*s* to determine the rate at which aircraft can arrive at their facility. The rate is converted to a linear spacing, called *Miles in Trail.*

(i.e. a spacing of 10 miles in trail requires each successive aircraft in an inbound stream of aircraft to be 10 miles apart.) The Flow Managers will then allocate these spacings to form incoming traffic streams which will merge along the ATC-preferred routing into the airport. This continues, creating a stream with the proper spacing at the entry to the Terminal Area. (i.e. two 20 miles in trail arrival paths can be merged to create a single 10 miles in trail path which goes directly to the runway.)

Ground stops are implemented when an arrival airport has an unexpected problem, such as a runway closure or a runway configuration shift. Ground stops allow the controllers to stop selected traffic from specific airports or regions to stop or reduce the traffic flow. When the ground stops become excessive, or the delays can be foreseen, a formal ground delay program may be run by the Central Flow Control Facility which will issue EDCT*s*. (EDCT*s* are discussed in length in section 4.4)

Arrival metering is the process of time ordering the arrivals to build streams of aircraft for final approach. This is only carried out when excessively large holding queues have built up around an airport due to either a severe capacity reduction, or an airport closure. These queues are then held outside of the terminal area, and are the responsibility of the ARTCC. By exactly controlling the holding patterns, the controllers can try to efficiently space streams of traffic to match the current landing rate.

4.1.3 Deviations in the Schedule of Crew Trips

As described in Chapter 2, the Schedule of Crew Trips is the schedule of flying assignments for all crew members over the course of one schedule period, such as a month. Anytime a crew does not complete its scheduled flights there is an irregularity in this schedule. Irregularities come from two sources. They can originate within the Schedule of Crew Trips when a crew member calls in sick, or otherwise is unable to make a normally scheduled crew trip away from the crew base; or they can be a caused by irregular operations originating either in the Passenger Schedule, or in the Schedule of Aircraft Rotations.

The most common cause for irregular crew operations is the cascading effects from earlier irregularities. These cascading effects can affect the Schedule of Crew Trips in three ways. They can cause a crew to be unavailable to fly at some location; they can cause a crew to exceed its allowable daily or weekly flying time; or they can cause a crew to not fly because the aircraft is unavailable.

When the Crew Schedules are prepared, they are feasible, meaning that all of the legal restrictions and agreements are met. (See 2.4) An deviation from the plan can change that. A pilot may accrue unexpected flying time due to an enroute delay or may exceed the daily duty time limit. Further, a time deviation may cause a pilot to not get the required rest before the next duty period, forcing him to delay the departure the next morning or be unavailable for the trip. All of these are deviations which cause a crew member to not be able to make subsequent departures, due to *going illegal*. These may lead to further cascading irregular operations in rescheduling the crews over the next few days.

A previous irregularity from the Schedule of Crew Trips can also lead to this type of problem. As crew members are substituted, their personal flying status, relative to both union and FAA restrictions, will no longer match up with that planned by the monthly Schedule of Crew Trips, and weekly or monthly limits may be reached. It then becomes possible for a crew member to become unavailable for the next trip from the Crew Base. The AOC controllers and Crew Schedulers will have foreseen this event in time to make corrections and reschedule the remaining monthly crew trips for this crew.

The Schedule of Crew Trips can also be impacted by cascading effects from the cancellation of a flight. A cancellation directly causes irregularities in all three schedules. To the Crew Schedule, the crew of the canceled flight are then out of position for future flights. Therefore, one canceled flight can impact several crews.

4.1.4 Deviations in the Schedule of Aircraft Rotations

The basic problem in the of the scheduling of aircraft rotations is the need to perform routine maintenance at regular intervals. The Aircraft Routers in the MOC create schedule plans which have the aircraft available overnight at maintenance facilities within various limits on accrued flying time.

There is, however, a fair amount of flexibility in the Schedule of Aircraft Rotations. Though the overnight maintenance checks, A checks and B checks, are required at certain preplanned intervals, the FAA may be able to grant some leeway under irregular operations to allow the airline to delay these procedures until the aircraft can be returned to a maintenance base. Aircraft do not require maintenance every night, and if they are rerouted, they may be able to get the required maintenance checks performed at its new overnight stations. Further flexibility is achievable using spare aircraft in the fleet that are undergoing overhauls or unexpected maintenance. These spare aircraft are generally taken out of the schedule of rotations. An aircraft has many redundant systems and may be *legal* to fly, perhaps only on certain types of trips, even if the airline had planned to take it out of service to repair a failed redundant system. Thus, the Aircraft Router has several options to create a new schedule of rotations for each new day of the schedule.

Irregular operations that originate in the Schedule of Aircraft Rotations come about from failures of aircraft systems, as well as cancellations of flights and substitutions of tail numbers. These cause an aircraft or several aircraft to change from their current planned rotation to a different rotation. The problems that Aircraft Routers in the United States face are eased by the extensive use of hub and spoke networks. This allows for easy substitution of aircraft and the return to the original schedule of rotations after an irregularity caused by a substitution. In most US airlines, 95% or more of all flights are into (or out of) a hub airport. Therefore, the Router can expect to see the substituted aircraft coming back through the hub airports frequently, and have many option to perform future substitutions.

4.2 Operational Versions of the Major Schedules

The fourth phase of the schedule generation process, execution scheduling, is composed of two functions: first creating and maintaining operational versions of each major schedule; and second, rescheduling during irregular operations. (See Chapter 2) The latter is detailed in section 4.3 below.

The operational versions of the System Schedules are the hour to hour updated schedule that the AOCC will actually be executing on any given day. The three System Schedules are generated completely, prior to the beginning of the schedule period. The AOCC will attempt to implement these schedules as planned, particularly the Passenger Schedule. However, in the process of implementing the schedules, deviations will occur. These come in four forms, 1)time deviations and 2)irregular operations as mentioned above, as well as 3)*planned deviations*, and 4)*planned deviations due to irregular operations*.

Time deviations are the simple deviations from the Passenger Schedule that do not cause irregular operations. These are small time perturbations from the Passenger Schedule, and do not involve rerouting of passengers, aircraft, or crews. Specifically, these deviations do not impact connecting complex operations. The Operations group is not very concerned about deviations of this magnitude and simply track them for purposes of updating other stations of slight delays, or slightly early arrivals to allow for more efficient gate scheduling and handling, and to arrange for on-time departures of the next service.

Planned deviations are changes to the Passenger Schedule that come about after the schedule has gone into effect. These may represent a permanent schedule change, the final resolution of an operational irregularity, such as an unplanned major maintenance procedure, a special charter or training flight, or a new aircraft being brought into service. These planned changes, are far enough in advance to allow the airlines time to notify passengers and operational personnel. For example, the passenger may receive a phone call telling him or her that the flight has had its departure time changed, perhaps by no more than 5 minutes, or the aircraft type has changed from a DC-9 to an MD-80.

Planned deviations due to irregular operations are the resulting changes in the Schedule of Crew Trips and Schedule of Aircraft Rotations that occur after the airline has restored the Passenger Schedule by the process of

Execution Scheduling. This includes the temporary changes to the Schedule of Crew Trips, or the Schedule of Aircraft Rotations brought about in solving the irregular operations. The airline is most concerned with implementing the Passenger Schedule, as this is all with which the traveling public is concerned. These planned changes are normally just "*recovery*" changes in the assignments of crews to crew trips and aircraft to rotations.

4.3 Rescheduling

The AOC Controllers are responsible for making sure the airline will operate the Passenger Schedule as closely as possible to the plan, thereby producing reliable service for the passengers. As irregular operations upset the planned schedules, the AOC Controllers use rescheduling to correct the irregularities. Rescheduling is the process of changing from planned actions with the overall intention of moving back to the original schedules.

The most common problem facing the AOCC are Passenger Schedule deviations. These deviations will normally manifest themselves as delayed operations. For purposes of analyzing rescheduling methods, we can break these deviations up into delayed operations at an spoke station, and delayed operations at a hub.

4.3.1 Delays at a Spoke Station

Operations at the spoke stations are at a much smaller scale than at the hubs for the many reasons mentioned earlier. Consequently the problems faced and the solutions available at the spoke stations differ greatly from their hub counterparts. We will examine the problems and solutions involved in both delayed arrivals to the spoke station and delays that occur *at* the spoke station.

Delayed arrivals at the spoke station are aircraft that will not reach the station at their scheduled arrival times. Delayed arrivals are usually the result of delayed departures from hub airports, and we may assume that the AOCC has used all possible tools to reduce the delay, including enroute speedups. The goal of the SOCC at the spoke station is also to reduce the delay and end irregular operations. Resolution techniques will depend on how severely delayed the incoming flight is. We will partition delayed arrivals into short and long delays (see Figure 4-1).

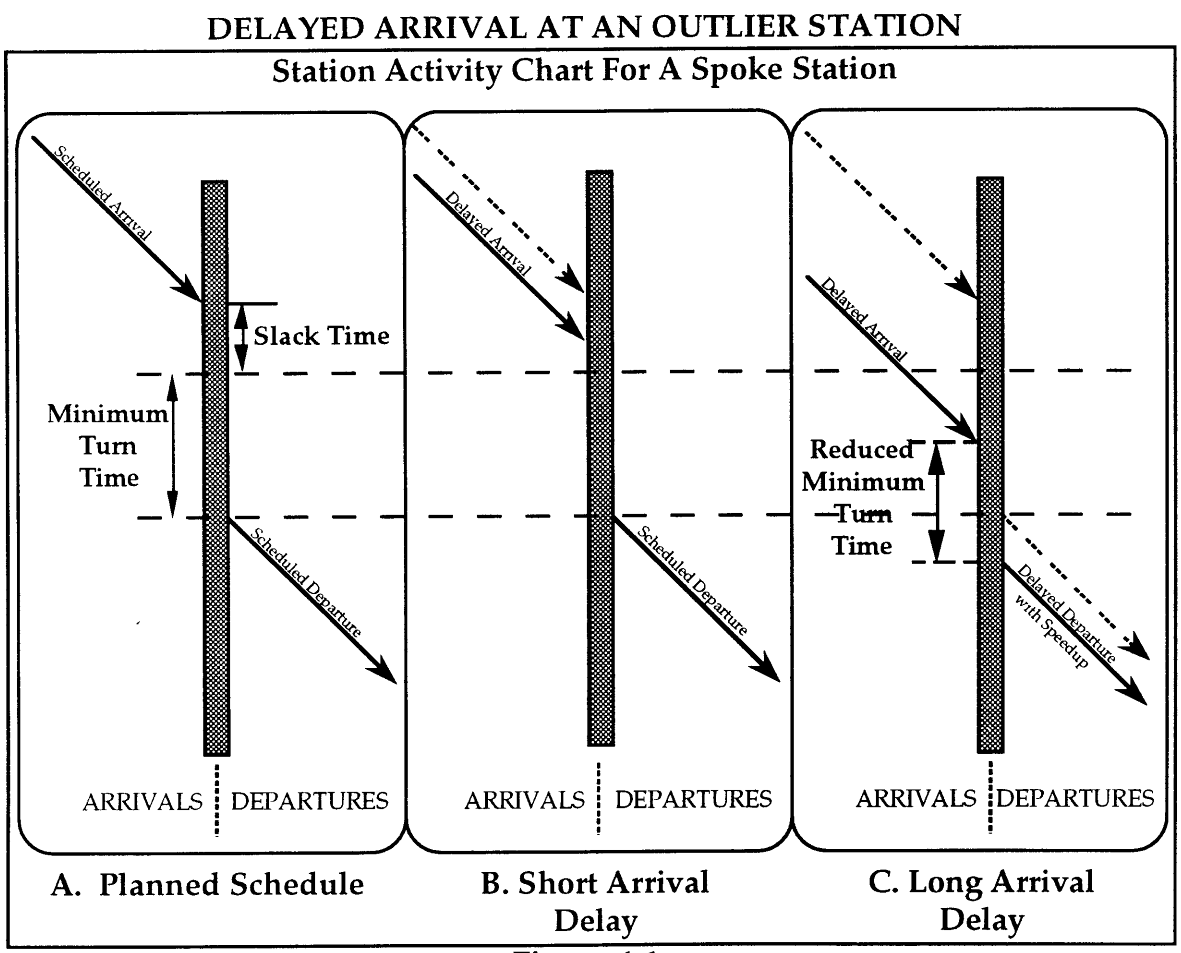

Figure 4-1

As mentioned earlier, most aircraft have slack time planned into their rotations at the spoke stations. This slack can be seen in Figure 4-1A as the additional time scheduled between arrival and departure beyond the minimum aircraft turn time. Short delays (Figure 4-1B) arrive during the slack period, and do not interfere with the normally required minimum turn time for the aircraft at that station. All delay can be absorbed with the slack time at the spoke station. As defined earlier, these delays are time deviations and do not affect the operations any further.

Arrivals at the spoke station having a long delay (Figure 4-1C) do not leave enough time for the planned minimum aircraft turn time between the delayed arrival (black line) time and the scheduled departure (dashed line) time. Because the delay cannot be completely absorbed by the planned slack time, these delays can potentially become irregular operations. The AOCC has a few options to try to further reduce delay. They can direct the SOCC at the station to attempt to cut the minimum aircraft turn time (see 4.2.2) by allocating all available equipment and personnel in preparation for servicing this arrival. The AOCC can also instruct the pilots to enact a speedup to reduce the travel time to the next hub airport. Finally, if another aircraft of the same type is available on the ground at the station with a later departure time, the AOCC may have the option of performing an equipment swap by switching the rotations for these two aircraft. If these options reduce the delay enough to avoid problems at the hub, then the airline has successfully kept this delay as a time deviation. If the flight is still substantially late at the hub airport (see 4.3.2), it has become an irregular operation.

Delayed operations can originate at the spoke airport as well. These delays can come about for any of the reasons mentioned in 4.1.2, including weather, aircraft systems failures, and ground systems failures. The result is a delayed departure from the spoke aircraft. Because of the hub and spoke interaction, these delays are normally carried directly to the hub airport as delayed arrivals. The AOCC again has the option of instructing the pilot to perform a speedup or performing an equipment swap.

4.3.2 Delayed Operations at a Hub Airport.

Due to the nature of hub and spoke systems, delays at the hub airports have very serious negative implications. Individual delayed arrivals can disrupt connecting complexes, and potentially displace passengers. Delays caused at the hub airport can disrupt operations for a few days as the airline scrambles to recover. Likewise, delayed departures can upset the gate schedule, and likewise disrupt future operations

Individual delayed arrivals are the result of delayed departures from the spoke stations, described above. These delays can be separated by degree into three categories: late arrivals within the arrival bank, late arrivals within the bank interval, and late arrivals during the departure bank or later. (See Figure 4-2) The degree of delay will affect the options and procedures the airlines have for recovery.

Late arrivals within the arrival bank are *mostly* time deviations, with no irregular effects. There may be no need to change any of the schedules, as there usually is enough time to for all passengers and cargo to make their connections. An area where trouble may arise is the aircraft and crew turns. Aircraft turn times are generally longer than the bank interval. Departure deviations may arise if the delayed arriving aircraft is scheduled to be at the beginning of the departure bank, or if the crew is transferring to another aircraft that will be in the beginning of the departure bank. The AOCC may be able to adjust the departure bank to allow for the delayed aircraft or crew to depart at a later time, *still within the departure bank.* In other words, the aircraft and crews have been rerouted, but the Passenger Schedule only suffers minor time deviations. At some hub airports, the SOCC may even use an automobile to drive the crews between flights to reduce crew connection times. These time deviations are noted by the AOCC in the operational versions of the System Schedules. If it is impossible to compensate, the late arrival should be considered as a late arrival within the bank interval.

Delayed arrivals during the bank interval (see Figure 4-2A) may lead to irregular operations, particularly in aircraft and crews. Because the late arriving aircraft will not have enough time for all passenger and baggage to make scheduled connections, there will be delays in the Passenger Schedule as the AOCC delays departures. The goal of the AOCC is to keep delays in the Passenger Schedule as time deviations, and have any irregular operations occur only in the Crew and Aircraft Schedules. The AOCC has a few options for dealing with this situation. Delaying the beginning of the departure bank in conjunction with switching in both the Crew and Aircraft Schedules can be used to keep the passengers close to on time. This may shorten the allowed connection time for passengers on the delayed flight to transfer to some of the early departures in the departure bank. If the delay is farther into the bank interval, then the late arrival should be considered with the third group, late arrivals during the departure bank.

The third type of late arrivals to a hub airport are delayed arrivals after the departure bank has started. This directly causes irregular operations in all three System Schedules. There is the further risk of passenger misconnects, in which passengers miss their flight out of the hub, and consequently must be rescheduled on later flights or on other airlines. The AOCC has three recovery strategies from this problem. A subset of flights can be delayed to allow for most passenger connects, but with some misconnects. All flights in the departure bank can be delayed to allow all passenger connections. The delayed flight may also be canceled.

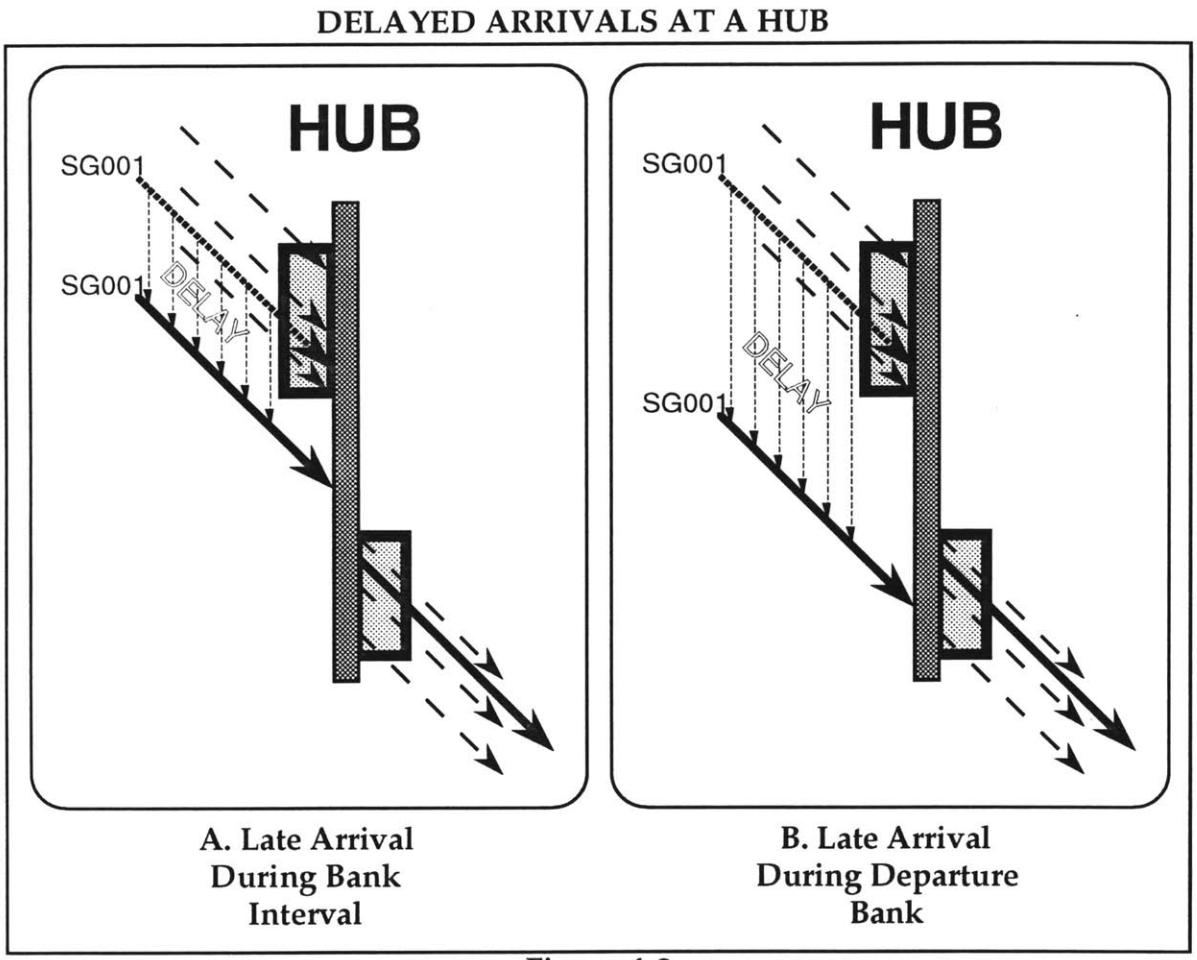

Figure 4-2

The AOCC may delay a subset of flights to allow for the greatest number of connections. These delayed flights become delayed arrivals into spoke stations, as described above. This is a good option if the new delay can be absorbed at the spoke stations. Irregular operations from these delays as well as all the switching that takes place will be caused by this option, although not severely. Delaying a subset of departures trades off a percentage of passenger misconnects for fewer delays in the Passenger Schedule. This also frees up gates more quickly.

Delaying an entire departure bank will cause massive irregular operations. This procedure will, however, allow for all passenger connections. This is normally only used when the delayed arrival is a wide body flight, perhaps from overseas, with many connecting passengers to most outgoing flights or when several flights are arriving late. This is only feasible if there is enough positive time interval between connecting complexes to ensure gate availability for all these newly delayed flights.

If the delayed flight is going to miss the connecting complex completely, the AOCC may decide to cancel the flight. This involves leaving the aircraft and passengers at the spoke station, and begins a chain of cancellations until the aircraft can be brought back into service. These cancellations cause considerable irregularities in all three System Schedules. Furthermore, the passengers from all the canceled flights have to be rerouted onto later flights or other airlines.

The chain of canceled flights will depend on whether the hub is omni-directional or directional. In an omni-directional hub, there will be a flight back to the spoke station where the aircraft from the canceled flight is positioned. This allows the AOCC to cancel only this one additional flight before returning the aircraft into service. In a directional hub, no flight returns directly to the original spoke station. Here, the AOCC has two options: continue to cancel flights until the chain of cancellations returns to the spoke airport or cancel one flight out of the original departure bank, and have the out of service aircraft overfly the hub and go straight to the airport where the new canceled flight was destined. This option returns the aircraft to service faster, and, if the second canceled flight is next one on the aircraft's rotation, the irregularity in the Aircraft Schedule (and possibly the Crew Schedule as well) is repaired. Either option puts the aircraft back into service. The tradeoff remains for the AOCC to decide between inconveniencing more passengers, with the long chain of delays, or the net cost of flying an unplanned flight with few or no revenue passengers onboard, with the overflight. This cost is minimized if the aircraft is carrying many through passengers, who would have continued to fly onboard this aircraft anyway.

If a hot spare aircraft is available at the hub, it can be used in place of the out of service aircraft, instead of canceling a flight out of the hub. This allows the airline to inconvenience fewer passengers and cancel fewer flights. When the spare aircraft and original aircraft are both at the same station, the spare can be taken back out of service. Otherwise, the spare will take over a new rotation, and the out of service aircraft will become the new spare.

Problems that originate at the hub airport are the cause of massive irregular operations. Bad weather can reduce an airports capacity in many ways. When the drop in capacity is large, the ATC Flow Managers will call for a ground delay program (see 4.4 below) to be run to manage the flow into the airport. Major hubs, such as Dallas-Ft. Worth and Chicago, run at close to the airports full capacity for most of the day. Therefore, there is not much time to adjust and recover from these irregular operations.

During the ground delay program, all flights are delayed. This has the effect of stretching out the connecting complexes. Figure 4-3A shows the actual timeline for American Airlines connecting complexes at Dallas-Ft. Worth International Airport (DFW). Arrival banks are on the left, departure banks on the right. All complexes are numbered. (For example, the first complex's arrival bank begins at approximately 0520 and ends at approximately 0600. The corresponding departure bank, made of the same aircraft, begins at 0630 and ends at 0715.) Note that most arrival banks overlap the preceding complex's departure bank. This is an example of a negative time interval between complexes. American operates 12 distinct connecting complexes of up to 61 aircraft at DFW.

In Figure 4-3B we have imposed a simulated 3 1/2 hour ground delay program due to severe rain storms cutting capacity in half. The banks that are scheduled during the ground delay program are stretched out due to the delays that will be imposed. There is room toward the end of the day to reduce the time interval between connecting complexes, and that is included in 4-3B. Even so, the final complex cannot be completed until well after midnight.

When the ground delay program is run, every scheduled flight is assigned a new departure time by the ATC Flow Managers. However, the aircraft is also assigned a bank of time it is allowed to operate in called a *slot*. The AOCC does not have many options to recover from problems of this sort. The AOCC can fly all flights in their slots and operate well beyond the normally scheduled times using the previously mentioned techniques to recover from delays. Alternatively, the ATC Flow Managers allow the airlines to cancel flights and *swap* flights into the slot of the canceled flight. This swap process allows the AOCC to have two recover methods: 1)*thinning* out the complex and 2)canceling one entire complex

DFW TIMELINE WITH A GROUND DELAY PROGRAM

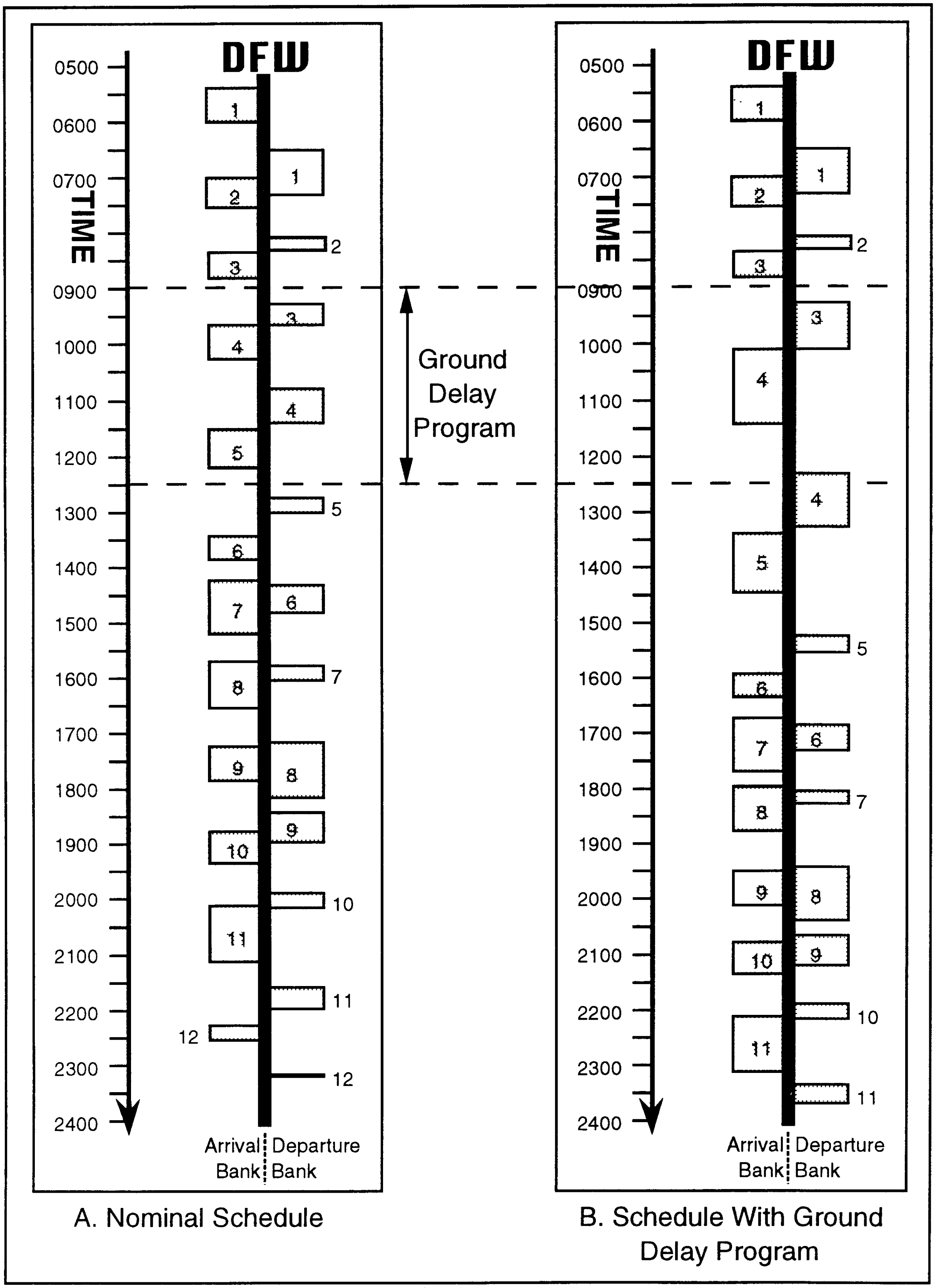

Figure 4-3

Thinning out a connecting complex refers to the planned cancellation of a subset of flights within the connecting complex. This will reduce the number of operations within the complex, shortening the length of arrival and departure banks, hopefully back to near their original durations. By canceling flights to reduce the size of a complex, subsequent complexes will not be as badly delayed. Efficient programs, such as American's ***Hub SlAAsher*** allow thinning out to be done with the fewest passengers inconvenienced, by keeping the set of flights that allow the most passenger connections. The thinned flights are canceled in the manner described above to build proper chains of cancellations.

The final recovery option is to cancel out an entire complex. This may allow all subsequent complexes to be swapped up. (See 4.4 below for a description of swapping of flights as allowed by current FAA flow management procedures.) In effect, this procedure cancels the *last* complex of the day, as each complex moves closer to its original scheduled time. This reduces total daily operations at the hub by one or more full complexes, while still allowing the airline to carry all or most of it passengers, by aggregating them (if possible) into the remaining flights. This is attractive if the complexes have a significant communality amongst the spoke stations.

In Figure 4-3B American Airlines could cancel complex number 5, the remaining complexes will swap up and nearly restore their original scheduled times. This allows the airline to finish operations closer to the normal time, and to lessen the passenger inconvenience, as most remaining flights are nearer their scheduled times. The idea of canceling and swapping up is also useful in markets with shuttle service. As the delay nears or exceeds the shuttle interval, a few flights may be canceled and the airline can still operate remaining flights much nearer to their original scheduled times. The activities at the station used to be completely rescheduled.

4.4 ATC Delay Programs and Slot Swapping

During times when airport runway capacity is severely reduced or the airport is shut down, the appropriate AARTC will request that Central Flow Control run a ground delay program. A computer program is used to reassign departure times for all Aircraft Scheduled to fly to the impacted airport. The assignments are done on a "first come first served" basis, with departure times computed to create a controlled flow of arriving aircraft at the rate the airport expects to be able to handle. This *airport acceptance rate,* estimated by the local ATC controllers, is determined by expected weather conditions at the airport and by the runway configurations which are expected to be available.

The ground delay program can be run at four levels: internally, Tier 1, Tier 2, and nationally. Internal ground delay programs cover only those short haul flights originating within the AARTC that contains the impacted airport. Internal ground delay programs are generated by the AARTC's own TFM unit. Once delays become longer than 30 minutes, CFCF must be consulted to run one of the larger delay programs. Tier 1 is the smallest CFCF ground delay program, and extends to include all flights originating in adjacent AARTCs . Tier 2 extends this to the next set of adjacent AARTCs. Running the program nationally includes all domestic flights destined for the impacted airport. International flights, because of the long flying times, are exempt from these programs.

The logic of the ground delay program run by CFCF is simple and deterministic. Given estimates of the airport acceptance rates (AARs) as inputs, the program builds a schedule of properly spaced arrivals. The arrival times are called *CTAs* for Controlled Time of Arrival. The program assigns the CTAs to the scheduled arrivals on a first come first served basis. Once a CTA has been assigned to a flight, the program subtracts the expected flight time and issues an *EDCT* (Estimated Departure Clearance Time) for the flight. This is a time for lift-off and local controllers will adjust the departure time from the gate or from a "penalty box" somewhere on the airport where the boarded aircraft are stored during delays. The list of EDCTs is then created and distributed to the ATC network and to the airlines via various data networks.

Ground delay programs easily can break up the connecting complex and can lead to irregular operations over a large portion of an airline's network. The airlines have been allowed one tool to counteract this process. They are allowed to petition the CFCF to accept *slot swaps,* which potentially can be refused.

Once a ground delay program is run, the airport is, in effect, slot controlled, because arrivals are limited to a restricted number of pre-assigned *slots*. The slots are the CTAs generated by the ground delay computer program, but each slot is actually defined as being from 10 minutes prior to the CTA until 20 minutes after the CTA, though the limits may be changed by the CFCF. This window allows the airline some freedom in re-scheduling.

Slot swapping is the process by which the airlines are allowed to cancel one flight and re-assign a the arrival slot to another flight. The flight that is *swapped up* leaves another open slot. This slot may also be re-assigned. This process gives the airline flexibility to attempt to restructure its connecting complexes.

There are only a few rules governing slot swapping. A cancellation, for any reason, must begin every string of swaps. No swapped up flight is eligible to fill a slot that is prior to its original scheduled arrival time. All swaps must be submitted to the CFCF for approval and no flight can be swapped more than once. Therefore, with a few carefully chosen cancellations, in conjunction with any normal unplanned cancellations, the airline may be able to reconstruct much of its splintered connecting complexes.

Chapter 5 Areas For Future Study

In the process of conducting research to assemble this study, we were able to identify several areas where the interaction between the Department of Transportation and the airlines can be improved. Most of these areas are related to the use and implementation of ground delay programs by Air Traffic Control. Other areas for improvement related to the process of using spacing programs, the DSP*s* and ESP*s*.

5.1 Ground Delay Programs

The problem with how ATC handles ground delay programs is that the programs do not work well within the framework of how the airlines operate. As we have said previously, the key to modern airline scheduling is the hub and spoke network structure with connecting complexes. In order to operate efficiently, the airline must maintain the integrity of the connecting complexes.

In the process of implementing a delay program when weather changes lower an airport's capacity, four phases are normally seen: *internal* delays for flights originating within the AARTC with the impacted airport, *Tier 1* delays for flights from adjacent AARTC*s*, *Tier 2* delays for flights in the next set of adjacent AARTC*s* and *national* delays for all flights originating within the United States. The four phases are implemented sequentially.

Internal delays are calculated by way of a simple formula and are handled by the Traffic Management Unit and the Air Traffic Controllers within the AARTC. It is not necessary for the AARTC to coordinate these activities with any other AARTC or the Central Flow Control Facility. The flights affected by internal delays are the shortest in duration. Because of the short flight times, delaying these flights will provide the quickest relief for the impacted airport. All of these factors lead to internal delays being used frequently.

Tier 1 delays are delays to all internal flights as well as all flights originating in AARTC*s* adjacent to the AARTC with the impacted airport. This involves contacting the CFCF and having them "run a program." The *program* is generated by computer assigning slots on a first come first served basis for all flights within the Tier 1 AARTC*s*. This involves coordination with all AARTC*s* involved. The process is further slowed as notification has to be sent directly to the airline of all EDCT*s*. Tier 2 and national delays continue the Tier 1 actions to the next set of adjacent AARTC*s* and to all domestic flights, respectively.

The Tiered structure of delays creates problems for the airlines by breaking up the connecting complexes at the hub airports. Internal delays will affect most or all of the flights by the regional carrier with which the major airline is affiliated. Likewise, some short flights on the major carrier may be affected. Tier 1 and Tier 2 delays will dismantle the connecting complexes for the major airlines. Only national delay programs keep the complexes intact by maintaining the temporal relationship of all arriving flights through the delays.

Several options can improve this interaction. On the ATC side, efforts can be made to use only national programs, and to improve how they respond to an airport being impacted. This problem can also be eased by allowing the airlines more flexibility with the slots assigned with the EDCT*s*. This can be done by allowing swapping or selling of slots between the airlines, or by auctioning slots. The FAA has recently been considering allowing unlimited swaps of each slot. Full adoption of this program would also be a benefit to the airline.

5.1.1 Improved Implementation of Ground Delay Programs

There are several ways that ground delay programs can be implemented that would benefit the airlines. First and foremost, doing away with tiered implementation of programs in favor of using strictly national delays imposed by the CFCF. This would reduce the fracturing of connecting complexes that is associated with tiered ground delay programs being implemented at hub airports.

Currently, ground delay programs are ended as soon as weather conditions improve at the airport. Normal Miles in Trail control methods are then used for traffic management until flights are back on schedule. This results in too many aircraft being in the air too soon. This causes excess airborne holding which adds cost to the airlines in both fuel consumed, and flight pay to the crews. This problem can be lessened by running the ground delay program for the remainder of the day or until the assigned slots match the original flight times.

To avoid these problems, the airlines would prefer to have the CFCF begin programs in anticipation of reduced capacity at the airport. American Airlines currently attempts to implement its own traffic management to anticipate these delay programs, and avoid the three problems mentioned above. Taking these actions has benefits for the airlines who do not act early, however, because more slots are available. It is easy to visualize a very expensive game of chicken started this way. The CFCF has the advantage of not worrying about individual airlines, and can take actions to benefit the traveling public in general.

Current ground delay programs are based on deterministic hourly estimates of airport capacity. When capacity improves ahead of time, the airport becomes *starved* for arrivals, and capacity can be wasted. The only weapon the ATC has against this is to release the internals early, but this has the problems mentioned previously. By taking a more stochastic view on capacity changes, and *ramping up the arrival rate* the CFCF could reduce the total delay that is created by event, by avoiding wasting capacity at the airport.

5.1.2 Exchange of Slots Between Airlines

During a ground delay program, airlines are allowed to swap the slots created by the EDCTs. There are strict rules for this practice (See Chapter 4) that limit swapping to only flights within the airline, or it's affiliated regional carriers. By allowing swaps to take place between airlines or slots to be sold between airlines, the airlines will have more flexibility to reach better solutions.

Regional carriers fly smaller planes into the airports where they operate than do the major airlines, however, the slots assigned to these flights are the same "size." By allowing the smaller carrier to *transfer* its slot to the larger carrier with the larger aircraft, a more efficient solution, in terms of passengers carried, is reached. This transfer can easily be accomplished through a sale, where demand will set a fair market value for these slots.

Each major airline wants to maintain its connecting complexes at its hub airports. The airlines, however, do not all maintain hubs at the same airport. This creates situations where one airline does not value its slots as highly as another because the affected airports is not its hub, but is for the second airline. In this case, a transfer will benefit both airlines, assuming the airline receiving the slot compensates the other airline either financially, or with another slot elsewhere.

From a pure economic viewpoint, this is a good solution because market forces will drive the entire air transit network to reach a more efficient solution than if each airline were limited to only its own slots. More passengers will be carried, as smaller airlines transfer slots to larger airlines with larger airplanes. Likewise, more passengers will enjoy completed trips, as each airline maintains its connecting complexes more fully and more total connections are possible through the ground delay program.

From the airlines' viewpoint this is also advantageous for the same reasons. They have more flexibility to maintain their connecting complexes through ground delay programs due to the availability of more slots. Likewise, when a slot is not very valuable to an airline, it can sell it and realize the *true market value* of the slot. This is especially true for smaller carriers to whom the slot is inherently less valuable.

There are also problems associated with this option. There is more work for the CFCF who will have to oversee all these transactions and keep track of who *owns* which slots. There is also the issue of income distribution. The slots are not sold to the airline, but assigned, however, the airlines will profit from selling the slots. In several other government regulated industries, notably wireless communications, the government has been unhappy with assigned licenses being sold for profit. Further, there are potential problems of abuse. Carriers may *speculate* on conditions and *list* additional flights in the hope of receiving more sellable or tradable slots.

5.1.3 Slot Auctions

Under this scenario, slot assignments are replaced by an auction of slots to any interested airline. Based on airport capacity, slots would be created for arrivals. These slots would then be auctioned to the airlines, who would assign flights on their own. The auction could be done either in money, or through a system of *pseudo dollars* assigned to each airline based on the number of flights disrupted by the auction. Again, this system has the advantage of creating more flexibility for the airline, and in an economic sense, allows for the efficient solution to be reached for the air transit network.[9]

There are several significant drawbacks of this system. If the auction is for money, there is an issue of both added cost to operate imposed on the airlines buying slots, as well as an equity issue since few small carriers will be able to afford buying a slot. If pseudo money is used, there becomes a problem of deciding how much each airline is assigned to maintain equity.

The implementation of the auction presents many more problems. Currently, the assignment of slots takes little effort due to automation, and can be completed in a matter of minutes. An auction would require a significantly larger effort, both on the ATC side to oversee and implement as well on the airline side. Some pattern of slot values must be created, and a bidding strategy decided upon. The auction itself will take a significant amount of time to conduct, further delaying the implementation of the resulting slot allocations.

[9]Milner, Joe. Oral communication.

5.2 Miles In Trail

So far we've only talked about problems with ground delay programs which only affect a small percentage of airports during a small percentage of time. Yet, this has been an area that has received a large amount of attention in recent years. However, there is another area that has not received much attention that may be even more significant in terms of total delay. This is the enroute and departure spacing programs imposed almost every day by the AARTCs, known commonly as *miles in trail* (MIT).

ATC spacing programs used to be plagued by what were called *static restrictions*. These were miles in trail restrictions that were in place every day to set limits on flow into various airports. When the extent of the delay caused by static restrictions was noticed, initiatives were taken to reduce the extent of these restrictions. Quite successfully, the static restrictions were reduced to zero. At the same time, however, enroute and departure spacing programs (miles in trail restrictions imposed as needed), increased to replace the missing static restrictions. The same restrictions are now declared each morning by these facilities.

These miles in trail restrictions account for numerous delays each and every day. Generating tools to reduce the use of these spacing programs will greatly increase the efficiency of the National Air Space. One such tool is Integrated Interactive Dynamic Flow Control (IIDFC).[10] This tool dynamically integrates several flow control techniques to achieve an *optimal* flow control solution for an individual airport.

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[10] Fedida, Fabien. A Dynamic Approach to Air Traffic Flow Management of Arriving Aircraft at a Congested Airport. Flight Transportation Laboratory Report R94-2. Cambridge, Massachusetts. 1994.

Bibliography

Andrews, J. W. Optimum Ground Holding When Delay is Uncertain. 1992. unpublished.

Anbil, R., C. Barnhart, L. Hatay, E. L. Johnson, V. S. Ramakrishnan. "Crew Pairing Optimization at American Airlines Decision Technologies." *Optimization in Industry: Mathematical Programming and Modeling Techniques in Practice,* J 31-36. 1993.

Anbil, Ranga, Eric Gelman, Bruce Patty, Rajan Tanga. "Recent Advances in Crew-Pairing Optimization at American Airlines." *Interfaces,* Volume 21: 1, 62-74. 1991.

Beatty, Roger. Recovery Strategies for Irregular Airline Operations. 1993. unpublished.

Barnhart, C., E. L. Johnson, R. Anbil, L. Hatay. "A Column Generation Technique for the Long-Haul Crew Assignment Problem." *Optimization in Industry:* Volume II, 7-22. 1994.

Fedida, Fabien. A Dynamic Approach to Air Traffic Flow Management of Arriving Aircraft at a Congested Airport. Flight Transportation Laboratory, Report R94-2. Cambridge, Massachusetts. 1994.

Goeddel, Dennis L., Maria Vallera, Howard Eichenbaum. A Benefits Assessment of the FAA's Enhanced Traffic Management System (ETMS): The Impact of Initial Products of the ATMS Program. Volpe National Transportation Systems Center. Cambridge, MA 02142. 1992.

Graves, Glenn W., Richard D. McBride, Ira Gershkoff, Diane Anderson, Deepa Mahidhara. "Flight Crew Scheduling." *Management Science,* Volume 39, No. 6, 736-745. 1993.

Henderson, Danna K. "Command Center on the Prairie." *Air Transport World.* 38-40. May 1991.

... "The Best SOC, For Now." *Air Transport World.* 99-100. October 1992.

Hoffman, Karla L., Manfred Padberg. "Solving Airline Crew Scheduling Problems by Branch-and-Cut." *Management Science,* Volume 39, No. 6, 657-682. 1993.

Jarrah, Ahmad I. Z., Gang Yu, Nirup Krishnamurthy, Ananda Rakshit. "A Decision Support Framework for Airline Flight Cancellations and Delays." *Transportation Science,* Volume 27, No. 3, 266-280. 1993

McGee, William. "Despatchers: Out of Sight, Out of Mind." *Air Transport World.* 32-34. May 1991.

Mette, Matthias. <u>Sequential Heuristic Algorithm for Minimum-Cost Rescheduling of Connecting Complexes in Airline Hub Operations</u>. 1994. unpublished.

Meyer, John R. <u>Airline Deregulation: The Early Experience</u>. Auburn House Publishing Company. Boston, Massachusetts. 1981.

Simpson, Robert W. <u>Briefing on Computerized Airline Scheduling</u>. 1989. unpublished.

Taneja, Nawal K. <u>Airline Planning: Corporate, Financial, and Marketing</u>. Lexington Books. Lexington, Massachusetts. 1982.

... <u>Airlines in Transition</u>. Lexington Books. Lexington, Massachusetts. 1981.

Wells, Alexander T. <u>Air Transportation: A Management Perspective</u>. Wadsworth Publishing Company. Belmont, California. 1984.