

Irregular Airline Operations:

A Review of the State-of-the-Practice in
Airline Operations Control Centers

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Abstract

The primary purpose of this paper is to summarize the state-of-the-practice in Airline Operations Control Centers (AOCC) during the aftermath of irregular airline operations. An overview of the structure of a typical AOCC is given as the foundation of the discussion. The main causes of irregularities are considered, using operational data from the US domestic market. A review of the current information systems, and decision support systems in use in AOCC's is given, based on field trips to US airlines, and an international carrier based in the Asia Pacific region. An extensive literature review of research on the topic of irregular airline operations is presented, and a new decision framework is introduced.

Keywords: Flight Rescheduling, Airline Schedule Recovery Problem.

Introduction

Airlines are constantly faced with operational problems which develop from severe weather patterns and unexpected aircraft or airport failures. A significant amount of computational time and effort is invested in developing efficient operational schedules for airlines which are impacted by these irregular events. Over the last decade, airlines have become more concerned with developing an optimal flight schedule, with very little slack left in the system to accommodate for any form of variation from the optimal solution. However, very little research has been done on the problem of addressing the impact of irregular operations, and developing potential decision support systems which could aid in short term aircraft rescheduling. The impact of irregular airline operations on the daily activities of a carrier can lead to significant loss in profitability.

In this paper, an overview of the Airline Operations Control Center is presented as the basis for discussing irregular airline operations. This is followed by a discussion of the primary causes of irregularities and resulting flight delays and cancellations at major hub airports in the US domestic market, derived from information obtained from the US Department of Transportation. In addition, there is a review of existing decision support tools and solution methodologies currently in use at airline operations control centers of major US domestic carriers and an international carrier, outlining the major characteristics of these systems. An extensive literature review of airline operations is given, summarizing research that has been done on the topic of irregular airline operations, as well as work on other closely related research topics.

Overview of the Airline Operations Control Center (AOCC)

Airline operational planning is generally handled in two phases, strategic and tactical. Strategic planning is concerned with creating a flight schedule of services to be offered to passengers (called the Schedule of Services), and is established by the Commercial/Marketing department. The Operations group then generates the Nominal Operational Schedule (NOS) for the airline's generic resources such as aircraft rotations and crew rotations. It subsequently schedules specific airline resources by assigning tail numbers, and individual crew members to a given flight. This second step creates the Resource Operational Schedule (ROS), and constitutes the resource allocation phase of the total scheduling process. The resource allocation steps are carried out by various airline groups. The reader is referred to Grandeau (1994) for a more comprehensive discussion of the overall airline scheduling process.

Given these resource schedules, the tactical side of the Operations group is responsible for the final stage of the scheduling process: Execution Scheduling. Execution scheduling is the process of executing the system resource schedules on a daily basis. This involves three main activities: executing the pre-planned schedules, updating the schedules for minor operational deviations, and rerouting for irregular operations. The tactical operations of a regular scheduled air carrier are usually under the 24 hour/day control of a central organization often referred to in generic terms as the Airline Operational Control Center (AOCC), although it may have a different name at each airline.

This section presents a brief summary of a typical AOCC, outlining its organization, primary activities within the airline, and operational facilities. The facilities and personnel of a particular AOCC will vary considerably depending on the type and size of the airline. AOCC centers can range from a single controller/dispatcher on duty to

several dispatchers and hundreds of other personnel handling flights throughout the carrier's entire global network. During the process of operation control, the AOCC is supported by the Maintenance Operations Control Center (MOCC) which controls airline maintenance activities, and by various Station Operations Control Centers (SOCC) which control station resources (gates, refuelers, catering, ramp handling, and passenger handling facilities).

Operations Control Centers are usually linked to the Aeronautical Radio Inc. (ARINC) and the Societe International Telecommunications Aeronautiques (SITA) networks to send and receive teletype/telex messages. Communications with maintenance and engineering, customer service, and airport services are maintained to facilitate prompt contact with the appropriate personnel. Teletype, telex, facsimile, telephone, leased lines, and public data networks combine to provide an effective medium for collecting information and communicating revised operational plans developed by the AOCC center. In some cases, the AOCC has communications systems connected to VHF, HF and Satcom radio links, air traffic control centers, and other relevant locations, allowing them to effectively gather and disseminate information instantaneously.

Functional Groups Within the AOCC

The AOCC is organized into three functional groups, each with a distinct responsibility within the schedule execution process. These are: 1) the Airline Controllers, 2) On-line Support, and 3) Off-line Support; as shown in Figure 1. The airline Operation Controllers are responsible for maintaining the current operational version of all the system resource schedules (crew, aircraft and flight), and for the management of irregular operations. The final operational decisions are made by one (or more) Operation Controller(s). The operation controllers at larger US airlines may have a

dedicated airline Air Traffic Control (ATC) coordinator, to deal with Air Traffic Flow management advisories from the ATC system.

Figure 1 Information Flow Diagram for the Airline Operations Control Center

They are assisted by four types of on-line support personnel: the flight dispatch group, the crew dispatch group, MOCC, and SOCC. The Flight Dispatch group is responsible for flight planning, flight dispatch and enroute flight following. The Crew Operations group is responsible for tracking individual crew members as they move through the airline's route network, for maintaining up to date status for all crew members, and for calling in reserve crews as required. The airline controllers, flight and crew dispatch groups are usually located together in the AOCC. The later two support groups, the MOCC and the several SOCC's are usually not physically located at the central AOCC. Ancillary off-line services such as the maintenance of the navigation database, meteorology, and operations engineering (or flight technical services) are usually located at the operations control center, and serve to provide supporting resources for all AOCC personnel. In addition, the crisis center which manages activities after an accident or incident is often an integrated part of the Airline's Operational Control Center.

Information Flow within the AOCC

The airline Operation Controllers are the center of the airline operation control process. They are the sole operational group within the AOCC with the authority and responsibility to resolve problems that develop during the course of both regular and irregular operations. Airline Operation Controllers receive information from every facet of the airline during operations, through established information channels as represented in Figure 1. From these inputs, the Controllers maintain an updated

version of the airline system resource schedules which includes delays, irregular routings for aircraft and crews, and additional flights. These can be called the “Current Operational Schedules “ (COS). As the focal point in the AOCC for flight and schedule management, controllers interact with key personnel and divisions.

During normal operations, Dispatchers are responsible for the successful release of a flight, depending on maintenance issues (deferred minimum equipment list [MEL] or configuration deviation list [CDL] items), aircraft restrictions (such as noise), the availability of required operational support (fuel, gates, ground power, airport facilities) at the departure, destination and alternate airports. During irregular operations and emergencies, the Dispatcher will inform the Operations Controller of the problem, and their role is to handle the additional coordination that such situations demand. If the airline is experiencing irregularities, the Operation Controllers have to devise modified operational schedules on a very short notice. The Current Operational Schedule is the plan that the airline will follow in order to return to the Nominal Schedule of Services. These modified schedules are disseminated to the relevant airline divisions, and stations of the system.

Irregular Airline Operations

In order to effectively model any physical system, it is imperative for the researcher to develop a thorough understanding of the underlying problem being considered, as well as all the major factors that may affect the system. In the initial stages of the research, a comprehensive review of flight delays in the US domestic airline system was conducted in an effort to accomplish this task. In addition, field trips were made to existing airline operations control centers to further help establish the state-of-the-practice procedures for dealing with irregularities. The reader is referred to the Appendices for a more

detailed description of the survey questionnaire used on these field trips. In this section, a summary of the major findings of the delay study and field survey of current AOCC are presented.

The daily operations of regularly scheduled airline carriers are prone to unexpected irregularities which develop from several factors ranging from severe weather conditions to the unavailability of eligible flight crew. In many cases, these factors can have a significant impact on an airline's operations, resulting in substantial deviation from the planned schedule of services. Since 1993, the US department of transportation has recorded information on flight delays throughout the domestic air travel market. The Air Traffic Operating Management System (ATOMS) database system contains the number of scheduled flights delayed more than fifteen minutes by cause of delay (e.g. weather, and air traffic control volume) and by airport. Flights which arrive within fifteen minutes of the scheduled arrival time are considered "on-time" by the DOT.

As part of the research effort, data from the ATOMS database has been used to assess the primary causes of flight delays at major hub airports in the US domestic system, as categorized by the DOT. The major findings of the analysis will be influenced by the way in which the data is collected, as it is the responsibility of the reporting airport to assign the delay cause to each scheduled flight when necessary. The following list summarizes the major categories of irregularities as established by the ATOMS program. They are:

- Weather - Wind, fog, thunderstorm, low cloud ceiling
- Equipment - Air traffic radar/computer outage
- Runway - Unavailable because of construction, surface repair, disabled aircraft
- Volume - Aircraft movement rate exceeds capacity of the airport at a given time
- Other - Anything excluding weather, volume, runway, and equipment

The airports considered in the study were hub complexes for the six largest US major passenger carriers (American AA, United UA, Delta DL, Continental CO, USAirways US, and Northwest NW). In total, twenty airports were examined in the study. This sampling of airports represents a wide range of aircraft movement levels, and corresponding passenger traffic levels.

Several important observations were made during the course of reviewing, and analysing the delay data obtained from the ATOMS database. The main points of the empirical study are summarized below:

- Loss of capacity due to severe weather and traffic volume account for 93% of flight delays at hub airports.
- There is a marginal correlation between the overall level of aircraft movement at an airport and the level of flight delay experienced.
- The level of flight delay at an airport is affected by its geographical location, and the resulting meteorological conditions.
- The variation in the level of flight delay at a given station is closely related to the seasonal weather changes.
- The level of hub activity at an airport can have an impact on the level of flight delay.
- In the majority of the airports studied, the highest percentages of delays were experienced in January and July of a given year.

Implications for the Development of Decision Support Systems

It is evident from the empirical study that the majority of flight delays result from severe weather conditions. The ability of a given aircraft routing to absorb any delays is minimal, as most routings have been optimally determined, with very little slack time built into the flight sequence. Thus, a delay in flights early in the day may cause continuing lateness unless the airline pro-actively rescheduled its resources. In order to effectively deal with irregularities, it is thus apparent that a system-wide approach should be applied to the problem, if one hopes to efficiently resolve airline irregularities. However, current practice generally takes a localized approach in dealing

with irregularities. In the next section, a review of existing solution procedures and decision support tools used by the AOCC is given to highlight the need for more efficient methodologies to deal with abnormal operations.

Review of Existing Information Systems and Decision Support Tools

The overall impact of irregularities on the daily operations of an airline will depend on the level of precautionary measures the carrier has built into its schedules to deal with typical irregularities. Many carriers have developed extensive resolution procedures which are generally implemented manually in the aftermath of irregularities, with little if any dependence on automated decision support systems. Decisions regarding future operational schedules and actual operations of the airline are made based on forecasted and often out-dated data and information, and this can have a significant effect on the value of the decision process. In some cases, the airline may decide to delay or even cancel flights, only to find out that these actions were unnecessary for the resolution of irregularities in the network.

Airlines have identified the need to improve the processes which assist airline controllers in the real-time operations of the carrier. They have invested heavily in state-of-the-art, Airline Operations Control Centers (AOCC), sometimes referred to as system operations control centers, which gather an extensive array of operational information and data. However, very little effort has been placed in developing solution procedures and methodologies which could complement the decision making capabilities of experienced airline controllers. In order to appreciate the need for such systems, the following is a summary of some of the resolution procedures and decision support systems, currently in use at Airline Operation Control Centers of major US domestic carriers, and an international carrier based in Asia.

Rakshit (1996) discusses the “System Operations Advisor” (SOA), a real-time decision support system that has been developed and deployed for use at United Airline’s AOCC (which they refer to as the Operations Control Center [OCC]) to increase the effectiveness of its operational decisions. The SOA system consists of three primary components: the Status Monitor, the Delay and Swap Advisor, and the Delay or Cancellation Advisor. The purpose of the Status Monitor subsystem is to alert the airline controller of potential irregularities such as delays and cancellations through a graphical user interface. The interface provides mechanisms to launch tools such as the Delay and Swap Advisor for developing solutions to existing operational problems. The Delay or Cancellation Advisor can then be deployed in order to determine potential resolution procedures to problems which have developed from irregularities in the airline’s network. It is important to note that decisions regarding delays and cancellations of scheduled flights are made independently of each other in this current system.

The AOCC at American Airlines is called the System Operations Control center (SOC), and relies on an array of decision support tools to make informed decisions about the operations of the carrier. The airline’s primary goal in the aftermath of irregularities is to return to the operational schedule as soon as possible, regardless of its impact to potential revenues. The controllers consider the number of passengers booked on a given flight segment instead of the actual value of the flight. In resolving irregularities, the airline controllers subjectively incorporate passenger flow issues such as connectivity, goodwill, and volume of traffic, into the decision process.

The airline has identified crew scheduling as the important parameter in the resolution of irregularities in the network, and consequently, most aircraft substitutions are done within a given fleet. In the aftermath of an irregularity, the carrier first establishes a

reduced flight schedule, and then figures out how to implement this schedule. It takes into consideration such issues as critical departure times, mission compatibility, and system balance in the daily flight cycle. American Airlines describes mission compatibility as any decision which minimizes downstream effects in schedule variation, and provides a feasible resolution in a timely fashion. Decisions are generally made to initially delay flights, and then if necessary determine flight cancellations.

Delta Air Lines recently opened its new operations control centre in Atlanta, responsible for monitoring weather, flight schedules and maintenance problems that may develop during the course of normal operations. The airline makes use of readily available operation data to fine tune its flight schedules to accommodate for prevailing weather conditions. It is apparent however, that most of the decision making regarding flight delays and cancellations at Delta is manually executed, with little if any reliance on automated decision support systems. The airline is currently in the process of developing such software, including a program named the Inconvenienced Passenger Rebooking System, which allows the airline to notify passengers of cancellations or delays and aid in passenger flow recommendations. In addition, they are reportedly in the middle of developing software to assist in the redeployment of flight crews in the aftermath of irregularities.

In recent years, many airlines have come to rely extensively on pre-emptive decision making, developing flight cancellation plans which are implemented long before an airport or region is actually impacted by severe weather conditions. At Continental Airlines, they have developed a resolution procedure referred to as the Severe Weather Action Plan, which is used to minimize the number of aircraft and crews remaining in a geographical region forecasted to have bad weather conditions. The airline controllers

believe that such preemptive actions are beneficial to the carrier, as it makes schedule recovery easier, and greatly facilitates restarting normal operations. However, they may in fact compromise revenue operations, which could have occurred without the influence of the prevailing irregularities. Continental recently opened its new operations control centre, similar to those existing at American, United and Delta airlines.

Northwest Airlines is currently in the process of developing decision support systems for use in the carrier's operations control center. In the interim, the airline has developed and implemented several alternative aircraft "thinning" procedures that incorporate both operational and economic factors in the decision making process. "Thinning of flights" is defined as the response to irregular operations, based on forecasted adverse weather conditions that are expected to reduce the operational capacity of airports in the given region. The thinning process is designed to match operations with the level of reduced airport capacity, while ensuring that net revenue contributions are maximized, as well as minimizing customer inconvenience, and disruptions to crew and maintenance scheduling. The overall guidelines for thinning operations are to recover safely, and efficiently to normal operations as soon as physically possible, in the aftermath of the irregularity. Similar to Continental Airlines, it is Northwest's policy to pre-cancel flights in preparation for the reduced operational capacity.

At Garuda Indonesia, the AOCC is referred to as Operations Movement Control (EM), and it serves as the core of Garuda's operations. The primary information system is the Resource Management Operations Control (ROC) system , which is used for monitoring the actual operations of every Garuda flight. The airline's Nominal Operations

Schedule which is generated by Operations Planning (EP) using the Airline Resource Planner (ARP) is electronically transferred (via floppy disk) to the ROC system.

However, there is no direct line connection between to the two computer systems.

Actual operational data in the form of a departure message from each airport station is transmitted via SITA telex, and automatically entered into the Resource Operations Control ROC database/graphical display system. The departure message includes information on actual arrival time at station, aircraft type, aircraft's next destination, departure time, estimated arrival time, delay status, passenger count, cargo, mail, captain in command, and fuel uplift data. The departure messages are stored for each flight leg in a centralized operations database in DBase 3 format. This data can be accessed and analyzed using the database management system Paradox. Any additional changes or modifications in flight schedules such as charter flights, special flights, etc. are manually entered into the ROC system via keyboard. A hard copy output of the flight schedules from the ARP program (prepared by EP) is used as a back-up to computer systems, as well as to manually record changes in the schedule in the event of an irregular operation.

At the Operations Control facility, four micro-computers serve as a platform for the ROC monitoring system. One computer acts as a dedicated server, with the remaining three units providing display capabilities and limited operational access to the stored data. The ARP/ROC systems have been in use at Garuda since 1990. Before that all operations were manual. In addition, Operations Control has access to the reservation system ARGA and the departure control system DCS database via a separate computer terminal. The information is used during irregular operations, to determine the impact of cancellations on revenue (manually).

Review of Research Work on Irregularities

Mathaisel (1996) reports on the development of a decision support system for AOCC which integrates computer science and operations research techniques. The application integrates real-time flight following, aircraft routing, maintenance, crew management, gate assignment and flight planning with dynamic aircraft rescheduling and fleet rerouting algorithms for irregular operations. As discussed by the author, the algorithms help airline controllers optimally reroute aircraft, crews and passengers when operational problems disrupt the execution of the schedule plan. The system includes a real-time, interactive, graphical aircraft routing displays; a rule system which provides warnings of constraint violations and usual conditions; and the ability to generate what-if solution scenarios. The integrated system is demonstrated by simulating a disruption to a planned schedule and by using one of the available tools, a network flow algorithm, to determine optimal rerouting alternatives.

The problem of irregular airline operations has been considered in research projects conducted by Dusan Teodorovic, et al. and in work done by the Research and Development Department of United Airlines. Teodorovic and Gubernic (1984) discuss the problem of minimizing overall passenger delays in the aftermath of a schedule perturbation. They attempt to determine the least expensive set of aircraft routings and schedule plan using a branch and bound procedure. Their methodology is based on the assumption that all the aircraft in the fleet have the same capacity, and they only considered a marginally sized fleet of three aircraft operating a total of eight scheduled flights. Teodorovic (1985) presents research on the reliability of airline scheduling as it relates to meteorological conditions, the ability to identify an indicator for quantifying the adaptability of such airline schedules to weather conditions, and an overview of a

potential solution procedure. The author outlines this heuristic algorithm for minimizing the number of aircraft required to accommodate a given traffic volume, while ensuring that aircraft are assigned to only one flight within a given time period.

Teodorovic and Stojkovic (1990) discuss a greedy heuristic algorithm for solving a lexicographic optimization problem which considers aircraft scheduling and routing in a new daily schedule while minimizing the total number of cancelled flights in the network. The algorithm developed is based on dynamic programming, and is characterized by a sequential approach to solving the problem as flights are assigned to aircraft in sequences. The solutions obtained using this methodology are highly sensitive to the decision matrix, and the ranking of the various objective functions. The model does not consider the impact of crew scheduling in the aircraft scheduling process. Teodorovic and Stojkovic (1995) outline a model for operational daily airline scheduling which incorporates all operational constraints, and is used to reduce airline schedule perturbations. Their heuristic model based on the FIFO principle and a sequential approach based on dynamic programming, is developed to facilitate and incorporate the work and experience of the dispatcher in the decision process regarding traffic management. The model developed is used to determine the aircraft rotations, as well as the crew rotations, while minimizing the number of cancelled flights.

The Research and Development Department at United Airlines has conducted several projects on the topic of irregular airline operations, and has presented material on its efforts at annual symposiums of AGIFORS (Airline Group of the International Federation of Operations Research Societies). The work at United is part of the development of a comprehensive decision support system for use in the carrier's operations control centre. Jarrah, et al. (1993) present an overview of a decision support

framework for airline flight cancellations and delays at United Airlines. Their underlying solution methodology is based on network flow theory, as the models cast some of the problems faced by flight controllers while dealing with irregularities into minimum-cost network flow problems.

Jarrah's paper outlines two separate network flow models which provide solutions in the form of a set of flight delays (the delay model) or a set of flight cancellations (the cancellation model), while allowing for aircraft swapping among flights and the utilization of spare aircraft. The models assume that a disutility can be assigned to each flight in order to reflect the lost revenue if the flight is cancelled, and that the disutility of delaying each flight is assessable. Both models are solved using Busacker-Gowen's dual algorithm for the minimum cost flow problem in which the shortest path is solved repeatedly to achieve the necessary flow in the network. The network models presented are solved independently of each other, and does not take into consideration crew and aircraft maintenance constraints. This solution framework is deficient in that it does not allow for a trade-off between cancelling and delaying a given flight in a single decision process. In addition, the solution methodology does not allow for potential substitution of aircraft with varying capacity, and operational capabilities.

Yan and Yang (1997) develop a decision support framework for handling schedule perturbations which incorporates concepts published by United Airlines. The framework is based on a basic schedule perturbation model constructed as a dynamic network (time-space network) from which several perturbed network models are established for scheduling following irregularities. The authors formulate both pure network flow problems which are solved using a network simplex algorithm, and network flow problem with side constraints, which are solved using Lagrangian

relaxation with subgradient methods. They outline the basic schedule perturbation model which is designed to minimize the schedule-perturbed period after an incident, while maximizing profitability. In addition, they consider the effects of flight cancellations, flight delays and ferry flights as solution alternatives in the decision process. The framework is designed to aid airlines in handling schedule perturbations caused by aircraft breakdowns, and assumes scenarios with only one broken down aircraft and a single fleet type. In addition, the models do not incorporate aircraft maintenance and crew constraints in the formulation.

Cao and Kanafani (1997a) discuss a real-time decision support tool for the integration of airline flight cancellations and delays. This research is an extension of the work of Jarrah (1993), using many of the modelling concepts presented and discussed in Jarrah's paper. The authors present a quadratic 0-1 programming model for the integrated decision problem, which maximizes operating profit while taking into consideration both delay costs and penalties for flight cancellations. They discuss special properties of the Flight Operations Decision Problem (FODP) model which are exploited to develop a specialized algorithm to solve the problem in real-time. The model considers the airport network as a complete system, and traces the effect of delay and aircraft reassignment from one station to the next. The authors consider as an extension to their base model, issues of ferrying surplus aircraft and multiple aircraft type swapping capabilities. In a subsequent article, Cao and Kanafani (1997b) present an effective algorithm to solve the FODP model and discuss computational experiments with a continuous mathematical problem, derived from the 0-1 quadratic problem. In the case studies presented, aircraft ferrying, crew scheduling and airport capacity constraints are ignored in the solution procedure.

Arguello et. al (1997) present a time-band optimization model for reconstructing aircraft routings in response to groundings and delays experienced in daily operations. This model is constructed by transforming the aircraft routing problem into a time-based network in which the time horizon is discretized, resulting in an integral minimum cost network flow problem with side constraints. The authors outline conditions in which exact solutions are attainable, and discuss the complexity of the problem relative to the size of the underlying airline network. In addition, they present computational results for a marginally sized case study of a single fleet of 27 similar aircraft, serving a network of 30 stations with 162 flights. The problem is initially solved as a relaxed linear programming problem, and if necessary a mixed integer problem, based on the underlying structure of the transformed network, is solved.

The ability of an airline to recover from severe weather conditions and resulting irregularities will depend on its interaction with the air traffic control (ATC) system. Under such conditions, ATC typically imposes restrictions on aircraft movements at affected airports and implements what is generally referred to as a slot allocation scheme, as well as ground-delay programs. The response of the airline to these imposed conditions will be based on available data in the system operations control center. The guidelines governing such slot substitutions have been recently changed to help accommodate the operating needs of carriers in the ATC system. Most of the published literature on the topic of slot allocation has been rendered obsolete, as changes to the substitution guidelines have now significantly altered recovery procedures in use at AOCC.

The problem of crew reassignment (crew recovery) in the aftermath of irregular airline operations has been considered by researchers at the Logistics Institute of the Georgia

Institute of Technology. Lettovsky et al. (1995) have developed a mathematical programming based solution methodology which uses an integer programming model to optimally re-assign crews to flight segments. In a presentation given at the INFORMS meeting in the fall of 1995, one of the researchers outlined a model which reassigns crews to flight legs, while minimizing the additional cost and operational difficulties to the airline. The solution strategy initially identifies a set of eligible crews, whose original assigned unflown flight segments are used to form new crew pairings which are then reassigned to individual crew members through a set covering problem.

During the normal operations of a carrier, situations often develop wherein modifications have to be made to the existing schedule plan. In addition, due to the inherent variation in passenger demand over the course of the week, airlines find it necessary to adjust their daily flight schedules to adequately meet demand. This will result in the need to make minor modifications to aircraft routings and possibly fleet assignments. Talluri (1996) describes an algorithm for making aircraft swaps that will not affect the equipment type composition overnighing at various stations throughout the airline's network. The algorithm repeatedly calls a shortest-path algorithm, and the performance of the swapping algorithm is a reflection of the availability of very fast shortest path algorithms. He also outlines the application of the swapping procedure in the airline schedule development process.

Given a predetermined flight schedule, the fleet assignment problem is to determine which aircraft type is assigned to a given flight segment in the carrier's network. The aircraft routing problem is traditionally solved after the successful completion of the fleet assignment problem. It involves the allocation of candidate flight segments to a specific aircraft tail number within a given sub-fleet of the airline. The process of

aircraft routing has traditionally been a manual activity at airlines, but in recent years, researchers have developed solution procedures that can be applied to the problem.

In all the published literature dealing with irregular airline operations, there is an underlying assumption that the fleet assignment problem is solved before considering the aircraft re-routing problem. There has been extensive work done on the topics of fleet assignment, aircraft routing and crew scheduling. In recent years, there has been a trend towards addressing hybrid airline problems such as the combination of the aircraft assignment and routing problem, and the combined fleet assignment and crew scheduling problem. Researchers have started to explore these so-called hybrid strategic planning problems, combining different phases of the airline planning process, which have been traditionally considered in sequential order. However, these hybrid problems have been considered only for the strategic phase of the airline planning process.

One such problem is that of the combined aircraft fleet and routing problem.

Barnhart et. al (1997) discuss a model and solution approach to solve simultaneously the fleet assignment and aircraft routing problems. The authors state that the methodology incorporates costs associated with aircraft connections, and complicating constraints (such as maintenance requirements, and aircraft utilization restrictions) which are usually ignored in traditional fleet assignment solution procedures. The model is string-based and a branch and price solution approach is used to solve the problem. This hybrid solution procedure combines the standard integer programming IP solution technique of branch and bound, and explicit column generation. As described by the authors, a string is a sequence of connected flights that begins and ends at a maintenance station, satisfies flow balance, and meets the required maintenance

constraints. The methodology is validated using operational data from a long-haul carrier.

Soumis et. al (1980) present a model for large-scale aircraft routing and scheduling problems which incorporates passenger flow issues. The solution methodology proposed is a heuristic adaptation of the Frank-Wolfe algorithm for an integer problem with a special structure. The procedure involves solving alternatively the aircraft routing problem, and the passenger assignment problem until a prescribed criterion is satisfied. The authors discuss the technique used to transfer information from the passenger flow problem to the aircraft routing problem.

Throughout the course of daily operations, airlines face a major operational problem in assigning aircraft capacity to flight schedules to meet fluctuating market demands. Berge and Hopperstad (1993) discuss the Demand Driven Dispatch (D3) operating concept that attempts to address this problem. Utilizing up-to-date and more accurate demand forecast for each scheduled departure, aircraft are dynamically assigned to flights in order to better meet anticipated passenger demand. The solution procedure requires the frequent solution of large aircraft assignment problems, which are formulated as multi-commodity network flow problems, and solved with heuristic algorithms. The authors outline case studies of actual airline systems in which increases in passenger loads are achieved, along with reductions in operating costs, resulting in a net improvement in operating profit. From a conceptual standpoint, the potential may exist to conduct aircraft swapping with multiple aircraft types (different crew rating). Some of the concepts used in Boeing's Demand Driven Dispatch methodology can be used as a foundation for incorporating the issue of dynamic aircraft assignment in the resolution of flight schedules in the aftermath of irregular operations.

A New Approach to Rescheduling Flights

Clarke (1997) has developed the Airline Schedule Recovery Problem (ASRP) which provides a comprehensive framework that addresses how airlines can efficiently reassign operational aircraft to scheduled revenue flights in the aftermath of irregularities. The mathematical formulation of the problem enables flight delays and cancellations to be considered simultaneously, i.e., in the same decision model. The decision model allows for multiple fleet type aircraft swapping in flight rescheduling, provided the candidate aircraft is capable of flying a given flight segment. In addition, the impact of air traffic control (ATC) traffic flow management initiatives and crew availability are incorporated into the model through restrictions on aircraft movement at affected airports in the network system.

The ASRP is based on a time-space representation (schedule map), which allows the use of efficient tree-searching algorithms to quickly solve the underlying subproblem of finding the best possible aircraft routing, subject to one or more operating constraints. Based on concepts from network flow theory and linear programming theory, algorithms have been developed that can be used to solve the airline schedule recovery problem in a real-time environment. The algorithms and solution methodologies developed in this research have successfully demonstrated that it is possible to develop efficient procedures for flight rescheduling.

The Airline Schedule Recovery problem is best described as a hybrid three dimensional decision model as it simultaneously solves the fleet assignment problem and the aircraft routing problem which are normally solved sequentially. As a result, aircraft maintenance requirements are implicitly satisfied in the aircraft assignment output from the implemented algorithms. This unique solution approach to the aircraft

routing aspect of the problem is different from traditional procedures currently employed in the strategic phase of the planning process, and in the aftermath of irregularities.

Summary and Conclusions

The purpose of this paper was to provide an introduction to the Airline Operations Control Center (AOCC), and to summarize the state-of-the-practice at AOCC for dealing with irregular airline operations. Based on field trips to operations control centers, the author was able to identify some of the major characteristics of decision support systems currently in use at AOCC. This knowledge of the state-of-the-practice has been used in the development of a comprehensive framework, which airlines could use to efficiently reschedule flights in the aftermath of irregularities. The reader is referred to Clarke (1997) for a more comprehensive discussion of the decision framework.

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