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Disruption management in the airline industry

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DISRUPTION MANAGEMENT IN THE AIRLINE INDUSTRY

Master Thesis
in Aerospace Engineering

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Introduction

Air travel in Europe continues to grow at a rapid rate. Unfortunately, this growth has not been matched by availability of capacity. The consequences of on-going growth on the current European Air Traffic Management(ATM) system are reflected, in part, in delays and flight few efficiencies. The disconnected nature of the European ATM system also hinders its ability to cope with the growth in the air traffic.
We have a main distinction between operations made by the operational centre and by the airline company. The real problem is the cooperation and coordination of them. Successful operation of an airline depends on coordinated actions of all supporting functions. Nevertheless, each unit, with its own budget and performance measures, typically operates under its own instruction.

It is vital in the attempt to control last minute changes for crew controllers and the aircraft controllers' online information. A plenty of abundance of relevant data is saved in the data depot of large airlines, and by showing the correct information as quickly as possible substantial support can be given to the controllers.

The system adjourns as new information about the flights become available, thereby helping the controller to trace the ordinary status of his/her fleets. For trans-Atlantic flights, satellite navigation can help the aircraft controller to preserve the track of the actual position of the flights. For busy airports, the operation of listen in on the communication between ATC and the aircraft for the aircraft controllers. This can identify the position of an aircraft in the holding pattern, therewith making it doable for the aircraft controller to come up with skilled valuations of a possible arrival time.

A lesser alternatives are usually left to other groups like crew and passenger controllers. They can receive updated information but only by querying the information systems themselves thus the controller will dispatch querying commands to the relevant system to gain the information required.

Identical information is not still measured in the same way in the majority of the case. Thereby it can consider inconsistent data such as departure time for crew and aircraft, although the crew was on that aircraft. In day-of-operations this poses a challenge to the work of the controllers as they might have to act on last minute information.

Also while information from engineering is typically available for the OCC (operational control centre), information from less critical functions like catering, cargo and gate staff is not. Here, communication between relevant departments has to be established manually.

Chapter 1

Background

The complexity of operating an airline arises along with the need for planning because of several factors:

- An endless number of rules, regulations, union demands and preferences apply to crew and aircraft schedules.
- Airlines operate across time zones, cultures and continents and the operational scope is enormous.
- The airlines must create very tight plans that utilize resources with very little slack.
- Airlines operate in an unpredictable environment where disruptions often occur. The near absence of slack in the flight schedules can cause disruptions to have multiple knock-on effects further down in the flight schedule. These have to be repaired while respecting all the factors just described.

The planning in the airline industry takes place on many levels. Construction of timetables, aircraft rosters, and crew rosters are some of the tasks in airlines. It is clear that these planning activities take place before flights are carried out. The planning issues come out in proximity of the departure time and each departure is a product of years of careful planning. Therefore, when disruptions occur, flight controllers want to return to the original schedule as quickly as possible.

Airlines constantly monitor their operations. The state of operations is defined by the planned events (time table, fleet and tail assignment, crew scheduling, etc.) and the actual events. The actual events are often recorded in an on-line message stream and the average message density is often more than one message per second. Some actual events will indicate a discrepancy between plans and operation and raise question whether it is necessary to do something. The possible need to

do something is driven by the time rather than by an unexpected event.
Some unexpected events, such as minor delays, do not require changes of plans and cause limited inconvenience for passengers. Thus it is not necessary to work out any unplanned events or time triggers. In case it is necessary to do something about the event or time trigger, we will point it as a disruption.
First it is necessary to identify the possible actions and to evaluate these, then the evaluation involve assessment from the passenger, the crew and the aircraft perspective and also from other point of view. The proposed changes of the schedule may change these evaluations. From the passenger point of view it might, for example, be logical to delay an outbound flight as a flight out of an airlines hub to guarantee that passengers on a delayed inbound flight will be able to make their connection. This choice has to be then evaluated from the crew and the aircraft perspective. Following these assumptions this process can continue until an option, that is legal and satisfying from all perspectives, has been found, in line with [4].

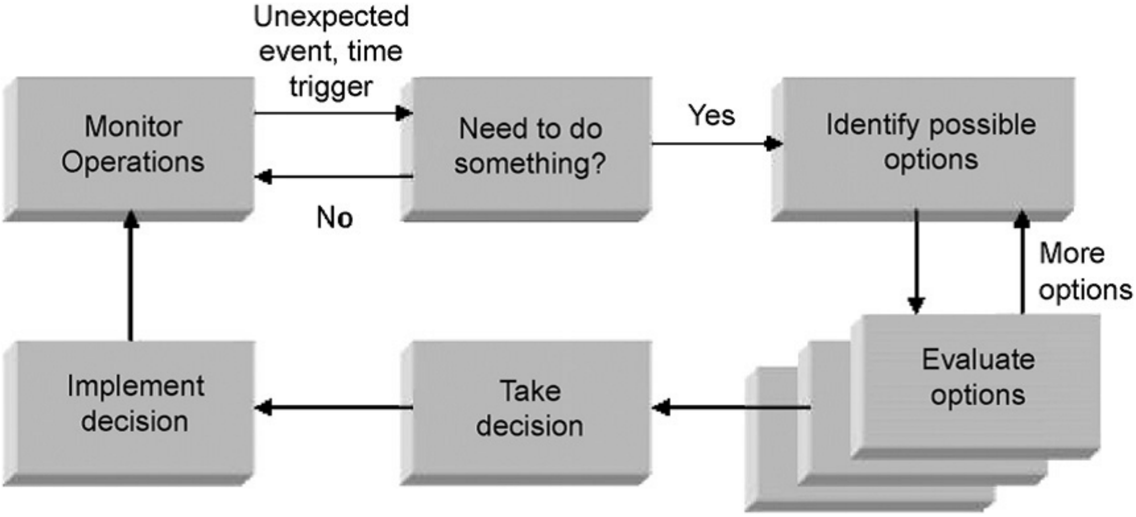


Figure 1.1: High-level view of the disruption management process. [4]

Based on the agreed option, one can decide whether it is necessary to do something now or whether we can postpone the final decision. This is dependent on the actions considered.
At this level of abstraction, the disruption management process differs from most control processes in complex systems involving humans. The most important distinct features are the broad array of potential options and the computational complexity of assessing the impact of each of these options.

1.1 Problem statement and limitations of the study

The scope of this report consists of the description of the disruption management and the costs of delay in airline industry. Analysis between the different authors and problem solutions for catching the best available options.

One of the difficult aspects of disruption management is to specify the objectives. Objectives fall in three broad categories: Deliver the customer promise (i.e. get passengers and their luggage to their destination) on-time with the booked service level, minimize the real costs including excess crew costs, costs of compensation, hotel and accommodation to disrupted passengers and crew, and tickets on other airlines, and get back to the plan as soon as possible.

We take in consideration the cost of delays to airline. Although delays cause costs to other bodies, such as airport authorities, air traffic control(ATC), handling agents, and to the passengers themselves. Nevertheless, delay are bad news for airlines, because the cost of delay hits airlines twice: in the contingency planning of a schedule(the 'strategic' cost of delay), and then again, when dealing with actual delays on the day of operations(the 'tactical' cost of delay).

The limitation of the study lies with the fact that airlines are already operating under intense operational and financial pressure, for that reason airlines have not carried out more evaluations of these enormous costs.

There are two fundamental challenges here: the development of better tools and resources to help manage the costs of delay and the actual reduction of delays itself.

1.2 Study purpose

The study firstly describs the problem of delay in the aircraft industry. The main part of the study consists of implementing solutions of airline operations for delay problems. It ranges from the number of assigned crew, the route planning time, the problem of the coincidences, the change in timetable and the procedure to apply when something goes wrong. The objectives to clarify this report are to provide information for the airline industry about new technologies for navigation and on the ways to implement them. It provides some algorithms or calculations and the analysis of their cost compared to the different authors. After reading the report, the airline operators will have a better general view of the delay problems, the main causes of it and how the new systems can change the disruption management. The thesis takes in consideration the following points:

1. Decsribe general principles and structure for the airline operation and planning.

2. Disruption management for the airline industry and the main causes of it, the main rules that regulate this process and of who are responsibilities.
3. Analysis of some datas of dealy.
4. Classification of the architectures for the airline operations problems and delay management.
5. Discussion about solution models of the disruptions problem.
6. Analysis of the delay cost.
7. Future Air Transport Operation and their contribution in the airline scheduling and traffic planning.

1.3 Outline of the report

The report is divided in eight chapters, each of them divided in sections and subsections. The main literature used is summarized in the Literature review. The methodology used to find the sources and the terminology follows in the second chapter and then a general overview of the airline management.
The main part of the report consists of the description of the disruption management and the costs of delay in the airline industry. Analysis between the different authors and problem solutions for catching the best available options.
A part of this work, the chapter seven, is also dedicated to the analysis of some specifics received from the Avinor company.
In the second-last chapter a brief description of new trends of the airline industry to obviate at this problem with the benefits offered by communication, navigation, surveillance air traffic management measures. These are key to future, improved efficiencies, allowing more direct routing, and to reducing delays.
Finally, in the last chapter the conclusion of our study, that will reply to all the points of the study purpose.

Chapter 2

Methodology

It is relevant to sunder the method research strategies in two categories, quantitative, qualitative or a combination of these two. Quantitative research strategy is numerical, the input of data without any control about it for anyone. All the informations recorded are transformed into numbers for other analyze, than to map the model and find deviations from the normal distribution. Quantitative research is related among variables, and it is a way of testing theory. Qualitative research method is trying to see from the point of view of the participants. The outcome depends on the interpretation of the data, through the analyze of information.
It is easy to note that this document is more qualitative than quantitative.

We have started the research utilizing some keywords on our research on internet and we find out some papers searching: 'disruption management', 'cost of delay in the airline industry', 'traffic planning', 'route and crew scheduling'.

Therefore we concentrate our attention over the Disruption Management and Delay in the airline industry. The disruption is one of the phases of the operational plan, and we bear in mind different authors and different solving problems and we will compare these and chose the best one that explain and solve the problem of interruptions during operations.

2.1 Literature review

The first part of this thesis is a general overview of the different operation that occur in the airline structure and the work is structured in a kind of arrays vision.

Consequently, the following chapter is a combination of many papers and we

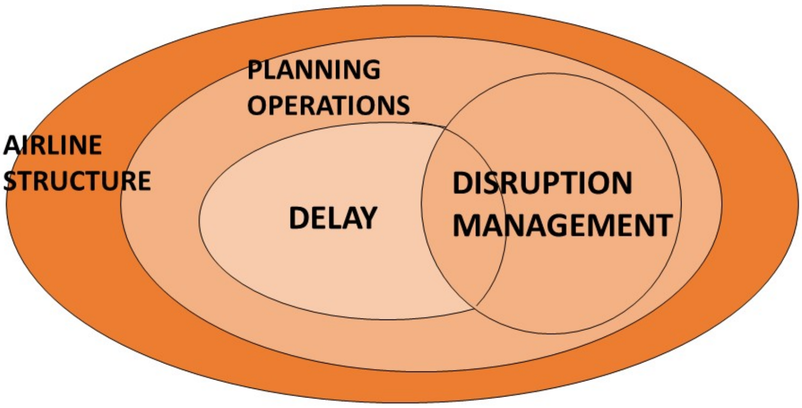


Figure 2.1: Representation of the arrays of the arguments treated

cite all of them in the Bibliography. It is easy to find some material about the airline management of different process and organization of the work.
At this point of the work we are preparing the ground for the second zoom inside the air traffic management, the Planning operation. In that part the main paper is the work of Jens Clausen, Allan Larseny and Jesper Larsenz: ”Disruption Management in the Airline Industry- Concepts, Models and Methods” that in the bibliography the number [11]). The planning way in the airlines is a conventional topic and it is simple to collect papers about it. Therefore, we analyze all the phase of the planning operations and also the main division in this field, that is between aircraft routes and crew scheduling. Consequently , we unroll the discussion about planning operation in a series of subchapter for better explain the overview in air traffic industries.

This paper says that the airline industry is notably one of the success stories with respect to the use of optimization based methods and tools in planning. Both in planning of the assignment of available aircraft to flights and in crew scheduling, these methods play a major role. Plans are regularly made several months preceding the actual day of operation. As a consequence, changes often occur in the period from the construction of the plan to the day of operation and all these changes can conduce to the delays and the consequent costs of the delays in that industry. When we take in consideration the delay problem, the main document is the chapter 4 of the book of European Air Traffic Management- Principles, Practice and Research of Andrew Cook, in the reference [54]. It is not likely to find out few documents about the delay costs in the airline industries and also the costs that passengers are willing to deal for avoid the delay, so we found some documents that treat more generally the problem in all the transportations way. Optimization tools play an important role also in handling these changes.

The last zoom is the one in the direction of the disruption management and, as a consequence, the recovery program for the crew, the airline and the integrated one. For the main argument the most important paper is ”Disruption management in the airline industry - Concepts, models and methods” written by Jens Clausen, Allan Larsen, Jesper Larsen and Natalia J.Rezanova, it is the number [12] in the reference.
The disruption procedures are investigated from many authors and is a good topic for find material, but a bit difficult is to perceive architectures varying as function of organization structure. Moreover, for the great quantity of authors and solutions proposed is not possible to show all the solution models and as a result it will be only illustrated the methodology applied.

In the second last chapter we present the new trends for the airline industry in the field of energy saving and consumption, but also the new ways to manage air navigation using new technologies. Whole Europe are participating in this project with the project NextGen.
We investigate in this chapter in what ways this new kinds of technology influence the field of our interest, the new contributions for the way of avoid delay and disruption during normal operations.
We will add a part of analysis of data from the Avinor database, and some study about the punctuality and the relations of the other elements with that. Here analysis will be based on day by day analysis , weekly analysis , peak point analysis and average analysis for respective delay events. The reliability of this work is objective, we based all the work on already know references and we add a part over the new trends of the industry for the future. All the news in this field will change also the way of managing and plan the operations.

The validity is for the summary of the different sources and the comparison of the models of some of the most famous authors that talk about the disruption problem, we also try to investigate the airline from a new prospective, the perspective of the passengers that want to avoid delay and they are disposed to pay for it.

Chapter 3

Airline structure

3.1 Strategy, business model and tactical

The first important difference that we have to clarify is between the notion of strategy, business model and tactical. *Business Model* refers to the logic of the firm, the way it operates and how it creates value for its stakeholders; and *Strategy* refers to the choice of business model through which the firm will compete in the marketplace; while *Tactics* refers to the residual choices open to a firm by virtue of the business model it chooses to employ.
Firstly, we want to investigate the structure of the Air Traffic Management with the figure above we show a general overview of the phases' division.

As said Masanell and Ricart [1], two different group of elements make up the Business models: (a) the concrete choices made by management about how the organization must operate, and (b) the consequences of these choices. The choices include remuneration practices, procurement agreement, position of facilities, assets engaged, measures of vertical integration, and sales and marketing stratagems and every choice has some consequences. Evans and Wurster [13] discern three types of choices: policies, assets and governance structures . All the policy choices refer to courses of operation that the firm adopts for all aspects of its operation for instance, opposing the emergence of unions; locating plants in rural areas; encouraging employees to fly tourist class, providing high-powered monetary incentives, or airlines using secondary airports as a way to cut their costs, as show Zott and Amit [14]. Asset choices refer to decisions about tangible resources, such as the production of facilities, a satellite system for communicating between offices, or an airline ' s use of a particular aircraft model. Governance choices refer to the structure of contractual arrangements that confer decision rights over policies or assets.

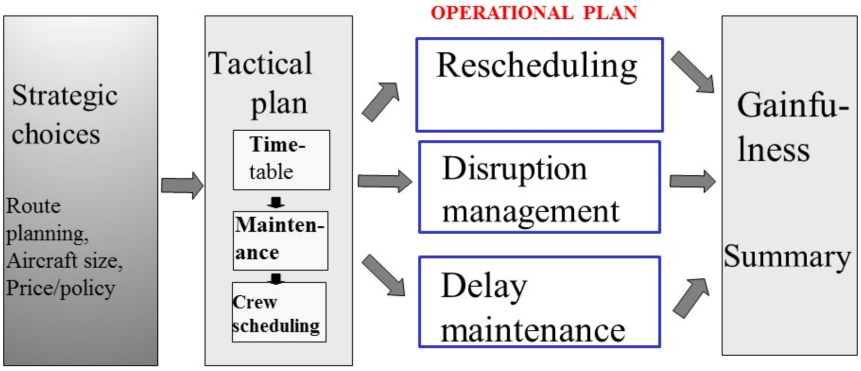


Figure 3.1: General aircratf management planning

Business models often generate *virtuous cycles*, feedback loops that strengthen some components of the model at every iteration for MacMillan [15]. While virtuous cycles are not part of the definition of a business model, they can be crucial elements in their successful operation.

Tactics are the residual choices open to a firm by virtue of the business model that it employs. Tactics are important, as they play a crucial role in determining how much value is created and captured by firms, from Khanna, Oberholezer-Gee and Sjoman [16]. The business model employed by a firm determines the tactics available to the firm to compete against, or to cooperate with, other firms in the marketplace. Therefore, business models and tactics are intimately related.

Strategy is often defined as a contingent plan of action designed to achieve a particular goal. Strategy is a high-order choice that has profound implications on competitive outcomes. Choosing a particular business model means choosing a particular way to compete, a particular logic of the firm, a particular way to operate and to create value for the firm ' s stakeholders, as said Rivkin [17].
Strategy refers to a firm ' s contingent plan as to which business model it will use. It is important to note the word " contingent " - strategies should contain provisions against a range of environmental contingencies, whether they take place or

not. An outside observer will only be able to observe the realized strategy, rather than the entire contingent plan, from Masanell and Ricart [1].
In the aircrafts economic development it is important the division in different phases, each one is the direct consequence of the phase before. We show in the table below the different phases.

STRATEGIC	TACTICAL	OPERATIONAL
Routes	Normal week plan	Roll the plan
Type of aircraft (size)	Aircraft flights manietnance	Delay maintenance
Price/ policy	Supports	Scheduling
Out-source	Time cycle and frequence of flight	Disruption management
Planners	Crew scheduling	

Table 3.1: General overview

We continue our dissertation analyzing the main arguments of the table.

3.1.1 Size of the aircraft

For the study of the impact of aircraft size and frequency on airline demand we have to investigate before the concept of ”schedule delay”, first introduced by Douglas and Miller [31], and subsequently applied by Viton [32]. This concept was used in a linear regression model by Abrahams [33] to estimate total air travel demand in a single market. Abrahams used the frequency delay function introduced by Eriksen [34], and the stochastic delay function introduced by Swan [35]. These two functions have the same form as those proposed by Douglas and Miller, but the parameter values are different. These models was able to capture effects of frequency and aircraft size. Eriksen and Russon and Hollingshead [36] used, functions of service frequency and aircraft size but with the terms ’level of service’ or ’quality of service’, in their models of air passenger travel demand. Hansen [37] used service frequency, fare and flight distance to specify a passenger’s utility function, and built a model for demand analysis. Norman and Strandens [38] related service frequency to the waiting time and cost of passengers, and developed a probabilistic air travel demand model assuming uniform distribution for desired departure times over a time interval. More recently, Coldren et al.[39] developed an itinerary level market share model with the help of aggregate multinomial logit methodology. Aircraft size and type, together with such variables as fares, time of day, carrier market presence, itinerary level-of-service (non-stop, direct, single-connect, or double- connect) and connecting quality, are used as independent variables.

The airport managers, government policy makers and aircraft manufacturers have been asking the questions of whether the airlines would increase the size of aircraft in their fleet, rather than the number of flights, to accommodate increasing travel demand, and how airlines' choice of aircraft size would influence demand, market share and profit.

Aaccording to Wei and Hansen [2], airlines' market share ratio changes with their capacity share ratio in two circumstances: (1) when two airlines have the same number of aircraft seats and operate with different service frequencies; (2) when two airlines operate with the same service frequency but have different number of aircraft seats. We can assume that market share ratio increases much faster with the increase of capacity share ratio resulting from fixed number of aircraft seats and varying frequency than from fixed frequency and varying number of aircraft seats.

Airlines can obtain higher returns in market share from increasing service frequency than from increasing aircraft size. Therefore, we conclude that airlines have an economic incentive to use aircraft smaller than the least-cost aircraft, since for the same capacity provided in the market, an increase of frequency can attract more passengers. We find that, it is the net number of seats available to local passengers, the product of total seat capacity and the proportion of that capacity not used by connecting passengers, that plays the most important role in airlines' market share. With the same net number of seats available to passengers, there is no significant difference in attractiveness to passengers between a smaller aircraft with higher percentage of seat availability and a larger aircraft with lower percentage of seat availability. While passengers may prefer larger aircraft in the market for such reasons as comfort, amenity and security, we did not observe this effect here. Perhaps it is absorbed in the market-specific fixed effect in our estimations.

Nonetheless, Wei [3] take in consideration that the changes of airport landing fees could influence airlines' decisions on aircraft size and service frequency, and how the changes could influence airlines' profit, as well as airport congestion and delay. It is found that airlines' optimal aircraft size and service frequency are affected by landing fees, and higher landing fees will force airlines to use larger aircraft and less frequency, with higher load factor for the same number of passengers in service. It is also found that airlines will be better off if some of the extra landing fees are returned to airlines as a bonus for airlines using larger aircraft and consequently contributing to airport congestion alleviation.

3.1.2 Route networks

There are two most common types of route networks: point-to-point and hub-and-spoke. In the hub-and-spoke network airports are partitioned in two sets, called hubs and spokes. Most spoke airports are served from only one hub and hubs are connected by regular flights, as we can see from Mmia [40] and Szczerba, Galkowski, Glickstein and Ternullo [41]. A big percentage of the airlines operate hub-and-spoke networks, which is considered to be the most cost effective way of linking a large number of destinations. A common passenger itinerary in the hub-and-spoke network is composed by two or three legs.

According to Kohla, Larsenb,Larsenc,Rossd and Tiourinee [4], low cost airlines favour point-to-point networks. These networks directly link economically attractive pairs of destinations, providing little or no connecting possibilities. The main challenge, however, is to manage resources across the network to reduce impact of smaller disruptions, like aircraft unavailability or crew sickness. From the passengers perspective, frequent flights with small aircraft are ideal but the congested airspace, limited capacity at major airports and operational costs suggest increased use of larger aircraft.

3.1.3 Price policy

In this section we take in consideration the problem of tichet pricing in the airline industry. Different strategies such as pricing strategy, customer acceptance probability strategy and factors such as customer arrival rates and arrival distribution were considered. As stated by Joshi [5], initially the pricing policy for a single flight leg was developed. Three different pricing strategies namely time remaining, seats remaining and their combination were developed. Also, customer behavior such as probability of acceptance based on price offered and the time remaining to depart was investigated and after the simulation models for three different customer arrival rates they arrived at these conclusions:

- For a tourist destination where the probability of acceptance was based on price, the pricing according to seats remaining was the optimal policy. This policy gave a lower average ticket price and higher revenues thus benefiting both the customer and the airline.
- For a business destination where the acceptance probability was based on time, pricing according to time remaining generated the most revenue.
- For a mixed type of destination where the acceptance probability was based on both time to depart and the price offered, the pricing according to both seats remaining and time remaining outperformed all the other strategies.

Furthermore, as also stated by Carvalho and Puterman [42], we have two main strategies, the first, for the pricing of direct and indirect flights was cheapest at the beginning of the booking period and finish with the last ticket sold at the maximum price. The second strategy was the contrary path with the indirect flight sold at the maximum price in one first moment of the booking period and the price reducing there after, done to discourage the selection of indirect flights at the beginning in the booking process. The first strategy always perform better than the second strategy in terms of revenue generated with a significant difference for the arrival pattern resembling a business destination and insignificant for arrival patterns for the tourist and mixed destinations.

3.1.4 Maintenance

Aircraft maintenance checks are periodic inspections that have to be done on all commercial/civil aircraft after the appointed time or usage; military aircraft normally follow specific maintenance programmes which may or may not be similar to those of commercial/civil operators. Airlines and other commercial operators of large or turbine-powered aircraft follow a continuous inspection program approved by the Federal Aviation Administration (FAA) in the United States [6] or the European Aviation Safety Agency (EASA). Under FAA oversight, each operator prepares a Continuous Airworthiness Maintenance Program (CAMP) under its Operations Specifications, according by FAA in the [7]. The CAMP includes both routine and detailed inspections. Airlines and airworthiness authorities provides detailed inspections as 'checks', that could be of four types : A check, B check, C check, or D check. The main distinction are that A and B checks are lighter checks, while C and D are considered heavier checks.

As stated by the source [8] and also all the previous documents, we give a brief explanation of the main points of each check:

A check :The actual occurrence of this check varies by aircraft type, the cycle count (takeoff and landing is considered an aircraft "cycle"), or the number of hours flown since the last check. This is performed approximately every 500-800 flight hours or 200-400 cycles. It needs about 20-50 man hours and is usually performed overnight at an airport gate or hangar. The occurrence can be delayed by the airline if a series predetermined conditions are met.

B check : Almost the same occurrence schedule applies to the B check as to the A check. B checks may be incorporated into successive A checks. This is performed approximately every 4-6 months. It needs about 150 man-hours and is usually performed within 1-3 days at an airport hangar.

C check : This maintenance check is much more longer, in time operation, than a B check. This because a large number of aircraft components have to be in-

spected. According to Gopalan and Talluri [51] and the last source [8] this check leaves the aircraft out of service until it is completed the aircraft must not move out from the maintenance site. It also requires more space than A and B checks-usually a hangar at a maintenance base. The time needed to complete such a check is generally 1-2 weeks and the amount of work involved can require up to 6000 man-hours. The schedule of occurrence has many factors and components as has been described, and thus varies by aircraft category and type.This is performed approximately every 20-24 months or a specific amount of actual flight hours (FH) or as defined by the manufacturer.
D check : This is the most comprehensive and demanding check for an airplane. It is also known as a 'heavy maintenance visit' (HMV). This check occurs approximately every 6 years. It is a check that, takes the entire airplane apart for inspection and overhaul. Such a check can need up to 50,000 man-hours and it can usually take up to 2 months until the ending. This is in according to the aircraft and the number of technicians involved. It also requires the most space of all maintenance checks, and as such must be performed at a suitable maintenance base. Given the elevated requirements of this check and the tremendous effort involved in it, it is more expensive maintenance check then all the others. As a consequence of the cost of such a check, most airlines - especially those with a big fleet - have to plan D checks for their aircraft years in advance. Often, older aircraft being phased out of a particular airline's fleet are either stored or scrapped upon reaching their next D check, due to the high costs involved in comparison to the aircraft's value. Generally, a commercial aircraft undergoes 2-3 D checks before it is retired.

3.1.5 Organization of operations control

Most large airlines operate operation control centers (OCC) to perform on-the-day coordination of schedule execution. Their purpose is to monitor the progress of operations, to flag actual or potential problems, and to take corrective actions in response to unexpected events. Representatives of key airline functions work together, like for Chang, Howard, Oiesen, Shisler, Tanino and Wambganss [43], to ensure smooth schedule execution. According also to Kohla, Larsen, Larsenc, Rossd and Tiourinee [4] the most common support roles in airline operations control are:

- Flight dispatch and following: The flight dispatcher shares responsibility for flight safety, follows preparation and progress of a number of flights and raises alerts with other areas when problems occur. In Europe, the aircraft control role usually performs the task of flight following, while flight planning and dispatch is often performed outside of the operations control area.

- Aircraft control: Besides managing the aircraft resource, this is often the central coordination role in operations control. In Europe it is divided in long and short haul, in North America the most common division is according to geographical regions like North West, South West, etc.
- Crew tracking: The crew-tracking role is responsible for the staffing of flights. Crew check-ins must be monitored and crew pairings must be changed in case of delays or cancellations. The stand-by crew resource must be dispatched and perhaps reserve crew must be called in. In most airlines crew tracking is divided into cockpit and cabin crew.
- Aircraft engineering: Aircraft scheduling is responsible for unplanned service and maintenance of the aircraft as well as the short-term maintenance scheduling. Changes to the aircraft rotations may impact on short-term manteinance.
- Customer service: Decisions taken in the OCC will typically affect passengers. The responsibility of the customer service role in the OCC is to ensure that passenger inconvenience is taken into consideration in these decisions. Delays and cancellations will affect passengers who need to be informed and in some cases rebooked or provided with meals or accommodation item Air traffic control (ATC) coordination: The ATC role is not a part of the OCC as it is common for all airlines and operated by a public authority, for example the Federal Aviation Administration (FAA) in the US and EuroControl in Europe.

3.1.6 Flight scheduling

Fleet routing and flight scheduling are two critical activities in airline operations. In particular, they always affect aircraft usage efficiency, establishment of timetables, aircraft maintenance and crew scheduling. As a result, according to Yan and Tseng [9] they are essential to a carrier's profitability, its level of service and its competitive capability in the market. The flight scheduling process typically consists of two dependent phases: (a) the schedule construction phase and (b) the schedule evaluation phase. For the last paper [9], the construction phase is accomplished by editing a timetable according to the projected demand, the market share, and the time slots of the available airports. After this, the draft timetable is then reviewed during the schedule evaluation phase for operating feasibility, cost and performance considerations. The feasibility checks in this evaluation phase mainly include the fleet routes, fleet size, crew scheduling, and maintenance arrangements. Any improvements identified during this phase are requested to be fed back into the construction phase to further revise the draft timetable. As stated by Etschmaier and Mathaisel [44] also, the flight scheduling process iterates between these two phases until a desirable timetable is obtained.

The three main elements used to provide an air service are crew, aircraft and passengers and they must be planned and monitored to obtain operational efficiency. Crew scheduling consist of two problems: crew pairing and crew rostering. In the crew pairing phase, anonymous pairings (trips), starting and ending at a home base, are constructed. In total, as said by Kohla, Larsenb, Larsenc, Rossd and Tiourinee [4], the pairings must cover all positions to be covered in the flights defined by the timetable. Every change to the timetable (e.g. cancellation, flight retiming, or aircraft fleet type change) must be feasible for crew as well as aircraft and should minimize passenger inconvenience.

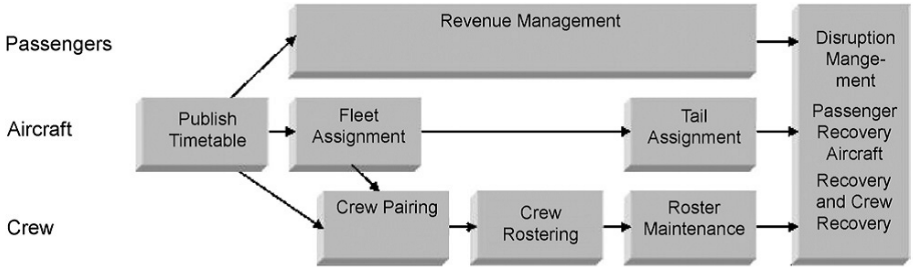


Figure 3.2: A simplified illustration of the scheduling of passengers, aircraft and crew [4].

3.1.7 Delay Maintenance

Scheduling the maintenance activities at Line Maintenance combines the information from health assessment procedures with the data available related to the flight operations, the maintenance costs, the maintenance resources availability and the overall maintenance programme in order for the most efficient maintenance schedule, according to the operator's maintenance policy, to be generated. According with Chyssolouris [45] and Chyssolouris, Lee and Dicke [46], a decision should be made for the aircraft's maintenance tasks, are:

- identify required maintenance tasks;
- determine decision criteria and weights for evaluating alternatives (maintenance plans);

- form alternatives (maintenance plans);
- determine the consequences of the different alternatives and their utility.

Papakostas, Papachatzakis, Xanthakis, Mourtzis and Chyssolouris [10] say that when the aircraft arrives at the airport, the line maintenance process is initiated, including maintenance data acquisition, aircraft status assessment as well as maintenance decision tasks to be executed.

An important criterion during the decision making process is the one related to the flight delay. It is important that the aircraft leave on time, or in case there is a delay, to be the least possible. A delay measure is used for assessing the alternatives' performance in terms of the aircraft delay due to a maintenance action.

3.1.8 Disruption management

From the book of European Air Management edidted by Andrew Cook [54], we know that the process of monitoring and scheduling the resources close to the day of operations was called Disruption Management or operations control. According also with Kohla, Larsenb, Larsenc, Rossd and Tiourinee [4], we know that a disruption situation originates in a local event such as an aircraft maintenance problem, a flight delay, or an airport closure. Ideally, most disruptions should also be resolved locally using resources directly affected by the event and within the timeframe of the event itself. In reality, disruptions tend to extend far beyond the events that originated them. All airlines try to anticipate the unexpected and to build some flexibility into their schedules. This flexibility can be used in recovering from unexpected events.

In the next chapters we focus the attention especially on the disruption management in the aircraft industry. We will investigate the cause and how to solve the problem with algorithms already existing.

Chapter 4

Planning Operation

The planning of flight and cabin crew is slightly different. For both crew groups individual flights are grouped to form pairings. Each pairing starts and ends at the same crew base. These pairings are anonymous. Afterwards, pairings are grouped to form rosters for a given person. In bidline rostering occasionally used for flight crew scheduling the pairings are grouped together to form anonymous rosters. The crew members then bid for these anonymous rosters, where usually senior crew members are favoured when assigning rosters to crew. Rosters are typically lines of work for 14 days or 1 month. Finally, as for Auguello, Bard and Yu [47], physical aircraft from a given fleet are assigned to flights in the tail assignment process. The complete process is illustrated in Figure below.

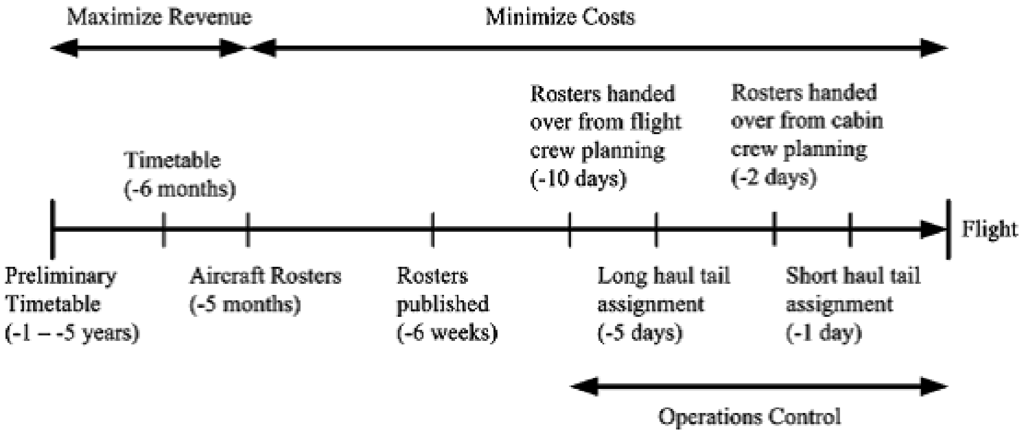


Figure 4.1: The time-line for the daily operation of an airline [11].

The main goal of the aircraft and crew scheduling process is cost minimization. Constructing such a plan is in each case complicated as for aircraft maintenance rules have to be taken into account, the right capacity must be at the right place at the right time, and the characteristics of each individual airport have to be respected. For crew, there are regulations on flying time, off-time etc. based on international and national rules, but also regulations originating in agreements with unions, local to each airline. After the planning, according to Abdelganhny, Elkollu, Narisimhan and Abdelganhny [48] and Ageeva [49] phase follows the tracking phase, where changes in plans due to e.g. crew sickness, aircraft breakdowns, and changes in passenger forecasts are taken into account. This phase normally resides with the planning department. The plans for aircraft assignments, crew assignments and maintenance of the flight schedule is handed over from the planning department to the operations control centre (OCC) a few days days ahead of the day of operation. The deadlines are different for different resources. Short-haul plans are usually handed over one day ahead of the operation date, while long-haul information is handed over three to five days before.

As the plan is handed over, it becomes the responsibility of OCC to maintain all resources so that the flight plan seen as an integrated entity is feasible, as mentioned by Anderson [50]. Events like crew sickness and late flight arrivals have to be handled. Furthermore, not only the immediately affected flights but also knock-on effects on other parts of the schedule can cause serious problems. The common practice in the industry of planning flight crew, cabin crew and aircraft separately reinforces the problem.

Generally,, as say Clausen, Larseny and Larsenz [11], a disrupted situation (often just denoted a disruption) is a state during the execution of the current operation, where the deviation from the plan is sufficiently large to impose a substantial change. This is not a very precise definition, however, it captures the important point that a disruption is not necessarily the result of one particular event. To produce recovery plans is a complex task since many resources (crew, aircraft, passengers, slots, catering, cargo etc.) have to be re-planned. When a disruption occurs on the day of operation, large airlines usually react by solving the problem in a sequential fashion with respect to the problem components: aircraft, crew, ground operations, and passengers. Infeasibilities regarding aircraft are first resolved, then crewing problems are addressed, ground problems like stands etc. are tackled, and finally the impact on passengers is evaluated. Sometimes, the process is iterated with all stakeholders until a feasible plan for recovery is found and can be implemented. In most airlines, the controllers performing the recovery have little IT-based decision support to help construct high-quality recovery options. Often, as stated by Abdelgahny A.and K., Ekollu and Narisimhan [48], the controllers are content with producing only one viable plan of action, as it is a time consuming and complex task to build a recovery plan. Furthermore the controllers have little help in estimating the quality of the recovery action they are about to implement. One generally available recovery option is cancellation of single flights or round trips between two destinations. From the resourcing perspective, cancellation is ideal - it requires no extra resources, it may even result in the creation of free resources, and little re-planning is required. However, from the passenger point-of-view it is the worst option, since a group of customers will not receive what they paid for. Indeed, determining the quality of a recovery option is difficult.

4.1 Planning process

The generation of recovery plans is a complex task, since many resources (crew, aircraft, passengers, slots, catering, cargoetc.) have to be re-planned. When a disruption occurs on the day of operation. First, infeasibilities in the aircraft schedule are resolved, then crewing problems are addressed. Afterwards, ground problems are tackled, and finally, the impact on passengers is evaluated by Clausena, Larsenb, Larsena and Rezanova [12]. Towards efficiency enhancement, Yan and Young [20] developed a decision support framework for multi-fleet routing and multi-stop flight scheduling. This framework was composed primarily of several strategic models which took account of a given draft timetable, a set of available airplanes, the airport slots, the airplane rental charges, and other cost data as basic input, so as to effectively solve for maximum profit.

In addition to Yan and Young's study [20], there have been several types of airline scheduling models developed in these years, such as Abara's [21] integer linear programming model for fleet assignment with fixed flight departure times, Teodorovic and Krcmar-Nozic's [22] multicriteria model for deciding on flight frequencies under competitive conditions, the Balakrishnan et al. [23] mixed integer program model for long-haul routing, the Hane et al. [24] multicommodity network flow model for solving daily aircraft routing and scheduling problem (DARSP) without departure time window.

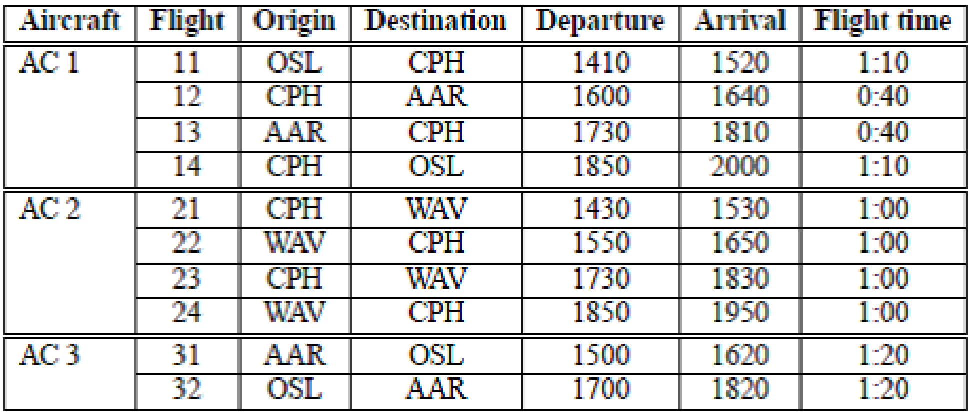
Sometimes, the process is iterated with all stakeholders until a feasible plan for recovery is found and can be implemented. Establishing the quality of a recovery option is a difficult duty. The objective function can be composed of several conflicting and sometimes non-quantifiable goals.

4.1.1 Models for airline optimization problems

Most of airline recovery models are formulated and solved similar to the corresponding planning problems, using the same network representations to model the schedules. Nonetheless, there are also some differences between the modelling approaches. In order to make a confrontation between recovery models and optimization problems occurring during the planning phase, we need to present the aircraft routing and the crew scheduling problem formulations, as well as their differences from the recovery models.

4.1.2 Network representations

The three most commonly used network representations for airline planning and recovery problems are time-line networks, connection networks and time-band networks. In order to illustrate the networks, consider a small flight schedule of an artificial airline Sample Air shown in Figure 4.2, where flights connecting Copenhagen (CPH), Oslo(OSL), Aarhus(AAR), and Warsaw(WAV)are given. Assume that the turn-around-time for an aircraft is 40 min in CPH and OSL and 20 min in AAR and WAV.



Aircraft	Flight	Origin	Destination	Departure	Arrival	Flight time
AC 1	11	OSL	CPH	1410	1520	1:10
	12	CPH	AAR	1600	1640	0:40
	13	AAR	CPH	1730	1810	0:40
	14	CPH	OSL	1850	2000	1:10
AC 2	21	CPH	WAV	1430	1530	1:00
	22	WAV	CPH	1550	1650	1:00
	23	CPH	WAV	1730	1830	1:00
	24	WAV	CPH	1850	1950	1:00
AC 3	31	AAR	OSL	1500	1620	1:20
	32	OSL	AAR	1700	1820	1:20

Figure 4.2: A sample schedule for Sample Air with aircraft rotations [11].

A node designates an airport at a specific time, while an arc represents an activity, such as a flight leg, a ground-holding, or an overnight stay. The arc flows express the flow of airplanes in the networks. Three types of arcs are defined below, as for Yan and Tseng [9]:

- A *flight leg arc* represents a flight connecting between two different airports. Each flight leg arc contains information about the departure time, the departure airport, the arrival time, the arrival airport, and the operating cost. The time block for a flight leg is calculated from the time when the airplane is prepared for this flight leg to the time when this flight leg is finished.

- A *ground arc* represents the holding or the overnight stay of airplanes at an airport in a time window. The arc cost, including the airport tax, airport holding (or overnight stay) charge, gate use charge and other related cost, denotes the expenses incurred for holding an airplane at an airport in the corresponding time window.
- A *cycle arc* functions to show the continuity between two consecutive planning periods. It connects the end of one period to the beginning of the next period for each airport.

Therefore, we can examine the model presented by Clausena, Larsenb, Rezanova and Larsena [12], where a node i, representing the flight leg l_i , is connected by a directed edge(i, j) to a node j, which represents the flight leg l_j , if it is feasible to fly l_j immediately after li using the same aircraft with respect to turn-around-times and airport. In addition, there is a set of origin and destination nodes indicating possible positions of aircraft in a fleet at the beginning and at the end of the planning horizon, respectively. A path in the network from an origin to a destination node corresponds to a sequence of flights feasible as part of a rotation. Schedule information is not represented explicitly in the network, but is used when generating the nodes in the network. Maintenance restrictions can be easily incorporated through the concept of a maintenance feasible path, which is a path providing sufficient extra time with the required intervals at a node corresponding to a station, where maintenance can take place. Note that the number of feasible paths may be very large-it grows exponentially with the planning time horizon. The Sample Air flight schedule represented as a connection network is shown in Fig.4.3.

A time-band network is proposed by Arguello [25], in order to model the aircraft schedule affected by disruptions, an disused in the context of aircraft recovery. The network can be constructed dynamically as disruptions occur, for a certain recovery time period. There is a set of station-time nodes and a set of station-sink nodes. A station-time node represents activities at a particular airport aggregate within a certain discrete time interval, called a time band. The time label of a station-time node corresponds to the availability time(the arrival time plus the turnaround time)of the first available aircraft in the time band. A station-sink nodes represent the end of the recovery period at each station. The edges in the network represent the flights. A scheduled flight from station A to station B has an emanating edge fore ach A-time node, in which there is an aircraft available, and for which the flight can be flown with in there covery period. Each of these edges will end in the B-time node corresponding to the time when the

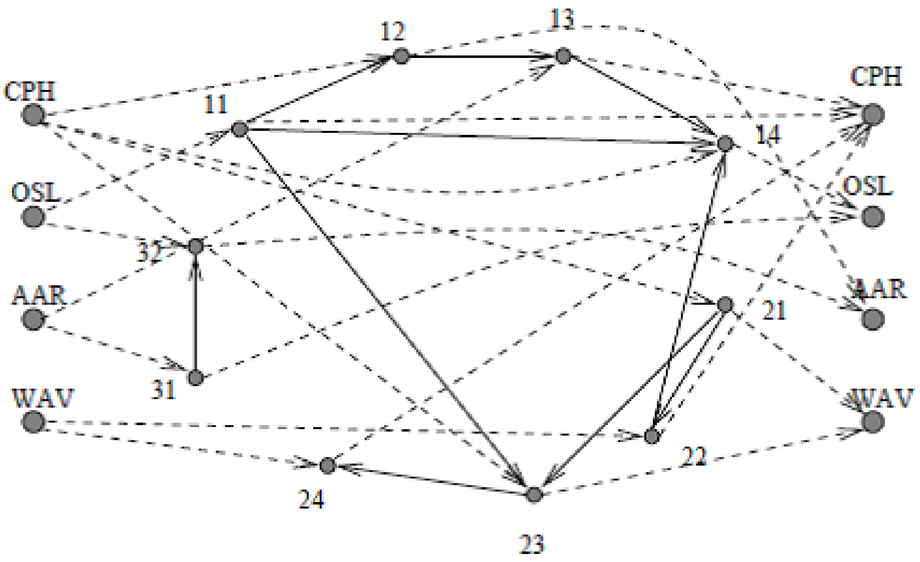


Figure 4.3: The sample schedule shown as a connection network. The rotation for AC1 corresponds to the path OSL-11-12-13-14-OSL [12].

aircraft becomes available at B. The number of emanating edges is the same for all station-time nodes corresponding to the same station. Finally, there are edges connecting each station-time node to the station-sink node for the relevant airport, as said by Clausen and Larsenz [11]. A recovery solution corresponds to a flow in the network. Edges of the originally scheduled flights, which carry no flow, correspond to cancelled flights, and retimins of flights correspond to the flow on the 'new' flight edges, indicating that flights are flown at a later time than scheduled. Fig. 4.4 shows the time-band network model for the Sample Air schedule, where aircraft AC2 is out of service from 14:00 to 21:00 due to an unexpected maintenance, and with time bands of 30 min. The network is constructed in a step wise fashion in order to avoid generating time-station nodes with no aircraft availability. As for Clausena, Larsenb, Larsena and Rezanova [12], two flows in this network, one starting in OSL and another in AAR, and ending in either OSL or AAR, determine the way to use the two remaining aircraft, AC1 and AC3.

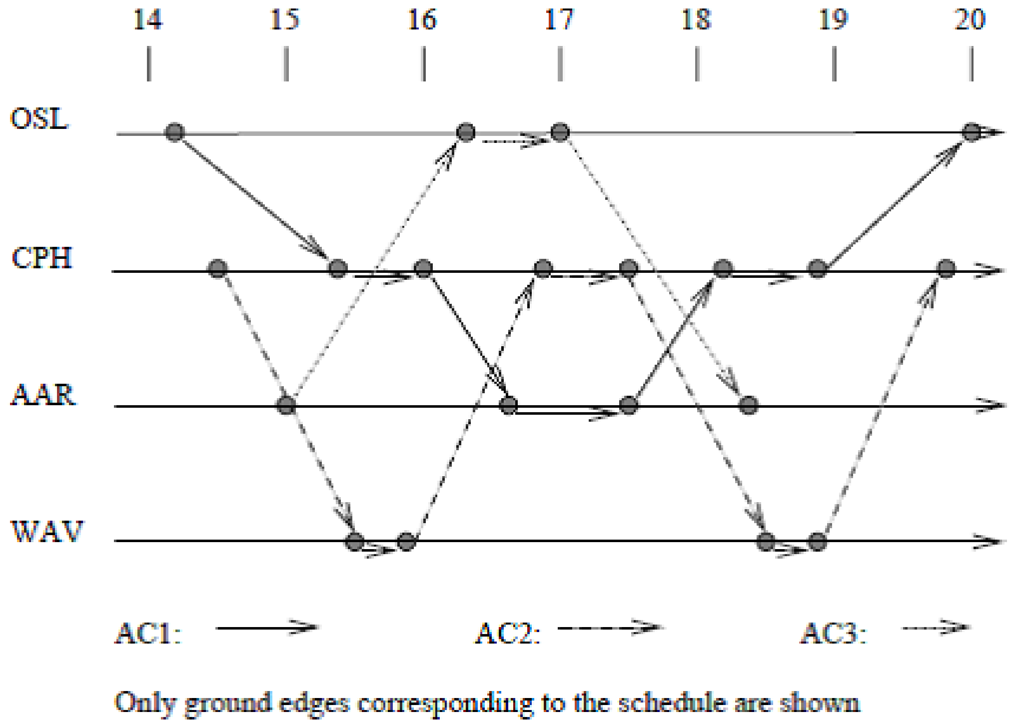


Figure 4.4: The sample schedule shown as a time-line network. The rotation for AC1 corresponds to the AC1 path [11].

4.2 Aircraft routing

An aircraft routing problem (also called aircraft rotation problem) determines the optimal set of routes flown by all aircraft in a given fleet, given that the fleet assignment is already performed. There are two general formulations of the aircraft routing problem: a set partitioning model and a multicommodity network flow model. The connection network and the time-line network can both be used to represent the schedule. In a multicommodity network flow formulation of the aircraft routing problem non-negative integer decision variables x_{ij} represent the flow on arc(i, j) of the network, each unit of flow representing one aircraft in a given fleet, by Barnhart, Boland, Clarke, Jonhson and Nemhauser [26]. Flow balance constraints of the problem at each node of the network ensure that each flight legis covered by exactly one aircraft and that the balance of grounded aircraft at each station is ensured. This also ensures that the number of rotations in the network is less than or equal to the number of aircraft in a given fleet. The aircraft routing problem can also be formulated as a set partitioning problem. Let F be these to favailable aircraft in a fleet. For each aircraft $f \in F$, an origin of and a destination df relative tothe planning horizon is given. Given a connection network with a set of flight nodes N, origins of and destinations df , Pf denotes the set of feasible paths between of and df in the network. If maintenance is to be taken into account, only maintenance feasible paths are considered by Clarke, Johnson, Nemhauser and Zhu [27]. The relations between the flights and the paths are given by binary parameters a_{ip}, which are equal to one if flight leg i is on path p. To determine which aircraft are to fly the scheduled flights, we define binary decision variables x_p^f, which are equal to one if and only if the flight legs on the path p with cost cfpare flown by aircraft, as said Clausena, Larsenb,Larsena and Rezanova [12]. The constraints of the problem ensure that each flight legis contained in exactly one of these lected paths, and that only one path must be chosen for each aircraft: Minimize

$$\sum_f \sum_p c_p^f x_p^f$$

subject

$$\sum_f \sum_p a_{ip} x_p^f = 1, \forall i \in N$$

$$\sum_p x_p^f = 1$$

$$x_p^f \in (1,0), \forall f \in F, p \in P^f$$

The aircraft recovery model can be formulated similar to the above aircraft routing problem, with extra binary decision variables determining if flight f is to be cancelled or not in the recovery solution, and expressing the costs of delays and cancellations in the objective function Clausen and Larsenz [11].

4.3 Crew scheduling

On passenger aircraft there are two types of crew: flight (cock- pit) crew responsible for flying the aircraft and cabin crew who service the passengers. Each of the crew groups are further divided by rank. A crew will typically get a plan of work for a period of two or four-week. The task of assigning crew to itinerariesis is generally very complex. It is there for esplit into two stages: crew pairing and crew assignment, also known as crew rostering, by Hoffman and Padberg [29]. Both the problems are usually formulated as generalized set partitioning or set covering problems with one constraint for each task to be performed. In the **crew pairing** problem the task is a flight to be covered and in the **crew assignment** problem the task is a pairing/other work to be covered. For an clear description of airline crew scheduling problems and solution methods refer to Barhnart et al. [26], the objective of the crew pairing problem is to find a minimum cost sub set of feasible pairings such that every flight is covered by exactly one selected pairing. Let F be the set of flights to be covered and P the set of all feasible pairings. Decision variable y_p is equal to one if pairing p is included in the solution and zero otherwise. The relation between pairing p and flight i is given by a parameter a_{ip}, which is equal to one if p contains i and zero otherwise by Klincewicz and Rosenwein [28]. The cost of a pairing is denoted c_p and includes allowances, hotel and meal costs, ground transport costs and paid duty hours. Minimize

$$\sum_p c_p y_p$$

subject to

$$\sum_p a_{ip} y_p = 1, \forall i \in F, y_p \in (1,0), \forall p \in P$$

Generation of pairings can be done using one of the two network representations presented earlier: the flight connection network, mainly used for domestic and short-haul operations, or the duty time-line network, mainly appropriate for international and long-haul operations. A pairing is a way from the source to the sink, usually represented by crew bases. However, not all paths represent legal pairings since duty rules, like maximum flying hours, etc., are not explicitly expressed in the network. These rules must be checked for each way in order to ensure legality. In order to solve the crew pairing problem one possibility is to construct all legal pairings. The challenge is that the number of legal pairings can be really large, typically varying from 500,000 for a minor airline to billions of pairings for major airlines. For smaller problems all legal pairings can be generated a priori by Barnhart et al. [30]. For larger problems, a limited a priori generation can be used as a heuristic, finding a good solution without guaranteeing optimality. Another approach is to generate the pairings as they are needed in a dynamic column generation process. The problem of generating the pairings then becomes a variant of the shortest path problem. The crew assignment, or better know as rostering, problem is solved for each crew type, i.e. captain, first officer, etc. Each crew member should be assigned to exactly one work schedule, while each pairing from the crew pairing solution must be contained in the appropriate number of selected work schedules, depending on how many crew members of each type are required for a given pairing of Clausen and Larsenz [11]. Let K be the set of crew members of a given type and let P be the set of pairings to be covered. For each crew member k the set of feasible work schedules is denoted S_k. n_p is the minimum number of crew members needed to cover pairing p and γ_p^s is equal to one if pairing p is included in schedule s and zero otherwise. c_s^k is the cost of schedule s for crew k. Decision variables are x_s^k, taking the value of one if schedule $s \in S_k$ is assigned to crew $k \in K$ and zero otherwise. Minimize

$$\sum_k \sum_s c_s^k x_s^k$$

subject to

$$\sum_k \sum_s \gamma_p^k x_s^k \geq n_p, \forall p \in P$$

$$\sum_s x_s^k = 1, \forall k \in K$$

$$x_s^k \in (0,1), \forall s \in S_k, k \in K$$

The network representation for the crew rostering problem is similar to the pairing problem, but instead of defining a way of flights as in the pairing problem the path consists of pairings. The problem can be solved with the same solution methods as the crew pairing problem, e.g.column generation.
Crew scheduling is an extremely complicated task, Hoffman and Padberg [29] describe a Branch-and-Cut optimizer for solving both pure Set Partitioning Problems originating from crew scheduling and crew scheduling problems, which include other types of constraints specifying. The optimizer takes as input a very large set of columns each corresponding to a feasible crew rotation (roster).
According with Kohl and Karisch [130], the most important aspects of the airline crew rostering problem are here described and the figure below provides a graphical representation of crew rostering catered to the different problem types described.

The input for a crew rostering problem consists in general of crew information, activities to be rostered, rules and regulations, and objectives for the creation of the rosters. When producing personalized rosters, each crewmember personal records, qualifications, pre-assigned activities, and vacation days are given. The records usually contain accumulated attributes such as hours flown during the current calendar year. Personal qualifications contain for instance information about the equipment the crewmember can operate or a list of destinations the crewmember cannot fly to. For cabin crew, language proficiency is an important qualification for international flights. Pre-assigned activities could be training, office duties or medical checks. The set of activities which are to be assigned consists of pairings, reserves , ground duties, and training activities. In the bidlines approach, only pairings and reserve blocks are usually considered as input. In the following, we will refer to the activities as tasks when they are assigned to an individual.

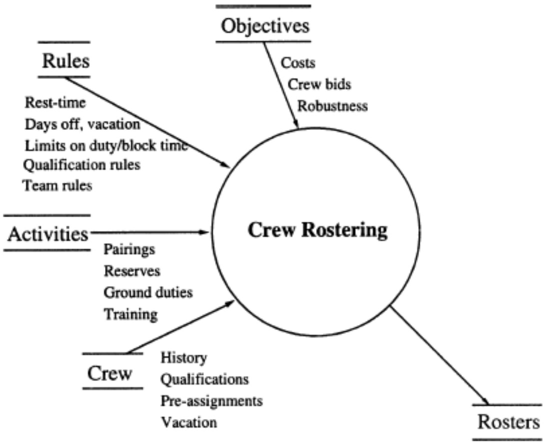


Figure 4.5: Representation of the airline crew rostering problem.[130].

The crew recovery problem formulations presented in the Operations Research literature are similar to the crew scheduling models, but often other decision variables are added, representing the decisions to be taken in order to recover disrupted situations, according to Klincewicz and Rosenwein [28]. For instance, a binary decision variable zi can determine if flight leg i is cancelled or not,or an integer decision variables i can decide the number of crew dead heading(flying as a passenger for repositioning reasons) on flight leg i. By introducing a cost in the objective function corresponding to decision variables responsible for recovery and adding the variables to the problem constraints, an optimal rescheduling solution can be found with respect to the objectives specified for recovering a particular disruption.

The idea of a time-line network is to represent the possible schedules in a natural way from the time-and-station point of view, which is not possible when using a connection network. A time-line network has a node for each event, an event being an arrival or a departure of an aircraft at a particular station. Time-line networks are activity-on-edge networks, where directed edges correspond to activities of an aircraft, and schedule information is represented explicitly by the event nodes. All event-nodes of a particular station are located on a time line corresponding to that station. The length of the time line corresponds to the planning horizon. There is a directed edge from one event-node to another, if the two events may follow each other in a sequence in a schedule of the same aircraft. Edges connecting nodes on the time lines for different stations correspond to flights feasible with respect to flying time, while edges connecting nodes on the time line for a particular station correspond to grounded aircraft, according to Hoffman and Padberg [29]. In the same way as for the connection network, a direct path is possible rotation for an aircraft. The time-line network for Sample Air is shown in Fig. 4.4. Notice that ground arcs that are not used in the aircraft schedule presented in Table 1 are omitted from the network for simplicity. When network representations are used in the recovery context, a network is usually built for shorter time periods, beginning at a time of disruption and limited by the time when the schedule is expected to be recovered. The source nodes in the network represent the exact positions of the aircraft at the time of disruption, while the sink nodes represent the expected positions of the aircraft at the end of the recovery of Clausena, Larsenb, Larsena and Rezanova [12]. The schedules within the recovery time window are then re-planned in order to repair infeasibilities caused by disruptions, while the schedules outside of the recovery time window are not changed.

Chapter 5

Delay

In airline traffic disruptions take place quite often and cannot be completely avoided. They carry to impraticable aircraft and crew schedules during the day of operations. One consequence of delays are additional, that are reactionary delays that take place when the operations control changes the departure of the flights, owing to late aircraft and crews. As stated by Duck et al. [52], we recognize two kinds of delays. On one side, there are primary delays, which cannot be influenced by the airline operations control, due e.g. to instructions of air traffic control. Reactionary delays on the other side, take place owing to actions of the airline operations control, such as the instruction to wait for a late aircraft or alternatively taking another one. In case of primary or reactionary delays leading to impraticable schedules, those schedules have to be reorganised. The process of generation of new schedules is called rescheduling or disruption management. One example of that can be Clausen et al. [53] for a global review on concepts and models for rescheduling of airline resources. The short-term rescheduling actions usually suggest additional costs meaning that overall the operational costs of a crew schedule can be obviously higher than the original planned costs.

Delays are always wrong things for the airlines because the cost of delay, according to Cook [54], hits airlines in two different ways: the 'strategic' cost of delay in the contingency planning of a schedule and the 'tactical' cost of delay during the day of operations. Both of these types of costs are concrete and quite often heavy. In airline trade the cost of passenger delay may be classified as either a 'hard' or 'soft' cost. Hard costs are due to factors as passenger rebooking, compensation, and care. Soft cost are more hidden, but the major cost components of airline delay like delayed passengers, crew, maintenance, fuel, and future emissions charges, may be dominated by passenger soft costs (Cook et al.[56]; Cramer and Irrgang).

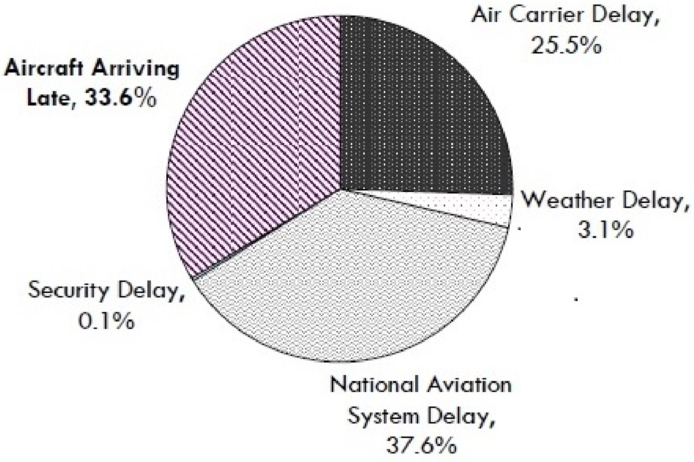


Figure 5.1: Delay causes among all major U.S. airports in November 2007. Source: Bureau of Transportation Statistics.[55].

Airline delays have increased in the past 5 years, according to Cohn and Lapp [55] and the cost impact of these delays is significant, including surplus for the fuel costs, overtime salary for crew members, costs associated with re-accommodating misconnecting passengers, as well as the lost productivity of delayed passengers. Moreover, the Air Transport Association has estimated that there were a total of 116.5 million delay minutes in 2006, resulting in a $7.7 billion increase in direct operating costs to the U.S. airline industry, as shows the table below.

There are many reasons for flight delays, such as mechanical problems, weather delays, ground-hold programs, and air traffic congestion. But the secondary delays that propagate from such root delays are also quite substantial. As stated by Cohn and Lapp [55] and [57] and Cook et al. [56], it is important the trading off between planned costs and operational costs. Given two different plans with different planned costs, it is difficult to define which of the two plans will perform

Direct operating costs (2006)	Annual delay costs	$ per Minute ($ millions)
Fuel	28.31	3,296
Crew	14.25	1,659
Maintenance	10.97	1,277
Aircraft ownership	9.18	1,069
Other	3.1	361
Total	65.80	7,663

Table 5.1: Direct costs of delays in the U.S. airline industry [57].

better operationally. Furthermore, it is difficult to determine whether improvements in operational performance outweigh increases in planned costs, given that the plan will be operated several times (often, daily) over the planning horizon, and that potential disruptions may or may not occur during any given day.

It is suggested to originate a method that does not increase planned costs, but can improve the operational performance. It possible to modify flight departure times so as to re-allocate the existing slack in the network. By re-timing flights, slack can be re-distributed to those flight connections that are affected by disruption and thereafter delay propagation. The flight re-timings are restricted such that crew pairings remain feasible and do not change in cost.

Finally, maintain the same aircraft rotations is fundamental. According to the computational results of Cohn and Lapp [55], based on data from a major U.S. carrier, demonstrate that this approach leads to notable improvements in expected delay propagation without any linked increase in planned cost.

5.1 Punctuality

The air transport industry neglects shorter delays, for shorter delays counting departure and arrivals no later than 15 minutes, compared with the schedule, are on time. In general transport context, passengers are not interested of scheduled arrival and departure times because the trend is to neglect small delays(Bates et al.[19]).
Moreover, according to Cook [54], air transport works within margin of tolerance with respect to timing. At airport, it is normal to have from five to ten flights scheduled to depart or arrive at the same time, this is physically not possible due to the limited capacity of the airport. 15 minutes of short delay may be insignificant from the viewpoints of the passenger, but it could be more significant if it generate a missed connection. There are three main level of coordination for the

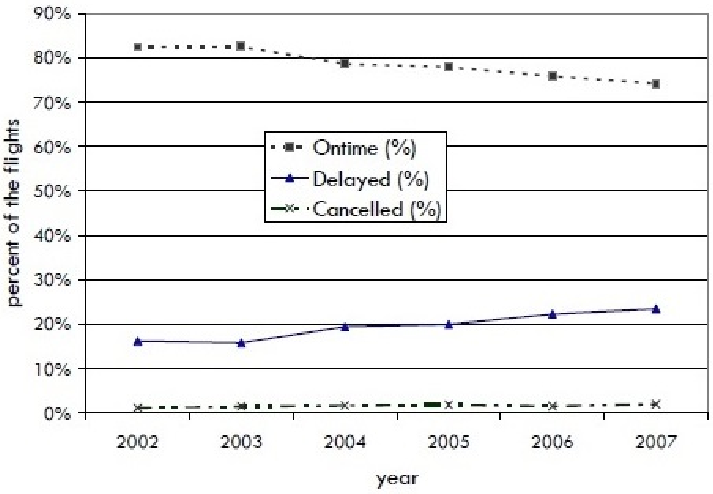


Figure 5.2: The increasing trend in delayed flights. Source: Bureau of Transportation Statistics[57].

airports congestion, as says the Cook [54] and the airport slot time is usually the same as the time in the airline's schedule. Airlines have windows of opportunity for mitigating against, and managing, delay costs, as illustrated below:

According to Forbes [59], the flight delays to airline prices may come from two sources. First, demand shocks that are observable to the airline and to users but unobservable to the research could lead to a positive correlation between flight delays and prices because not only prices, but also the number of flights and, as a result, flight delays may respond positively to an increase in demand. Second, the existing literature on hub networks also suggests a positive correlation between air traffic delays and ticket prices. While Mayer and Sinai [105] find that flight delays are significantly longer at hub airports than at nonhub airports, Borenstein [106] and Evans and Kessides [107] demonstrate that airlines charge higher prices at their hubs and at more concentrated airports.

As mentioned by Cook et al. [60], there are some cases where the flights are de-

Phase	Description	Example
Strategic	Resources committed at planning stage: advance contingency for delays	Buffers in schedules: large enough to absorb tactical delays, but without overcompromising utilisation of aircraft/crew
Predeparture	Slot management process. (Also decision point for fuel uplift.)	Re-route: accepting/filing a longer route to bring a departure slot forward
Airborne	Speed/route adjustment; depends on: ATC, weather, fuel uplifted	Change of cost index1; request to ATC for change to filed plan
Postflight	Aircraft, crew and passenger delay recovery	Re-booking delayed passengers. (Potential of associated ’soft’ costs.)

Table 5.2: Delay cost management by phase of flight [58].

layed over a passenger’s tolerance limit are likely to shift the realization of that service into the same category identified by Sauerwein et al.[108]. Switching operation, from one airline to another, or from a flight to a different mode or action, is a determinant of airline market share, and profitability also. There is, in any case, little evidence in the literature on how punctuality drives airline markets. Sultan and Simpson [109] have shown that Americans and Europeans concur on some aspects of service delivery priorities but differ on others. They observed that reliability is the common, most important quality aspect. Bieger et al. [110] compared service priorities for passengers flying with traditional carriers and low-cost carriers (LCCs), with punctuality being ranked similarly by both. In a stated preference survey, Teichert et al.[111] interviewed frequent-flyer programme (FFP4) members on European short-haul routes, demonstrating punctuality to be a dominating factor across the analytical segmentations. Suzuki et al.[112] modelled US domestic airline market share as a function of service quality. Some of the previous studies don’t assume unexpected change of gradient for functions modelling passenger demand as a function of service quality, it is asserted, whereas the utility function should be steeper for losses. After that they concluded that if an airline service quality falls below the market reference point, market share will decrease significantly, whereas a comparable service increase may not correspondingly increase market share. This clearly echoes Wittmer and Laesser [113].

Punctuality is a key attribute of satisfaction for many passengers. Unpunctuality may cause a reduction in market share, whereby the airline incurs a ’soft’ cost - i.e. a hidden cost which is not itemised in accounts, but impacts the bottom line. According to Cook et al. [137], flights which are delayed beyond a passenger’s tolerance limit are likely to shift the perception of that service into the ’interchangeable’ category identified by Sauerwein et al. [138]. ’Switching’ behaviour, from one airline to another, or from a flight to a different mode or action, is a determinant of airline market share, and hence profitability. Such tendencies will not only vary by market segment, but by person, by trip, and even within trip, a delayed flight with good customer service recovery could prevent the passenger from choosing a different airline next time. Airline priorities for passenger treatment will be strongly influenced by the yield from that passenger. They may also vary as a function of route and time of day, and, more rarely, time of year.

5.2 Models for calculating costs of delay

All the transport operators will employ the same inputs in the production of transport service, that are a combination of a vehicle, a driver/operative and a power source. Therefore, the outputs will be measured as function of vehicle kilometres produced as result of a combination of all the inputs. It is fundamental to take in account the division between fixed and variable factors and the associated costs have consequence on the structure of the market.

Air travelers normally make their travel plans by using published flight schedules, any arrival delay beyond the original schedule at their final-destination airports may impose so-called opportunity costs by being late to or missing business meetings, family gatherings, and the like. Roughly speaking, the passengers' costs incurred from delayed flights are estimated by the multiplication of the following three elements: (a) the amount of the flight delay (b) the number of passengers in the delayed flight, and (c) the individual air passenger's value of time. In the work of Baik et al. [131] the authors estimated and compared flight delays and corresponding delay costs by using two measurements: (a) average gate arrival delays and (b) 95th percentile gate arrival delays.

The main purpose of the buffer times is to reduce potential complaints for delayed flights. Thus, in this sense, buffer times are another type of flight delay hidden in flight schedules. This paper considers the buffer times in addition to the gate arrival delays. Another element that needs to be clearly defined is the number of air passengers on delayed flights. A landing airplane can have two types of passengers: (a) deplaning passengers sub categorized as either connecting passengers (who transfer to next flights) or arriving passengers (who arrive at their final destination airports) and (b) stopover passengers, who continue their flights without deplaning. In the paper [131], the gate arrival delay costs are imposed only on arriving passengers; they are not applied to connecting or stopover passengers and the goal of this paper is to present a procedure for estimating the flight delay cost as the variability of flight delays are considered.

It is not proper to assume that all the costs of delay are unit costs, strategic and

tactical delay are interdependent and most of the airline tries to anticipate delay in advance and strategic delay planning is used to off-set the impacts, and the costs, of tactical delays. One minute of tactical delay generates a marginal cost.
Each type of costs related to the tactical delay has its own dependencies to the time of occurrence and the duration, these marginal cost is escapable but these are in contrast to the strategic costs of managing delay. Strategic costs have the tendency to be really close to the unit cost.

Cost	Definition	Example
Unit	An average costs which is often fairly linear in the amount of good or service purchased, and based on a planned activity	Leasing aircraft at the strategic level of planning schedules. Associated with strategic management of anticipated delay.
Marginal	An extra cost, incurred in additional to a unit cost, often non-linear in the dis-utility and escapable in the short term	Re-booking passengers onto ranother flight due to missed connections. A tectical cost incurred due to actual delay

Table 5.3: Contextual definition of unit and marginal costs [54].

According to Cook [54], they create two models, one for the strategic costs of the delay and another one for the tactical costs of delay taking in consideration specific aircraft in specific phases of flight, they were able to make a quantitative estimation of the amount of strategic costs which should be invested to offset the tactical costs.

Cost type	Low	Base	High
Hard costs	0.11	0.18	0.22
Soft costs	0.05	0.18	0.20
Total	0.16	0.36	0.42

Table 5.4: Three cost scenarios for passenger hard and soft costs to the airline [58].

As stated by Cook et al. [58], the base cost scenarios presented in the Table 5.4 are derived from independently concurring sources (two European airlines) on total passenger costs for a 2003 reference base. Two airline sources have also been used to rationalise the equal (base scenario) split between hard and soft costs. Overall, the total base cost scenario for 2008 is 20% higher than the value of 2003 . In the last paper, the simple theoretical function has been used:

$$c_R = k \log t_D^2$$

where : c_R is reaccommodation cost euro per minute and t_D is the time (delay, mins), instead, the value of k is chosen such that: (1) the contribution of the care costs to the total is 20% ; (2) the flight-proportion-weighted grand mean is 0.18 euro per minute (required for all base scenario cases).

5.3 Cost evolution

The passenger costs associated with delays into direct, or hard costs, and indirect, or soft costs, but both of them have sn impact on the airline. These costs are a consequence of demands, from the travellers, and supplies, from airlines and airports. But another of these costs that it is possible to classify like the 'others' cost is the third category of cost and it is borne by the passenger. It is difficult to measure all the costs affecting the airline because of the complicated integration of information needed to compute direct costs and the complex assumptions required to model indirect costs. According with Ferrer et al. [132], the study of the effects of flight delays on passengers' flight behavior is take in consideration by examining passengers' flight behavior as a function of the number of delays, elapsed time after a delay and passenger segment.

As a consequence of all that costs it is really important the cost of the knowledge of delay in the airline industry. People know that it is common the probability of delay in airline sector and for that reason they are disposed to prevent the delay, for that they bought a previous flight for be sure to arrive on time. This create a chain mechanism, because a lot of the passengers, for prevent the delay, waste time waiting and that has a cost. For example, one hours of time for a working person is valued around 100/180 euros, as effect of that, it is to add the real cost for the person in that hour of time.
This have a real and big impact in all the other way of transport. For avoid the delay it is been builded in many cities a special railway only for the airport that is more expensive than the normal railway, it is common to have special busses only for the airports that cost more than the normal busses. How much the people are disposed to pay for avoid the delay?

In the field of distributing the soft cost as a function of delay duration, Kopelman et al. [114] found that adding an S-shaped schedule delay penalty improved the overall goodness of fit with empirical data and suggested that this makes sense behaviourally. Suzuki et al. [112] adapt a simple binary logit equation to form a

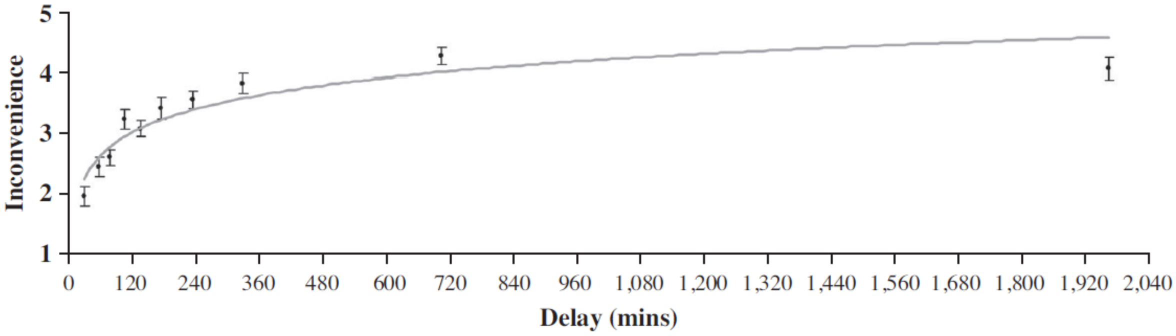


Figure 5.3: Inconvenience as a Function of Delay Experienced [60].

function with a detailed treatment for dealing with the asymmetries of loss aversion.
Another point to take into account is the cost index, that is a parameter set in the cockpit, which determines how the flight management system (FMS) will direct the aircraft. It quantifies the choice to fly faster to recover delay, or to fly slower to conserve fuel.
As stated by Cook et al. [61], cost index (CI) settings vary across aircraft manufacturers. The lowest value causes the aircraft to minimise fuel consumption and to maximise range. In Europe, a flight is often delayed before pushback and hence pre-departure delay recovery, or slot management, is an important for airlines.
Whilst fuel prices are accurately known by airlines, the other part of the CI ratio, the true cost of delay, is seldom known with any precision. CI values used by airlines are often based on limited supporting cost of delay information. The development of decision-support tools to enable cost-effective optimisation of environmental performance could also contribute significantly to the SESAR objective of reducing the environmental effects of flights by 10%, specifically by addressing excess fuel consumption (SESAR Consortium), but this is an argument that we will take in consideration in the chapter 7.

Normally, the interaction between airline costs and environmental impacts is small, but this situation is likely to change. Exogenous factors such as technology and policy affect the elements of delay management. Policies due to military access to airspace and environmental considerations that noticeably affect ATC and

ATM. External policies like the European Union (EU) compensation regulations for delayed passengers, along with internal airline policies on crew remuneration, determine the actual cost of a delay to the airline.

A duopoly city-pair airline market is showed, a special case of oligopolistic markets. Two carriers are engaged in price and frequency competition. Following most theoretical and applied literature of this kind, from the work of Schipper et al. [133] and Brueckner et al. [134]. Travelers consider both fare and service quality when making travel decisions. In the absence of capacity constraints, the primary service quality dimension is schedule delay, defined as the difference between a traveler's desired departure time and the closest scheduled departure time of all flights, as said by [135].

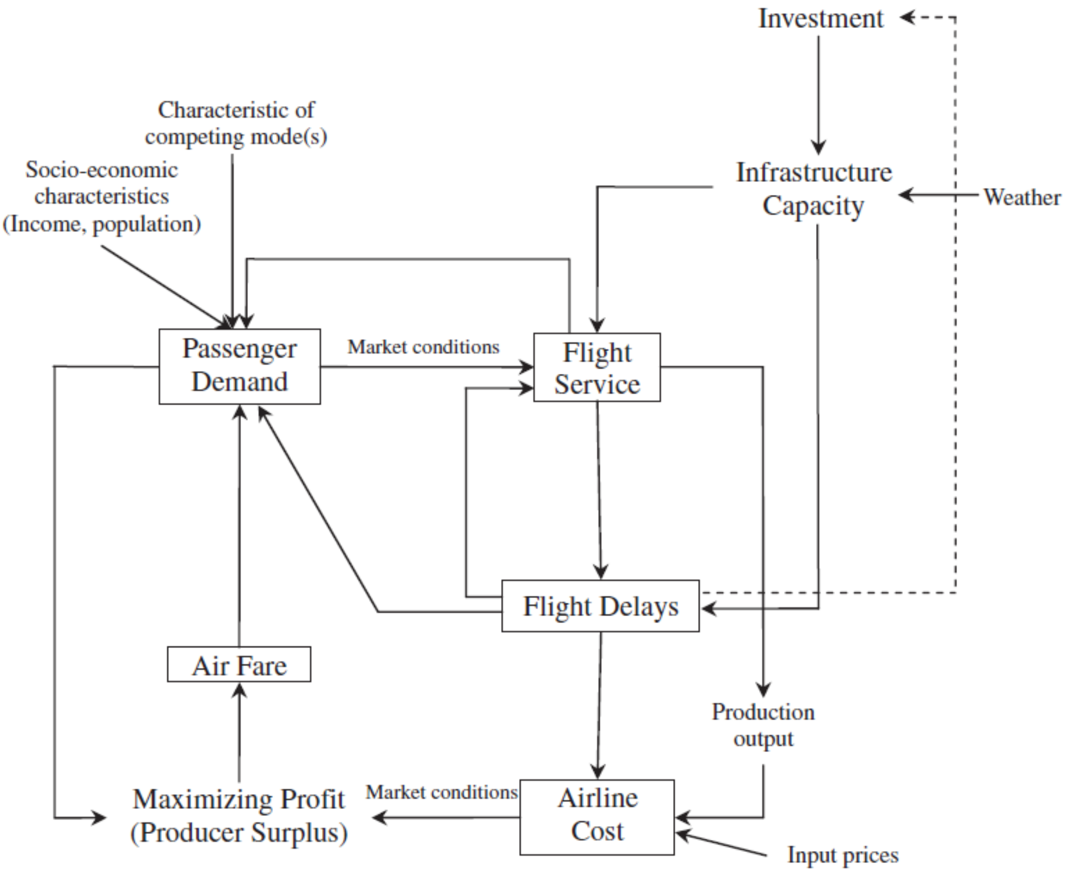


Figure 5.4: The modelling framework [135].

Distribution of the soft costs as a function of the delay time

The following equation can be used to express the propensity,$\prod$, as stated by Cook et al.[137], of a passenger to switch from a given airline, to other choice, after a delay during the trip experience of duration time, 't'. The familiar 'S'-curve produced has the characteristics of maintaining a low switching propensity for some time, then rapidly increasing through a zone of 'intolerance', before levelling off after a duration of delay, the passenger is already very likely to switch airlines. Whilst other theoretical expressions may be employed.

$$\prod = (1/(1+e^{a-bt^{c}})) - k$$

If the plot were of disutility per se, it is disputable that the curve would have a more complex shape on the right. By adjusting the constants ('a', 'b' and 'c') it is possible to produce a fit which accords in a semi-quantitative manner.

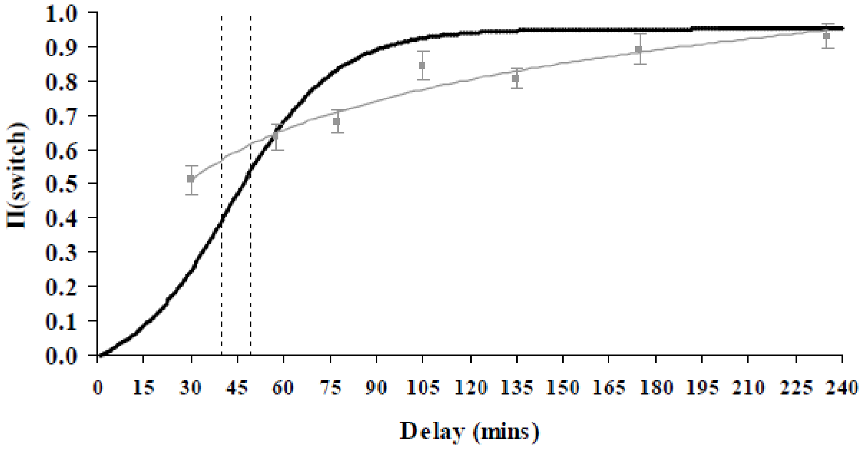


Figure 5.5: Hypothesised switching propensity by delay duration [137].

Chapter 6

Disruption management

When any disruption take place, airlines have to find a minimal cost aircraft reassignments and crew reschedules considering the available resources and satisfying all the operational and safety rules. Two multi-commodity network flow problems were modelled, one for aircraft recovery and the other one for crew recovery problems. A solution algorithm that takes in consideration both the effects was constructed as consequence of the aircraft and crew recovery problems solutions influence each other.
In a typical day, many problems can occurring, such as crew unavailability, unscheduled maintenance problems, gate delays, bad weather conditions, station congestion and airport facility restrictions that cause disruptions and the operational airline schedules can not be operated as planned. As a consequence of the disruptions several flights may be delayed or cancelled, a studied example of that is the thesis work of T. Butler entitled Optimization Model with Fairness Objective for Air Traffic Management, and aircraft and crews may lose their assigned flights. When one of these disruptions takes place, operations personnel in the airlines must find real-time solutions so that it is possible to return the airline to its original schedule as soon as possible, considering available aircrafts, pilots, flight attendants, passengers and cargo. An example of the recovery options commonly used is: flights may be cancelled or delayed. Aircrafts may be diverted or ferried to a destination without passengers, swapping aircraft among scheduled flights, flight attendants may be rerouted, and reserve flight attendants may be called, passengers may be rescheduled, and may fly on other airlines.

During the recovery plan all this element have to be replanned: many resources of airline such as aircraft, crew, passengers, cargo, etc. One of the solution according to the paper [62], since it is a complex task and the resource re-planning problems are usually solved sequentially. First aircraft re-assignments are made, and then crew re-scheduling problem is solved. It is more applicable to consider

the each problem separately, since the integrated problem makes the solution more difficult and complex due to large number of variables to be considered and increased number of constraints to be satisfied.
Aircraft recovery and crew recovery problems are taken in consideration separately. A lot of the recovery literature are concentrated on aircraft recovery problems, whereas the number of aircraft is smaller than the number of crew and the rules for crews are much more complex.

In this work we take in consideration most of the relevant papers published on recovery and disruption management over the last 20 years.
Clarke [63] provides the first overview of the state-of-the-practice in operations control centers in the after math of irregular operations. The overview is based on field studies at several airlines.The author provides an extensive review of the literature with in the airline disruption management and proposes a decision framework that addresses how airline scan reassign aircraft to scheduled flights after a disruptive situation. Kohl et al. [64] provide a general introduction to the airline disruption management and includeade scription of the planning processes in the airline industry.The paper reports on the experiences obtained during the largescale airline disruption management research and development project DESCARTES, supported by the European Union. A survey incorporating issues from the point of view of airports can be found in Filar et al. [65], and a small section devoted to disruption management is included in Yu and Yang [66].

The book by Yu and Qi [67] considers disruption management from a more general perspective.It includes chapters on disruption management for flight and crew scheduling for airlines as well as chapters on disruption management for a number of other applications. Ball et al. [68] give insight into the infrastructure and constraints of airline operations,as well as the air traffic flow management methods and actions.Simulation and optimization models for aircraft,crew and passenger recovery are also discussed.

6.1 Aircraft recovery

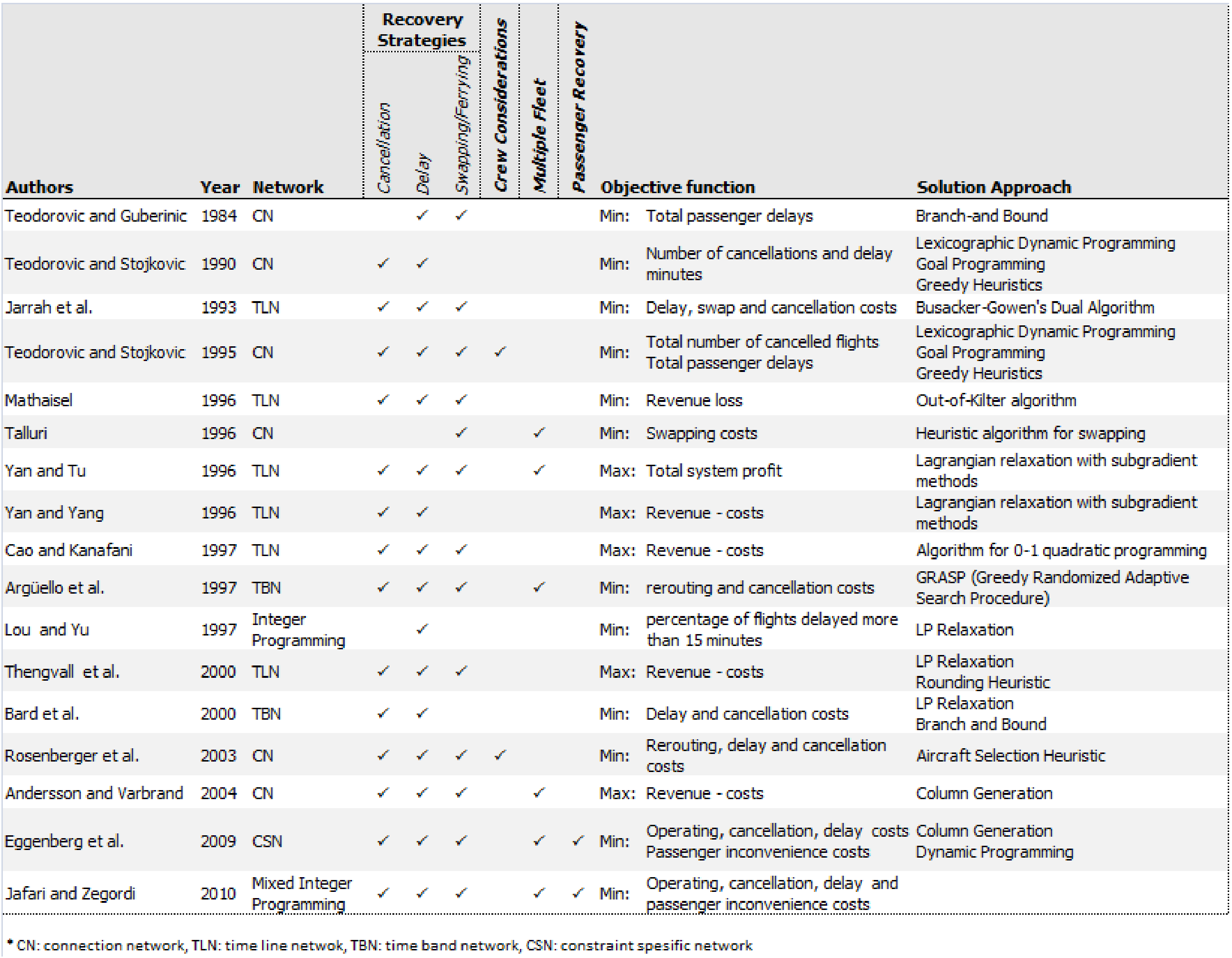
Teodorovic and Guberinic [69] were among the first to study the aircraft recovery problem. They discuss the problem of minimizing total passenger delays on an airline network for the schedule perturbation, by reassigning and retiming flights. The model is based on a type of connection network, which consists of two types of nodes.
Teodorovic and Stojkovic [70] consider aircraft shortage and discuss a greedy

heuristic algorithm for solving a lexicographic optimization problem which considers aircraft scheduling and routing in a new daily schedule. Teodorovic and Stojkovic [71] further extend their model to include also crew and maintenance considerations. Jarrah et al. [72] present an overview of a decision support framework for airline flight cancellations and delays at United Airlines.

Mathaisel [73] reports on the development of a decision support system for AOCC (Airline Operations Control Centers) 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. Talluri [74] deals with the problem of changing the aircraft type for a single flight while still satisfying all the constraints. They describe different algorithms for the swapping procedure in the airline schedule development process.

Yan and Tu [75] develop a framework to assist carriers in fleet routing and flight scheduling for schedule perturbations in the operations of multifleet and multistop flights. Yan and Yang [76] 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. Arguello, Bard and Yu [77] present a method based on the metaheuristic GRASP (Greedy Randomized Adaptive Search Procedure) to reschedule the aircraft routing during an aircraft shortage. Lou and Yu [78] address the airline schedule perturbation problem caused by the Ground Delay Program of the Federal Aviation Authorities. The goal is to improve airline dependability statistics defined by Department of Transportation as percentage of flights delayed more than 15 minutes. They design the polynomial algorithm for minimizing maximum delay among out flights. The problem is modeled as an integer program. Cao and Kanafani [95, 96] 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 [72], using many of the modeling concepts presented and discussed in Jarrah's paper. Thengvall, Bard and Yu [79] present a network model with side constraints in which delays and cancellations are used to deal with aircraft shortages while ensuring a significant portion of the original aircraft routings remain intact. Bard, Yu and Arguello [80] present the time-band optimization model for reconstructing aircraft routings in response to groundings and delays experienced in daily operations, where the objective is to minimize the costs of flight delays and cancellations. Rosenberger, Johnson and Nemhauser [81] propose a model which addresses each aircraft type as a single problem. The model principally follows an approach traditionally used in planning problems, namely a Set Partitioning master problem and a route gen-

erating procedure. Andersson and Varbrand [82] solve the complex problem of reconstructing aircraft schedules. A mixed integer multi-commodity flow model with side constraints, that each aircraft is a commodity, is developed. Side constraints are also used to model possible delays.
The figure below resume most of the literature descibed before.



Authors	Year	Network	Recovery Strategies			Crew Considerations	Multiple Fleet	Passenger Recovery	Objective function		Solution Approach
			Cancellation	Delay	Swapping/Ferrying						
Teodorovic and Guberinic	1984	CN		✓	✓				Min:	Total passenger delays	Branch-and Bound
Teodorovic and Stojkovic	1990	CN	✓	✓					Min:	Number of cancellations and delay minutes	Lexicographic Dynamic Programming Goal Programming Greedy Heuristics
Jarrah et al.	1993	TLN	✓	✓	✓				Min:	Delay, swap and cancellation costs	Busacker-Gowen's Dual Algorithm
Teodorovic and Stojkovic	1995	CN	✓	✓	✓	✓			Min:	Total number of cancelled flights Total passenger delays	Lexicographic Dynamic Programming Goal Programming Greedy Heuristics
Mathaisel	1996	TLN	✓	✓	✓				Min:	Revenue loss	Out-of-Kilter algorithm
Talluri	1996	CN			✓		✓		Min:	Swapping costs	Heuristic algorithm for swapping
Yan and Tu	1996	TLN	✓	✓	✓		✓		Max:	Total system profit	Lagrangian relaxation with subgradient methods
Yan and Yang	1996	TLN	✓	✓					Max:	Revenue - costs	Lagrangian relaxation with subgradient methods
Cao and Kanafani	1997	TLN	✓	✓	✓				Max:	Revenue - costs	Algorithm for 0-1 quadratic programming
Argüello et al.	1997	TBN	✓	✓	✓		✓		Min:	rerouting and cancellation costs	GRASP (Greedy Randomized Adaptive Search Procedure)
Lou and Yu	1997	Integer Programming		✓					Min:	percentage of flights delayed more than 15 minutes	LP Relaxation
Thengvall et al.	2000	TLN	✓	✓	✓				Max:	Revenue - costs	LP Relaxation Rounding Heuristic
Bard et al.	2000	TBN	✓	✓					Min:	Delay and cancellation costs	LP Relaxation Branch and Bound
Rosenberger et al.	2003	CN	✓	✓	✓	✓			Min:	Rerouting, delay and cancellation costs	Aircraft Selection Heuristic
Andersson and Varbrand	2004	CN	✓	✓	✓		✓		Max:	Revenue - costs	Column Generation
Eggenberg et al.	2009	CSN	✓	✓	✓		✓	✓	Min:	Operating, cancellation, delay costs Passenger inconvenience costs	Column Generation Dynamic Programming
Jafari and Zegordi	2010	Mixed Integer Programming	✓	✓	✓		✓	✓	Min:	Operating, cancellation, delay and passenger inconvenience costs	

* CN: connection network, TLN: time line netwok, TBN: time band network, CSN: constraint spesific network

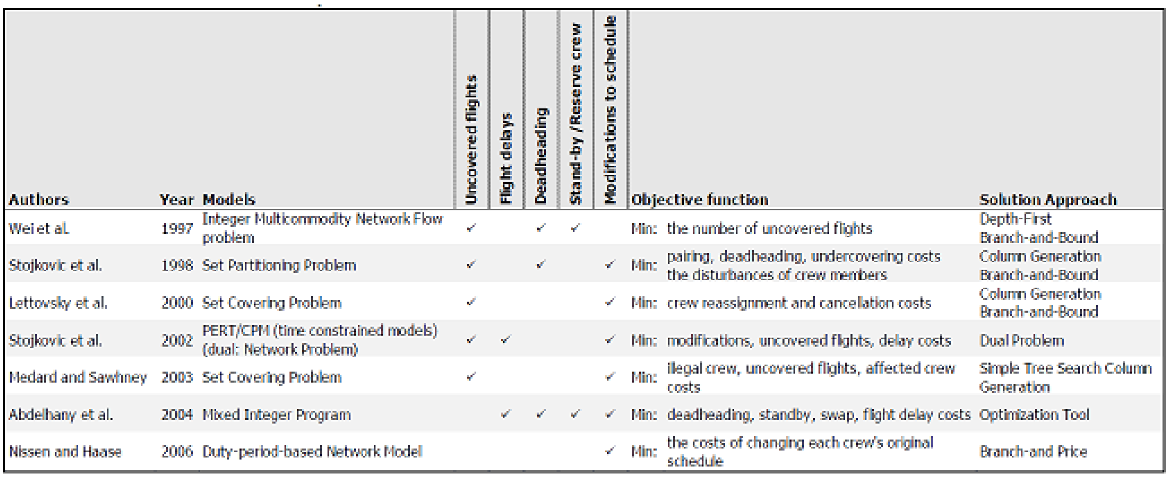
Figure 6.1: Overview of Aircraft Recovery Problem Literature [62].

Eggenberg et al. [83] has developed the constraint-specific recovery network model which can be seen as an extension of the time-band model by Bard et al. [80]. They have applied the model to the aircraft recovery problem with maintenance planning and passenger recovery problem. The most recent study on aircraft and passenger recovery has been performed by Jafari and Zegordi [84]. They developed a model to recover flight, aircraft and passenger simultaneously.

6.2 Crew recovery

The crew recovery problems, these problems have not been investigated as much as aircraft recovery problems. The largest number of research for these problems is made in the recent years. Wei, Yu and Song [85] develop an integer programming model and an algorithm for managing crew in case of disruption. The model repairs broken pairings and assigns crew to flights that are not covered. Stojkovic et al. [88] describe the operational airline crew scheduling problem. The problem consists of modifying personalized planned monthly assignments of airline crew members during day-to-day operation. The problem requires that all flights are covered at a minimum cost while minimizing the disturbances of crew members. They formulate the crew recovery problem as an integer non-linear multi-commodity flow problem. Lettovsky et al. [87] present a method based on an integer programming formulation. They develop a new solution framework. It provides, in almost real time, a recovery plan for reassigning crews to restore a disrupted crew schedule. Stojkovic et al. [88] present a model that involves determining appropriate real-time changes to planned airline schedules when perturbations occur to minimize customer inconvenience and costs to the airline. They propose a model that determines new flight schedules based on planned crew transfers, rest periods, passenger connections and maintenance. Medard and Sawhney [89] consider the crew recovery problem and integrate both crew pairing and crew rostering to solve time critical crew recovery problems arising on the day of operations. Abdelhany et al. [90] present a decision support tool that automates crew recovery during irregular operations for large scale commercial airlines. Nissen and Haase [91] present a new duty-period-based formulation for airline crew rescheduling problem where the aim is to determine new crew assignments minimizing the impact on the original crew schedule, after a disturbance in the schedule.

Lettovsky's Ph.D. thesis [92] is the first to consider truly integrated approach in the literature. His thesis presents a linear mixed-integer mathematical problem that maximizes total profit of the airline while capturing availability of aircrafts, crews and passengers. Lettowsky suggests solving problem using decomposition algorithms, but his approach has not been completely tested. Furthermore, Bratu and Barnhart [93] presents two models that considers aircraft and crew recovery and through the objective function focuses on passenger recovery. While reserve crews are included into the models they do not consider how to recover disrupted crews. They present two models: passenger delay metric and disrupted passenger metric. Both have same objective function which incorporates operation costs and passenger recovery costs. They test both models and conclude that only the disrupted passenger metric model is fast enough to be used in a real-time environment. The most recent studies on integrated recovery problems have been



Authors	Year	Models	Uncovered flights	Flight delays	Deadheading	Stand-by /Reserve crew	Modifications to schedule	Objective function		Solution Approach
Wei et al.	1997	Integer Multicommodity Network Flow problem	✓		✓	✓		Min:	the number of uncovered flights	Depth-First Branch-and-Bound
Stojkovic et al.	1998	Set Partitioning Problem	✓		✓		✓	Min:	pairing, deadheading, undercovering costs the disturbances of crew members	Column Generation Branch-and-Bound
Lettovsky et al.	2000	Set Covering Problem	✓				✓	Min:	crew reassignment and cancellation costs	Column Generation Branch-and-Bound
Stojkovic et al.	2002	PERT/CPM (time constrained models) (dual: Network Problem)	✓	✓			✓	Min:	modifications, uncovered flights, delay costs	Dual Problem
Medard and Sawhney	2003	Set Covering Problem	✓				✓	Min:	illegal crew, uncovered flights, affected crew costs	Simple Tree Search Column Generation
Abdelhany et al.	2004	Mixed Integer Program		✓	✓	✓	✓	Min:	deadheading, standby, swap, flight delay costs	Optimization Tool
Nissen and Haase	2006	Duty-period-based Network Model					✓	Min:	the costs of changing each crew's original schedule	Branch-and Price

Figure 6.2: Overview of Crew Recovery Problem Literature [62].

performed by Abdelghany et al. [94]. They have presented a decision support tool which integrates schedule simulation model and a resource assignment optimization model. The simulation model predicts the list of disrupted flights in the system.

6.3 Integrated recovery

The integrated problem is much harder to be solved. They require special attention and complex techniques in order to be solved to optimality in real time. Integrating the recovery of several resources (aircraft, pilots, flight attendants) in the same system is a difficult task,and only a few attempts to integrate resources has been presented in the operations research literature. The Ph.D.thesis of Lettovsky [97] is the first presentation of a truly integrated approach, although only parts of it are implemented. The thesis presents a linear mixed integer mathematical problem that maximizes total profit to the airline while capturing availability of the three most important resources: aircraft, crew and passengers. resembles thepresentmanualprocessatmanyairlines. Another work on integrated recovery is reported by Abdelghany et al. [98]. The authors address the situation, where a Ground Delay Program is issued by the US authorities, often due to anticipated adverse weather conditions. The authors present a mixed integer program similar to the formulation of Abdelgahny et al. [99], but where several resources can be rescheduled and flight legs can be cancelled.

6.4 Classification of the architectures for the airline operations problems

In these section are showed some different kinds of architecture take in account from the different authors. Here, it is considered the Descartes architecture, as example.

The Descartes (Decision Support for integrated Crew and AircrafT recovery)

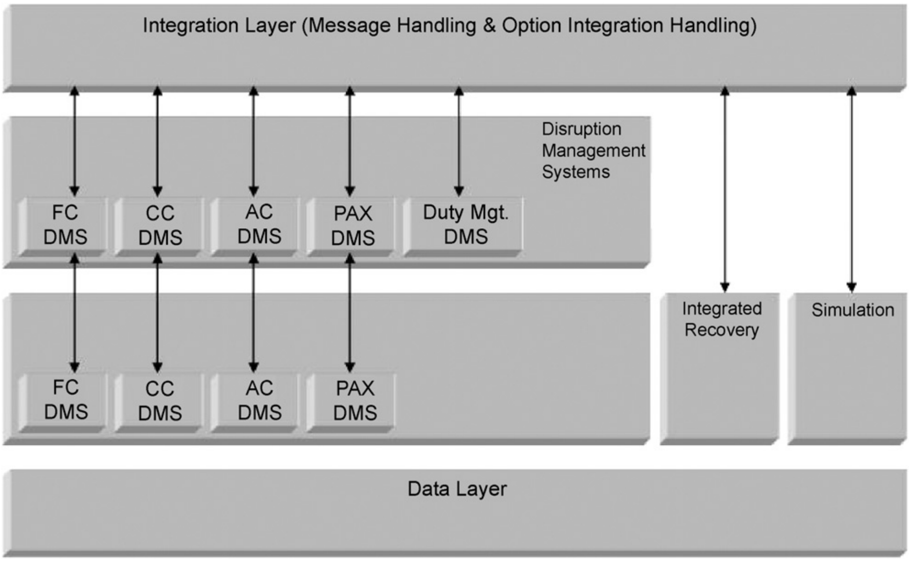


Figure 6.3: Overview of the architecture of the Descartes system. Notes: FC is flight crew, CC is cabin crew, AC is aircraft, DMS is disruption management system, DCR is dedicated crew recovery, DAR is dedicated aircraft recovery, and DPR is dedicated passenger recovery [4].

project involving British Airways (BA), Carmen Systems, and the Technical University of Denmark ran from 2000 to 2003. Its target was to develop a disruption management system based on a holistic approach. The system should integrate the decisions of the resources in one integrated possible resolution. The core was on the four main resources involved namely aircraft, flight and cabin crew, and passengers.

From the work of Zeybekcan and Ozkarahan [62] the algoritm proposed is shown below.

Using the sequential and interactive algorithm, both aircraft and crew availabilities are considered in the algorithm. Moreover, the overall problem is less complex than the integrated problem in terms of modeling and the real time solutions can be obtained in easier way. Some combinations of aircraft and crew availabilities can be considered. The algorithm can find solutions for multiple dependent or independent crew and aircraft availabilities. In some cases only aircraft disruptions can be recovered, but also aircraft and crew disruptions for same flight leg can be considered or aircraft unavailability for flight a and crew unavailability for flight b can be solved.

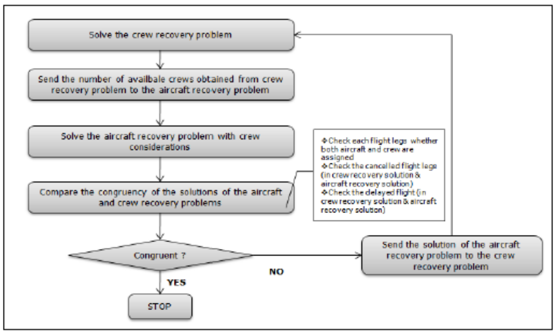


Figure 6.4: The sequential and interactive algorithm for aircraft and crew recovery problem [62]

It is presented the disruption management process in use at most of the airlines and it has five steps, according to Castro and Oliveira [136]. Operation Monitoring, where the flights are monitored to see if anything is not going according to the plan. The same happens in relation with crewmembers, passenger check-in and boarding, cargo and baggage loading, etc. Take Action, if an event happens a quick assessment is performed to see if an action is required. If not, the monitoring continues. If an action is necessary than we have a problem that needs to be solved. Generate and Evaluate Solutions, having all the information regarding the problem the AOCC needs to find and evaluate the candidate solutions. Take Decision, where the candidate solutions a decision needs to be taken. Apply Decision, after the decision the final solution needs to be applied in the environment, that is, the operational plan needs to be updated suitably.

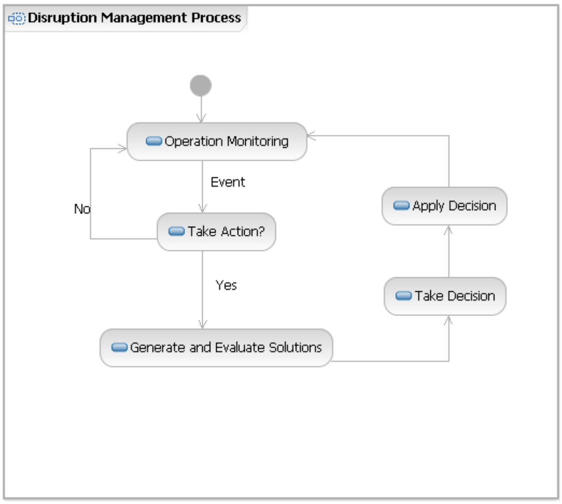


Figure 6.5: AOCC disruption management process[136].

Using an agent-oriented software methodology, developed by Castro and Oliveira, it is arrived to the architecture of the multi-agent system MAS, after also performing an analysis. The agent model and service model were the outputs of this process and the base for this architecture. It is illustrated below the architecture of the multi-agent system approach. The boxes represent agents and the narrow black hyphen lines represent requests/proposals made. The larger green lines represent the interaction between agents regarding negotiation and distributed problem-solving process. The narrow gray lines represent interaction within a hierarchy of agents and the normal black lines represent the interactions after a solution is found. It is important to know that in the Figure represents only one instance of the MAS. It is possible to replicate all agents with the exception of the Supervisor agent because it is the one that interacts with the human supervisor.

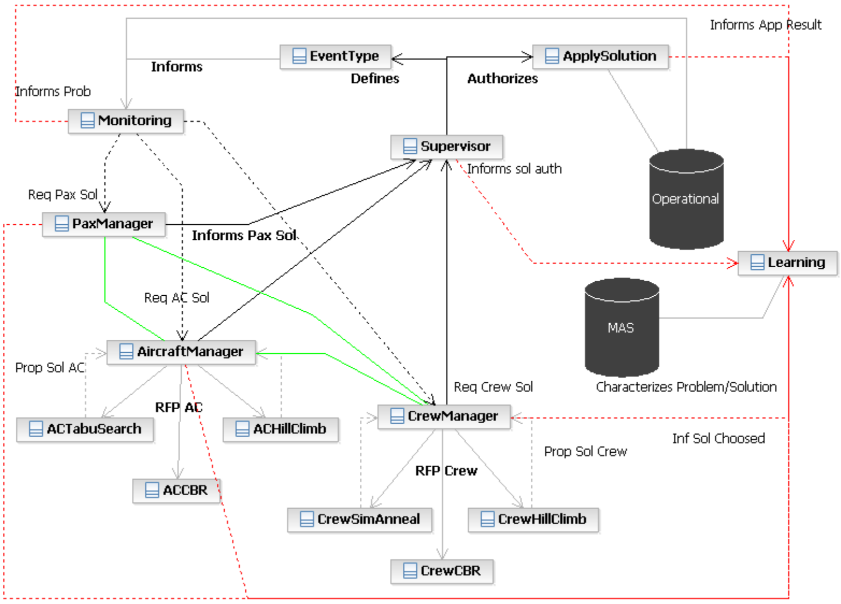


Figure 6.6: MAS architecture [136].

6.5 Matematical Model

The paper of Mercier and Cordeau [100] has introduced a model and a solution methodology for the integrated aircraft routing, crew scheduling and flight retiming problem. The methodology combines Benders decomposition, column generation and a dynamic constraint generation procedure. On test instances containing up to 500 daily legs, the approach yields solutions that significantly decrease crew costs while also reducing the number of aircraft and still ensuring appropriate aircraft maintenance. This would not be possible with a sequential solution process. When compared to a straightforward extension of the solution methodology previously developed by Mercier et al. [101], by aggregating some of the short connection linking constraints in the Benders subproblem and by generating some other constraints dynamically, the new approach decreases by a factor of more than 12, on average, the time needed to solve the integrated model with flight retiming without deteriorating the solution quality.

The thesis of Tiassou [102], concerns the development of a dependability assessment approach based on stochastic state-space-based models that can be easily updated during the aircraft operation, considering the information related to the current specific situation. We have identified the system behavior description, the mission profile information, the related requirements, and the maintenance accomplishment information as the relevant types of information to consider in the model. The model adaptation to the situation online is managed by updating the information in the model. The update is the result of an event or a change during the aircraft operation. Indeed after a major change, one has to check if its impact is significant or not. A re-assessment of the operational dependability is consequently required so as to have the up-to-date result.

As stated by Beygi et al. [103], one major cause of delay is the downstream propagation of initial delays to subsequent flights. Addressing operational concerns in the planning process can be quite challenging. First, metrics for evaluating the operational performance of a planned schedule must be developed. Second, cost functions must be developed to trade-off planned and (anticipated) operational costs. Finally, these cost functions must be incorporated in an already challenging planning process. In spite of delay propagation spans across multiple resources, schedule design, fleeting, crew scheduling, and maintenance routing must all be considered concurrently. By re-allocating the existing slack to those flight connections that are most affected to delay propagation, we can reduce downstream impacts without changing planned crew or fleeting costs and without changing revenue projections. Our computational results show significant opportunities for improvement without any increase in planned costs.

For Zeybekcan and Ozkarahan [62] has also considered the correlation and dependency of two problems. A new algorithm has been presented which solves aircraft recovery and crew recovery problems sequentially and in interactive manner. The subject algorithm takes into account the dependency of two problems, represents the correlation between them without integrating the two recovery problems. With this solution algorithm, both aircraft and crew disruptions are recovered at one time. The overall algorithm does not include any integration of aircraft and crew recovery problems. Thus, the problem complexity and huge number of constraints and variables are prevented; the real time solutions are obtained in easier and more practical way. Furthermore, it is possible to consider several combinations of dependent or independent aircraft and crew unavailabilities through the algorithm.

According with Petersen et al. [104], seeks to solve the airline integrated recovery problem by mathematical programming techniques yielding a passenger-friendly solution with crew considerations. Unless the disruption period affects only a small measure of flights, delivering a globally optimal solution is unlikely to be achieved within a reasonable runtime. Therefore schemes that limit the problem size and allow for efficient decomposition are essential in the construction of the solution procedure. With these strategies implemented as we have discussed, we have shown that the AIR problem is solvable under several reasonably sized disruptions. This paper is one of the first attempts to computationally solve the fully integrated problem.

Chapter 7

Analysis of some airline datas

7.1 Cause of delay

Air traffic operations are often disrupted by poor local or regional weather, such as snow storms or major thunderstorms, that result in lengthy flight delays and numerous cancellations and missed passenger connections. Because these disruptions account for a extremely large fraction of operational costs, it is critical that airlines be able to recover quickly and efficiently from such situations.

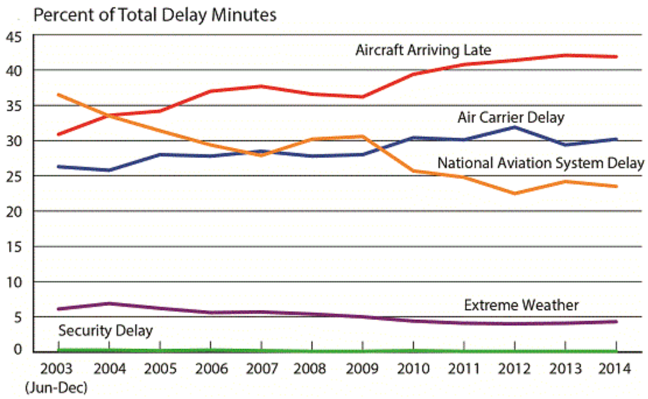


Figure 7.1: Total delay minutes during the years [140].

To this end, according to Barnhart et al.[139] the most advanced airlines have developed decision support capabilities that include dynamic operations recovery

through rescheduling and re-optimization of resources. Essential to such efforts is the sharing of real-time information among airlines, national and regional air navigation service providers (ANSP), and even passengers.
This one is one of the main causes of delay in the airline industry, but it is common to have also airport congestion that induces delays and it could be avoided with secondary airports. Consequently, the secondary airports are far from the center of city and that involves more time travelling to reach the interested location.
It possible to know the reason for a flight late or cancellation, since June 2003, the airlines had to report on-time data also report the causes of delays and cancellations to the Bureau of Transportation Statistics, so all the dates are available from June 2003 to the most recent month. Airlines report on-time data, if vehicles have 1 % of total domestic scheduled-service passenger gateway account on-time data and the causes of delay. The airlines account of the causes of delay in broad categories that were created by the Air Carrier On-Time Reporting Advisory Committee. The categories are Air Carrier, National Aviation System, Weather, Late-Arriving Aircraft and Security. The causes of cancellation are the equal and these are defined:

- Air Carrier: The reason of the cancellation or delay is related to requirements by the airline's control, such as maintenance or crew problems, aircraft cleaning, baggage loading, fueling, etc.
- Extreme Weather: Meaning meteorological conditions, actual or forecasted, that, in the opinion of the vehicle, delays or prevents the operation of a flight such as tornado, blizzard or hurricane.
- National Aviation System (NAS): Delays and cancellations attributable to the national aviation system that refer to a large set of conditions, such as non-extreme weather conditions, airport operations, heavy traffic volume, and air traffic control.
- Late-arriving aircraft: A preceiding flight with same aircraft arrived late, it can be responsible for the present flight to depart late.
- Security: Delays or cancellations caused by evacuation of a terminal or foyer, re-boarding of aircraft because of security violation, inoperative screening equipment and/or long lines in surplus of 29 minutes at screening areas.

The category indicated by NAS is the extreme weather which prevents flying and it represent the 4 % . There is another category of weather inside the NAS category. This one slows the operations of the system but does not avoid flying.

Delays or cancellations indicated by ”NAS” are the type of weather delays that could be reduced with corrective action by the airports or the Federal Aviation Administration. During 2014, 52.3 % of NAS delays were owing by weather, moreover NAS delays were 23.5 % of total delays in 2014. A true picture of total weather-related delays requests several tiers. Primarily, the extreme weather delays must be mixed with the NAS weather category. Then, we have to determine the weather-related delays included in the ”late-arriving aircraft” category. Airlines do not affair the reasons of the late-arriving aircraft but an assignment can be made using the proportion of weather related-delays and total flights in the other categories.

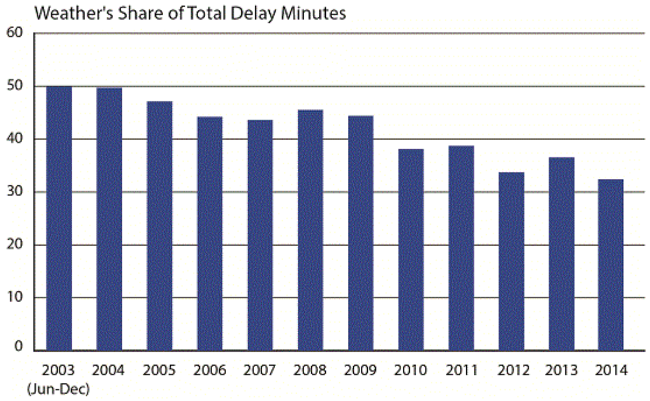


Figure 7.2: Weather’s share of total delay minutes during the years [140].

The Air Carrier On-Time Reporting Advisory Committee created this reporting system. The board decide to separate the extreme weather delays from the weather delays that could be regular direct improvements to the system, would provide a truer picture of the extent of weather delays. As consequence is better report all the delays related to weather as a single number.

7.2 Analysis

One part of the thesis deals with the analysis of some data received from the Norwegian company, Avinor.
They have provided a good quantity of information about some flights during January, February, March and April 2015. All the flights depart from Trondheim and they stay inside the Norwegian country, so the analysis will reach only the local transportation.
As first information, we looked to identify the number of flights for each day and we can easily see that the major number of flights is concentrated in the second part of the month.

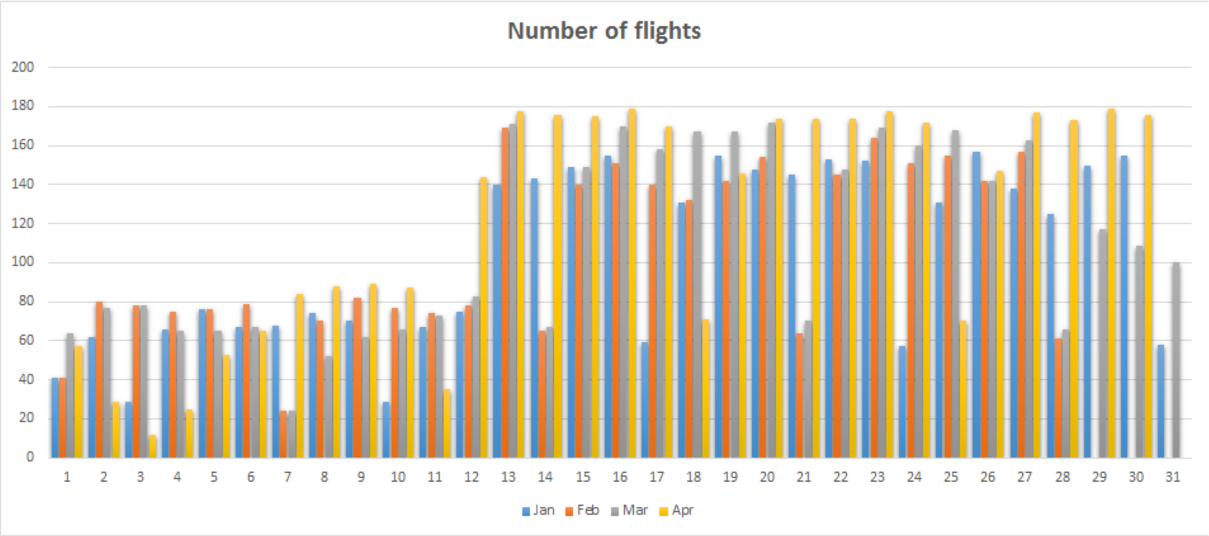


Figure 7.3: Number of flights in January,February,March and April 2015.

It is shown, also, the same graph of before but, in this figure, it is considered as function of the days of the week. Consequently, the graph points out, in a better and precise way, the distribution of flights. It helps to analyse that during all the weeks, during the lavorative weeks, the distribution is almost constant. Moreover, generally the weekends have less flights and especially on Saturday.

At the same time, really interesting is the previous graphic but with the weekly rappresentation. With two kinds of figure it easly shows that the distribution on flights for week is, more or less, the same each months. In that way is simple also to compare the number of flight with the other graphics below.

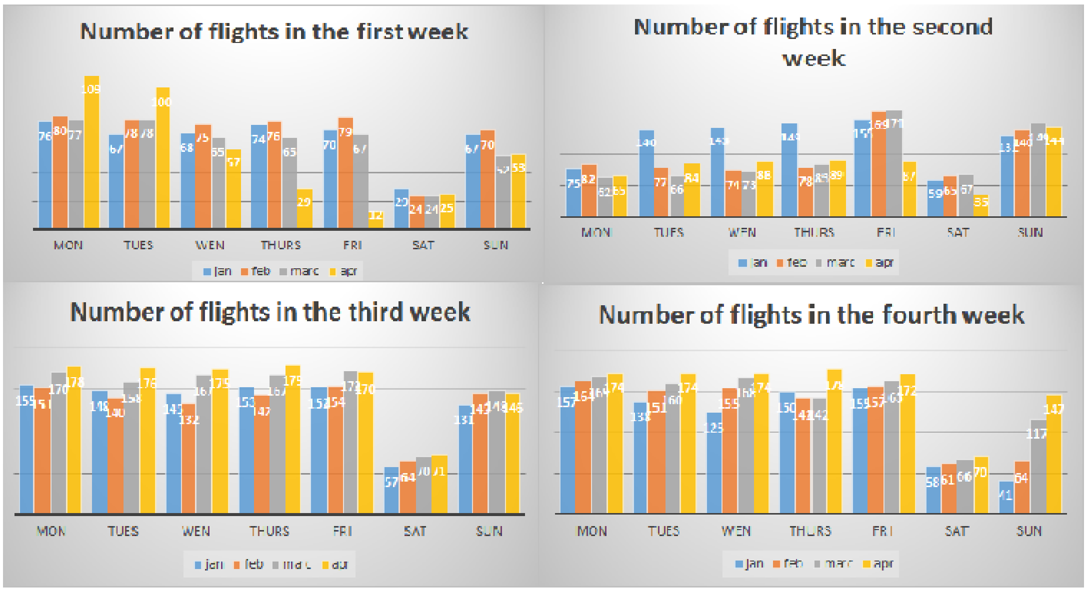
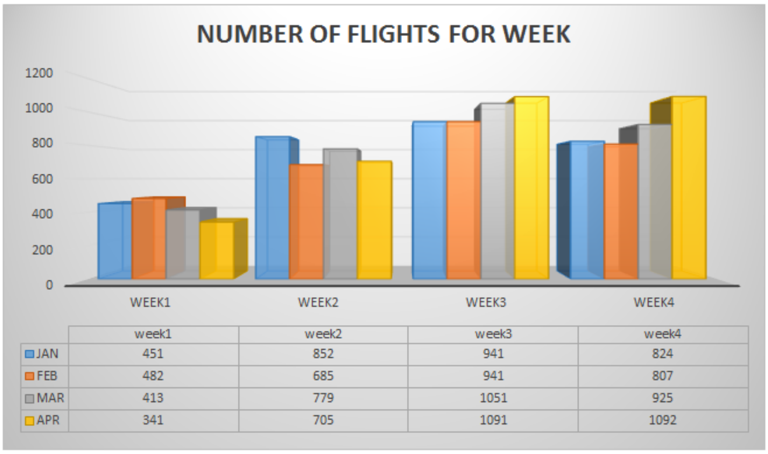


Figure 7.4: Number of flights each week in January,February,March and April 2015.

Secondly, we have plotted the trend of the absolute value of delay for each month as a function of days.
We have all the information, from the Avinor, about planned arrival time and real arrival time, with a simple calculation of the difference between this two values we have begun the analysis that showed the results below.

For all the investigation in the field of punctuality and avoidance of delay, the charts of the mean value of delay, expressed as a function of the weekly days and for the different weeks of every month are really exhaustive.
With this graph the major part of the distrimutions of delay are under the value of 00 : 15 : 00 and this is a good information, because all the important delay to consider are major than this value.

In the last graphic of this kind of informations, we manage to plot the standard deviation over all the population as a average for each month, taking into account all the previous specifics represented in the previous charts.
The standard deviation or standard deviation is a statistical dispersion index, Which is an estimate of how data can vary in population.



	week1	week2	week3	week4
🟦 JAN	451	852	941	824
🟧 FEB	482	685	941	807
⬜ MAR	413	779	1051	925
🟨 APR	341	705	1091	1092

Figure 7.5: Weekly distribution of the number of flight with a barchart.

The standard deviation is one way to express the spread of data around an index position, as can be, the arithmetic average or an estimate and therefore, has the same units of the observed values.

For this amount of data, we have not enough informations to know what the main cause of delay,hence we can't divide the datas for a more precise analysis as function of the main cause of delay. Furthermore, the input of specifics are also not fairly for a normal or special weekly examination and for special we intend a vacation period.

The last chart particularly interesting in the analysis of the datas are the sum of delay minutes for each day, it is shows at the same time the situation for each month.
Moreover, from this graphic it is clear that the month with major number of minutes delay is January.

7.2.1 Puntuality

Punctuality is the key for the satisfaction of many passengers. A reduction in the market share may also depend from the unpunctuality, wherewith the airline have to sustain a 'soft' cost. Punctuality sometime is a difficult concept to explain and it does not help the matter that a number of airline grades may be mixed

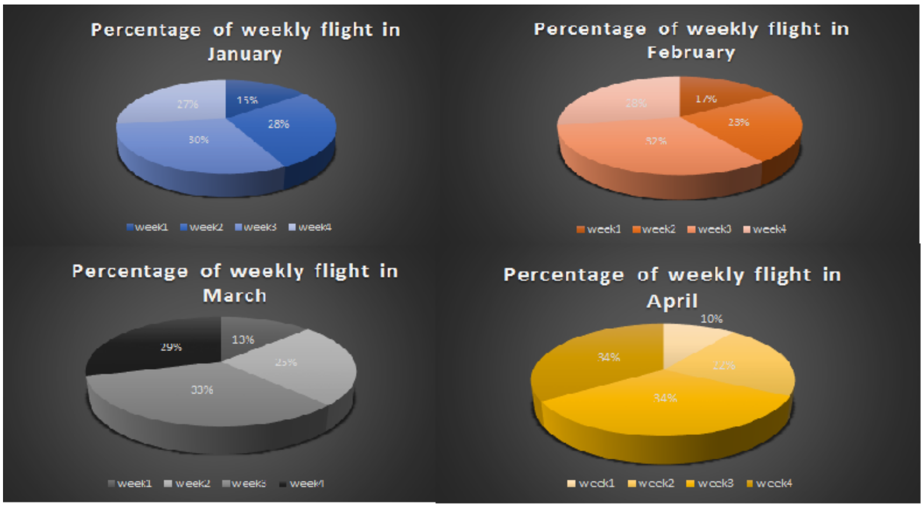


Figure 7.6: Weekly distribution of the number of flight.

by respondents, like the service frequency and flexibility, or the higher fares and flexibility. A integral model of airline market share have to include numerous choice factors, such as modal choice, airport choice and access mode. Several authors have addressed some airline choice attributes, or the outlook of junction airport and airline option. We identify who is most relevant the arrival delay than the departure delay. Besides, on the first leg delay of a journey of 45 minutes could represent a missed connection and a following arrival delay of four hours, after waiting for the next forward flight. If the flight had a delay of 15 minutes, then for most of the passengers, around 25 % of travellers, this should not create any kind of dissatisfaction, whereas a greater delay could lead to greater dissatisfaction. If the flight were to be on time, this did not create any satisfaction, whereas a greater delay, depending on the time delay, led to dissatisfaction, for around 15 % of travellers. On-time performance is considered a key factor for the passengers.

For the punctuality, with the data analysis, we manage to individualize the most important delay, such as all the ones that provide more than 15 minutes of delay.
As consequence, we create a program for scanning the datas and it picks up only the specifics with more than 15 minutes of delay. Finally, we plotted the graphic of the percentage of relevant delays as function of the different months.

From the Bar chart, we reach that the percentage of relevant delay for the first two month of the year is almost the same, around the 12 %. In the month of March the percentage decrease a bit, though it decreases decisively in the month of April,

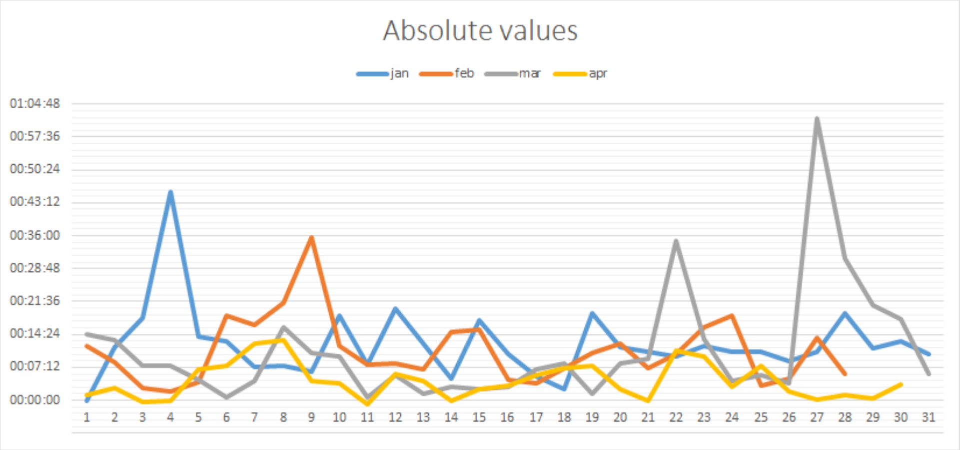


Figure 7.7: Absolute value of Delay from January to April 2015.

where we individuate only few values out of the average delay of 15 minutes.

7.3 Passenger point of view

The road user time spent is related to:

- Travelling aboard (runtime)
- Walking time
- Latency (including so-called hidden latency related to time between departures)
- Make transfer
- Delays

With latency refers to the discrepancy between the time you anytime were raised on, and the time that it is possible to travel in according to the itinerary. Wait regarded, at the first time, as half the time between departures. From this starting point multiplied wait with different weights depending on whether it is short or long trips and the length of travel time. Moreover, every weight Factors for travel components has a specified values.

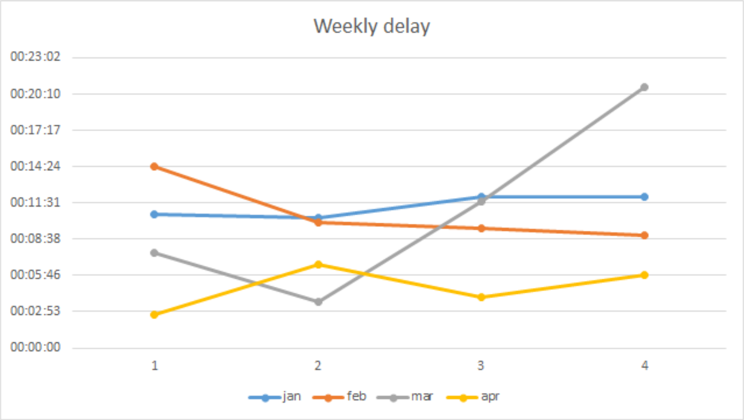


Figure 7.8: Weekly absolute value of Delay from January to April 2015.

	Train	Car	Bus	Gang /bicycle	Train	Car	Bus	Flight
Business Travel	443.7	443.7	443.7	161.1	443.7	443.7	443.7	519.6
work Packages	65.4	98.1	65.4	161.1	102.7	176.3	65.4	336.3
other travels	51.4	81.7	51.4	161.1	73.6	151.8	60.7	210.2

Table 7.1: Price for traveling abroad (2013 Nok for time)[141].

The first part of the Table shows Short trips (minor of 50 km) and the second half long journeys (major of 50 km).

7.3.1 Travelling aboard

It should be pursued to assume project dependent time values for driver who actually affected by the measure. If this does not possible, or for demanding used valuation of the various travel components from TOI [142], adjusted from 2009 figures 2013 crowns with SSB wage index (16.76 percent growth). The previous table shows the rates for traveling aboard (runtime). The rates are adjusted according to Statistics Norway's wage index. For shuttle travels utilized rates for main transport. This means for example that the rates for train to the airport set equal rates for flights. For travel components used the same rates, multiplied with weighting factors that converts time to ordinary journey aboard. The following weighting factors used, TOI [142], as stated by the document [141].

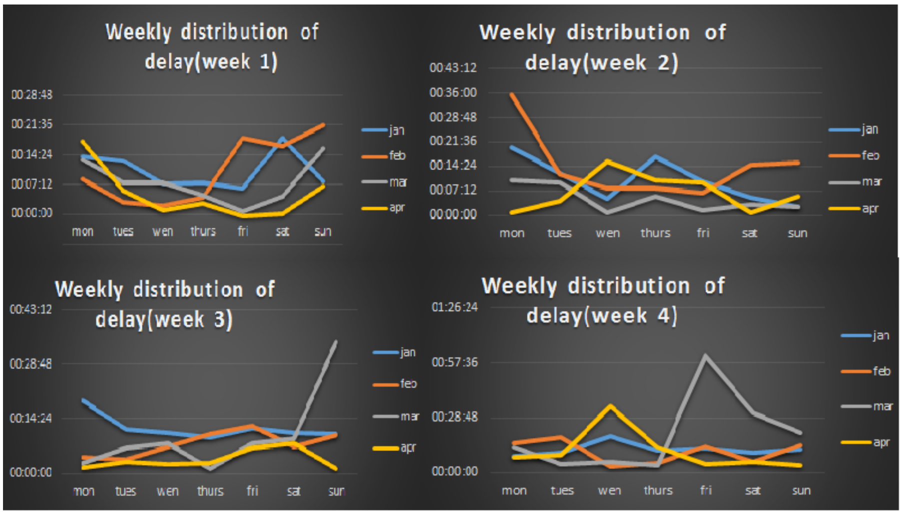


Figure 7.9: Weekly absolute value of Delay from January to April 2015 as function of the days of the week.

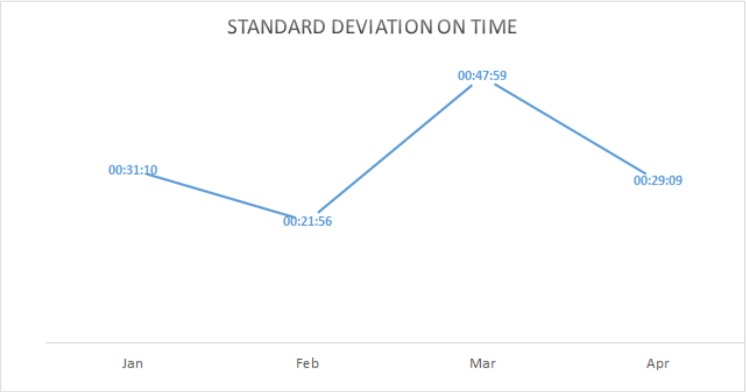


Figure 7.10: Standard deviation over all the population as a average for each month.

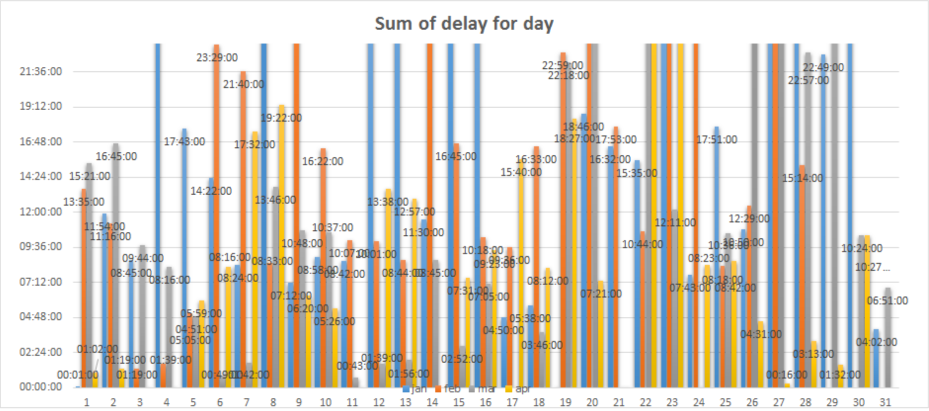


Figure 7.11: The sum of delay minutes for each day.

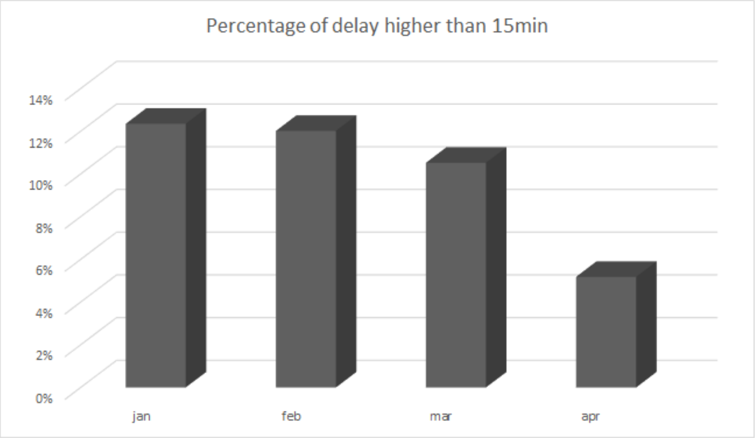


Figure 7.12: The percentage of relevant delays as function of the different months.

Chapter 8

New Trends Of The Airline Industry

As a conseguence of the ICAO statistic, that shown 2.5 Billion passengers and a growth in international travel of 8.8 %. Moreover 1.7 Million out of 9.4 Million flights in Europe were international - in or out of Europe, so a new and interoperable ATM system is necessary.
The mechanism of implementing rules also may be used to facilitate the coordinated introduction of new technologies.
Manufacturers have undersood the opportunity resulting from this approach and have prepared an initiative to organize the developement and introduction of new technology under a major project: SESAR (more famouse as SESAME). This is the future and it will develope the next generation ATM system, with a 2020 horizon. The SESAR initiative combines technological, economic and regulatory aspects, using the Single Sky legislation. In that way it is possible to synchronise the implementation of new equipement, from a geographical standpoint in all European Union member states, as well as from an operational standpoint by ensuring that aircraft equipage is cinsistent with ground technological evolution.

In the first phase of SESAR, called the 'definition phase', that has been costed in time from 2006 to 2008 and in money 60m euro. From that phase a common goal and vision for the developement of the European air traffic controll infrastructure togeter with an established timetable for its implementation was defined. The second phase of SESAR is a developement and deployment phase, besed upon the results of the definition phase, and organise the next generation of air traffic control systems and synchronise their deployment and implementation. This development phase(2008-2013) produced new generation of technological systems and components and the budget for this phase is 2.3-2.7 billion euro from the Community, EUROCONTROL and industry.
The following deployment phase, through 2020, will be carried out under the responsibility on the industry, without further public finding.

The word of air transport is changing, not only through the evolution of aeronautical technologies and economics, but also thrugh the interaction of society with ATM, which the industry must also take into account in terms of future strategies.

According to Sipe and Moore [116], the air traffic system established by NextGen and SESAR will permit functions to be executed by the most appropriate element given the strategic and tactical situation quite than limited to the existing roles predicated on 1960's technology and procedures. The current allocation of functions is based on historical technical limitations. To ensure the most efficient air traffic system (in terms of throughput, safety, environmental impact, etc.), the functions need to be assessed for their best allocation to prevent over-optimizing one area of the system at the expense of other areas.
The major elements, or actors, in the air traffic system are the airplane, ATC, and AOC. These are composed of sub-elements themselves and require assessment of the allocation of functions by management time horizon, that are capacity, flow, traffic, separation, and collision avoidance. Once functions have been allocated, simulations (fast-time and human-in-the-loop) and field trials can be used to develop and validate performance requirements for those functions.

There are three main changes to adopt to ATM. The first one is to utilize a new 4D principal trajectory, able to improving the predictability of the system. The second is a system wide information management, so that the sharing data across systems and between stakeholders is more easy, the latest is the automation, that makes possible for the human operators to concentrate on high value-added tasks.

8.1 Impact on Traffic

The growth in demand for air transport has generated new challenges for capacity and safety. A significant initiative, in that way, is the Single European Sky (SES) legislation designed by the European Commission to reduce airspace fragmentattion in Europe, as stated by Pilon [115]. As a complement to the SES initiative, the SESAR project support the SES, especially its technical objectives of systems interoperability and capacity enhancement.
NextGen and, similarly, the Single European Sky ATM Research Programme (SESAR) will redefine air traffic operations and management for the foreseeable future. NextGen is based upon six enablers [117]:

- Space-based navigation and integrated surveillance
- Digital communications

- Layered adaptive security
- Weather integrated into decision making
- Advanced automation of Air Traffic Management
- Net-centric information access for operations

In addiction, as stated by Sipe and Moore [116], digital data communications and the ability to provide net-centric information access enable large changes to current operations. Effectively employing these capabilities is the equivalent of voice radios first being carried on aircraft to communicate directly with the airport or the use of English as the common language for voice communications.
As shown in the figure 7.1, shared information can connect the air and ground elements to benefit the overall operation. The element most in need of the operational benefit may now perform the function based on shared data to ensure the timeliness of the decision making. NextGen provides '... an increased level of decision making by the flight crew and Flight Operations Centers (FOCs).'[117]

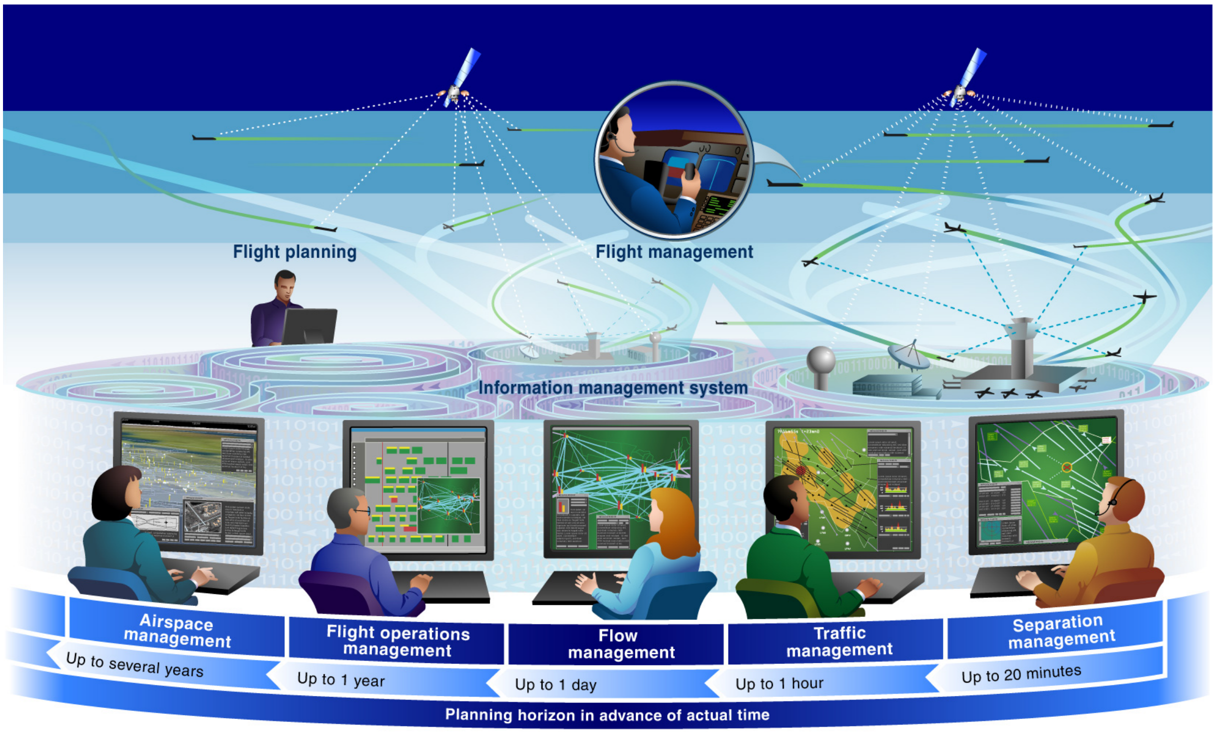


Figure 8.1: Air Traffic Sistem Operations [116].

In Figure 7.2, we show the primary elements of the Air Traffic System. In a digitally connected paradigm, the airplane, AOC, and ATC are connected to each other. In today's model, the three are connected but because of the analog voice nature of the connection, humans must perform much of the translation needed to have the three elements interact.

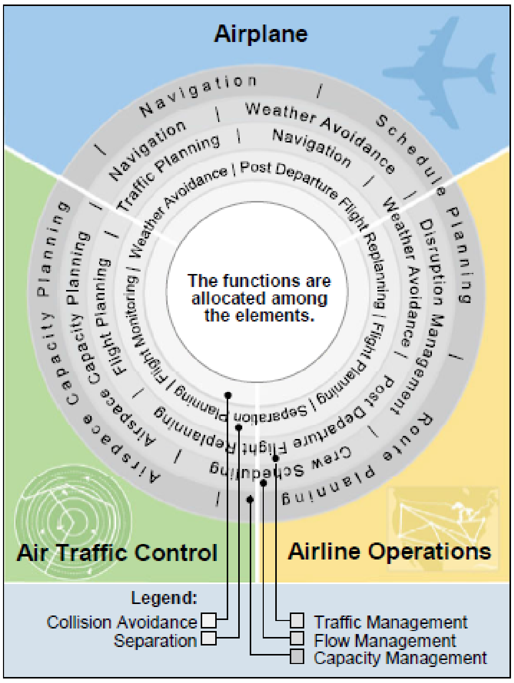


Figure 8.2: Overview of the element ATC,AOC and airplane [116].

The next level down, the allocation between ATCs and then the allocation among elements of an ATC (airport, terminal, en route, oceanic) must have the same iterative allocation trade and constraints checking done. All functions, of course, are not solely allocated to one element today. The dynamic nature of ATM and the very human centric nature of the current system mean that some functions are shared to varying degrees among the elements. When it talks of reallocating functions, we take in consideration that the primary control of the function shifts from one element to another.

For the Next Generation Air Transportation System (NextGen), it is envisioned that trajectory-based operations (TBO) will replace clearance-based operations in many parts of the airspace. New automated separation assurance functions are intended to help overcome the aforementioned limitations of controllers in manually maintaining safe separation between aircraft. The two primary separation assurance concepts are ground-based automated separation assurance [118] and airborne self-separation [119]. Research is ongoing in both areas.

A companion study [120] was conducted at Ames' Flight Deck Display Research Laboratory [121] to investigate the acceptability of trajectories generated by the ground-based conflict resolution algorithm. Pilots considered almost all trajectories acceptable, but indicated that there was room for improvement. The study results suggest that with the appropriate flight deck equipment flight crews may be able to generate more efficient trajectories in some cases and that the ground-based solution does not always consider all flight deck constraints and pilot preferences. Some improvements identified by this study have since been integrated into the conflict resolution algorithm.

8.2 Change in the services way

Maintaining planned services or safe and efficient operations requires material and real-time management capabilities. An obvious strategy is to advance traffic management for a more efficient use of resources. According with Inden et al. [123], the political objectives to accommodate a threefold of current traffic, to improve safety by a factor of 10, to reduce environmental impacts by 10 % and to cut ATM costs by 50 % large and coordinated joined publicprivate undertakings have been started in all major aviation areas, e.g., SESAR (likely to go into its deployment phase by 2014) in Europe and NextGen ATM in the US, as said Hotham [124]and Booz [125]. Future systems include GPS-based control of 4-D flight trajectories, system-wide information management (consistent undelayed data sharing, improved proceedings and algorithms) or a higher degree of automation of control and of procedures to stabilize or recover flight plans. As a major advance aircrafts will get more choice in choosing routes rather than being limited to air-streets. With further improvements and supported e.g., by advanced Airborne Collision Avoidance Systems (ACAS) spatial separations of aircrafts will be agreed by peer-to-peer principles: Therefore the "intelligent aircraft will be a critical element in 21st century ATM." cit. by Booz [125].
Rotations are planned in answer to the demand for transportation between origins and destinations in terms of its volume and distribution in time to connecting flights (e.g., in huband spoke networks), to distances (flight-time) or to availability of slots at airports as well as to the load-factors of aircrafts (utilization of a given fleet of aircrafts). Rotations include a number of legs (flights). In case of transfer connections the problem may also propagate to rotations of aircrafts oper-

ating connected flights. And with aircrafts also crews move in networks, air-craft maintenance is planned or many inventories of equipment distribute.
Operations footprints in terms of direct (variable) costs, resource and infrastructure utilization (fixed costs), environmental efficiency (emissions, consumption of water) depend on the efficiency of rotations.
A threefold of current traffic will be reached in 15-20 years, soon compared to the time it needs to realize new airports in Europe. Thus any large airport is under continuous physical as well as organizational re-construction. Thus if flights and not rotations are the organizing principle of control achievements of SESAR or NextGen are easier to be consumed by growth or by competition (for example cost cutting, service / quality increase).

Effective response to unexpected events implies that (1) non-expected states of operations occur (and that respectively information is valid), and that (2) the system is intelligent, which (3) can be physically implemented. There must be margin to re-allocate resource. Therefore flexibility (buffers, slack, or redundancy) is the raw material of operations intelligence. But flexibility is a winged resource. In this moment it is available, in the next it is not. And finally flexibility may be out of stock. There is no steady state in aviation operations. There is constant change only. Even if all internal parameters are controlled there are enough external ones. Given a threefold of current traffic thousands of maintenance conferences will run in parallel and the flexibility status of the system will fluctuate.

8.3 Network restructuring

In the future, data link has been integrated into air traffic facilities and many routine tasks such as transfer of control and communication are handled by the automation. Airspace is still divided into sectors, and all high altitude airspace is trajectory-based. Traffic levels range from 1x to 3x. The mix of aircraft categories is similar to today. All aircraft entering high altitude airspace are equipped with flight management systems, broadcast position and speed information via ADS-B. Aircraft meeting minimum equipage requirements can conduct their flights according to " trajectory-based flight rules " (TFR). According with Prevot et al. [122], TFR aircraft can always enter trajectory-based airspace, and are cleared to proceed, climb, cruise and descend via their uplinked trajectory. Flight crews of TFR aircraft receive most information via data link (including frequency changes) and do not verbally communicate with air traffic controllers unless by exception. TFR operations require data link capabilities to receive basic (FANS-like) data link messages including frequency changes, cruise altitudes, climb, cruise, descent speeds, and route modifications. They also need to meet a required navigation performance (RNP) value of 1. Aircraft without the appropriate equipage follow current day Instrument Flight Rules (IFR). They receive clearances and instructions like today, and are only permitted into trajectory-based airspace on an ”as available” basis.

Roles and Responsibilities

As stated by Prevot et al.[122], the ground automation is responsible for maintaining safe separation between aircraft. It is responsible for detecting strategic medium-term conflicts (typically up to 15 minutes) between all trajectories and for monitoring the compliance status of all aircraft relative to their reference trajectory. The ground automation is also responsible for detecting tactical short-term conflicts (typically 0 to 3 minutes) between all aircraft. Whenever the ground automation cannot resolve a conflict without controller involvement, it must alert the controller early enough so that she can make an informed decision and keep the aircraft divided. Flight crews are responsible for following their uplinked (or initially preferred) trajectory within defined allowance, and for the safe conduct of their flight. Flight crews can downlink trajectory change requests at any time. The ground automation probes the request for conflicts without involving the controller. If the requested trajectory is conflict free, the automation uplinks an acceptance message, otherwise it alerts the controller that there is a trajectory demand to be reviewed. Air traffic controllers are responsible for issuing control instructions to IFR aircraft. They can use conflict detection and resolution automation to generate new trajectories for all aircraft. Controllers use data link to communicate with equipped aircraft and voice for non data link-equipped aircraft. The controller is supervising the automation and is responsible for making decisions on all situations that are presented to her by the automation, flight crews or other ATSP operators, such as controllers or traffic managers.

SESAR architectures rely on a consistent replanning, in case of unexpected events stakeholders are responsible to take action accordingly to standard procedures, in future supported by systems developed by SESAR. Thus as a first step this new ICT is to be connected into a peer-to-peer network forming a second layer of ATM which interacts but not directly interferes with the first layer: flight management. There is another trend, marked by the visions of the Internet of Things [126] respectively of Things that Think [127] e.g., the next generation of aircrafts. The Car-2-Car Communication Consortium [128] is a further example aiming between others at avoiding accidents or the exchange of route information. At airports cover field vehicles (push-backs, tank- or deicing trucks) will manage their activity. As stated by Inden et al. [123], dolleys (transport carts) will be RFID tagged, motorized boarding stairs with GPS and suitcases be equipped with tags remembering owners not to leave them behind. In 2020+ not only aircrafts but most critical resources at airports will be able of some autonomy; almost any other will be at least connected. Directly or non-directly they will be able to participate in SMCs.

8.4 Look ahead

There are three main changes to adopt to ATM. The first one is to utilize a new 4D principal trajectory, able to improving the predictability of the system. The second is a system wide information management, so that the sharing data across systems and between stakeholders is more easy, the latest is the automation, that makes possible for the human operators to concentrate on high value-added tasks. SES Performance and Safety & Cost targets, develop some points for the improvement of the ATM. They want to enable EU skies to handle 3 times more traffic than nowadays, at the same time improving safety by a factor of 10, reducing the environmental impactper flight by 10 % and also cutting ATM costsby 50 %.

As said Hotman [129] is presented the future vision of the Air Transport in Europe, so it will be in the prevision for the 2050 from 9.4 Million to 25 Million flights and from 751 Million to 16 Billion passengers. Moreover the ground infrastructure comprising major hubs, secondary airports, airports and heliports connected to a multimodal transport network, because the existent structures are not enough for support the growing trends. At the same time, passenger and freight Infrastructure, services, operators, aircraft, airports, ground-handlers and the military are integrated into global inter operable multi-modal networks provided by a small number of organisations. As a consequence of the growing of technologies, it will be good to shared information platforms and new IT concepts facilitate planning and decision-making. It is expected an easier passenger access to airports -seam less door-to-door services. Airport design, processes and services are based on new highly efficient concepts with disruption resilient operations and the levels of automation mean unmanned flights are commonplace, opening new aviation applications.

SESAR is developing the new ATM System for Europe, because the Europe cannot be isolated in the global ATM context and the interoperability is key to ensuring coherent global solutions.
The interoperability means that it is not possible to have the same solution everywhere, but it is important that 'systems' are able to work together and for systems

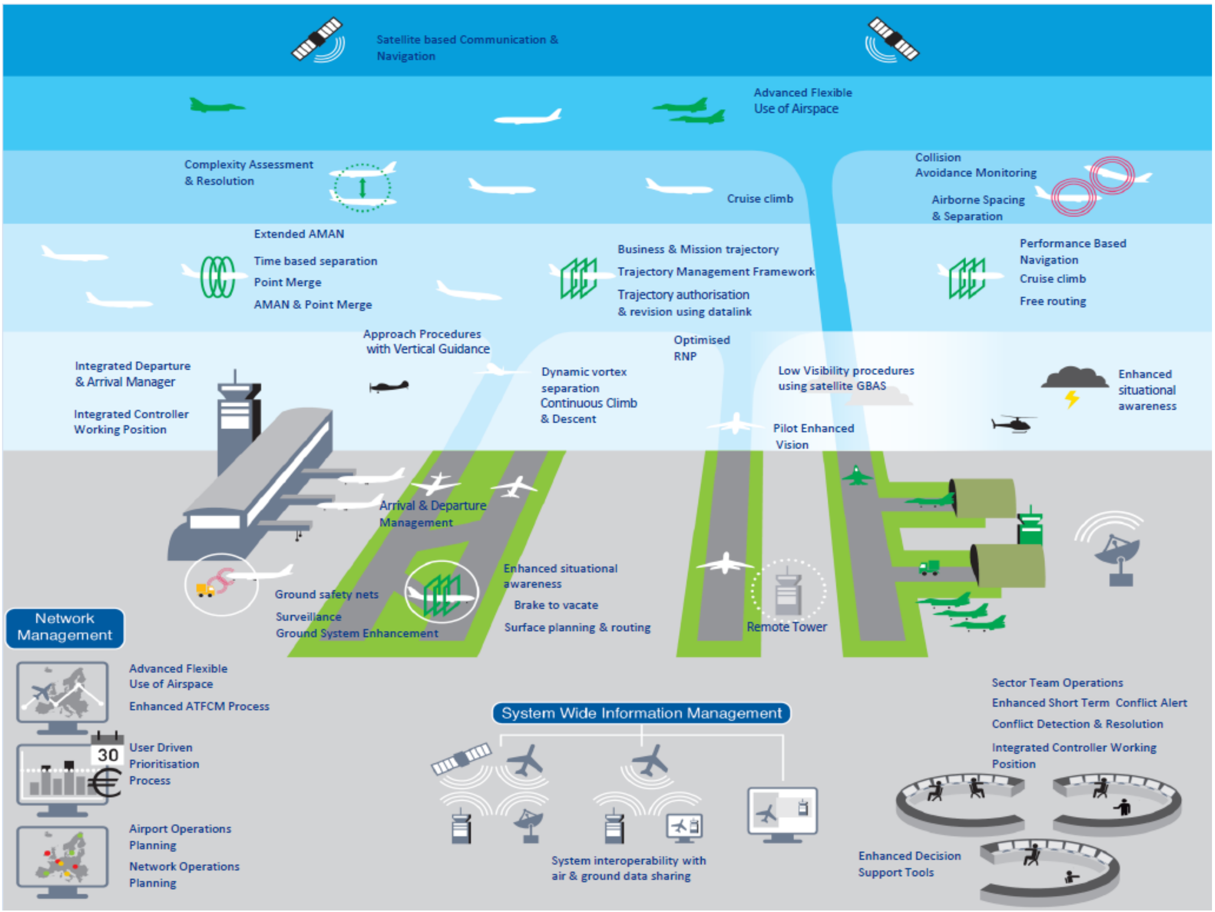


Figure 8.3: Overview of the ATM [129].

are considered many levels of these. The attention is focused over the aircraft because this is at the heart of worldwide interoperability and information exchange at the global level is becoming essential.

The goal is Global Interoperability and ICAO sets the framework for achieving this, but SESAR will support ICAO and the member states in defining the way ahead. SESAR is committed to working with ICAO to establish clear needs for high level global standards, supplemented by harmonised industry standards to support ’block upgrades’ of the future ATM system.

Chapter 9

Conclusion

In this chapter there is developed the discussion about the answer at the main questions in the study purpose.

The first point of the study purpose is taken into account in the second and third chapter of this work. It helps to create the ground of the successive argument and it also shows the main problem that could generate a delays or a disruptions in the airline industry. We know that the structure of airlines is divided into various phase and they are strategic, tactical and operational phases. part of the strategic phase are Routes, Type of aircraft (size), Price / policy, Out-source and Planners. The tactical phase is composed by Normal week plan, Supports, Aircraft flights maintenance, Cycle Time and frequency of flight, Crew scheduling. Finally, the operational phase is unrolled in Delay maintenance, Scheduling, Roll the plan, Disruption management.
In all these phases can be possible to experience delays, but the phase most subject to variations is the operational one.
Moreover, in the third chapter we investigate more precisely the planning operation for the crew and also the airplanes, so the background is complete to develop the main topic of the thesis.

To reply at the second statement point, one complete chapter in this work is dedicated to this and it is the chapter six. The disruption situation originates in a local event such as an aircraft maintenance problem, a flight delay, or an airport closure or large traffic in the airport, but also for problems of crew and/or plane scheduling or bad weather condition.
The plans for aircraft assignments, crew assignments and maintenance of the flight schedule is handed over from the planning department to the operations control centre (OCC) a few days days ahead of the day of operation. The deadlines are different for different resources. Short-haul plans are usually handed over one day

ahead of the operation date, while long-haul information is handed over three to five days before.
When one disruption comes, operations personnel in the airlines must find real-time solutions so that it is able to replace the airline to its original schedule as soon as possible.
An operations control center is required to make important operational decisions with significant operational and commercial ramifications and often under extreme time pressure and sometimes without complete information. Manual methods often mean that only one or two possible solution options can be considered with the prospect that a solution far from optimal across all the key areas may be implemented. As a result of the sequential nature of manual processes, implemented for one resource might very well have a profound impact on other areas.

In the chapter seven, it is address the problem of analysis of some datas from the Avinor company and this is indicated as point three in the study purpose. It is showed the more common charts and analysis to begin the dissertation about the punctuality in the airlines. The company unfortunately didn't provide enough material and informations for an accurate analysis.

For the sub-statements number four and five are fundamental the central chapters, especially the number five and six, so in conclusion it is possible to affirm that this section seeks to determine the difference between the approach of the previous authors. Considering the high number of work related presented, it is not possible to present a detailed comparison of their approach with each of the works mentioned. However, it is possible to present the main differences. In their opinion, their work is different from previous ones regarding the following key features:

- the scope;
- technology ;
- integration;
- quality costs.

In the field of restoration of operations, there are three dimensions: aircraft, crew and passengers. The authors classified its work according to the size that consider an integrated approach when you are able to address two of these dimensions. The authors' work differs from the previous ones and in that it considers the three dimensions of the domain. In this sense and to the best of their knowledge, their approach is fully integrated.

Both aircraft recovery and crew recovery problems have been considered. Both the aircraft recovery and crew recovery problems have been modelled as multi-commodity network flow problems where the underlying network is connection network. The paper has also considered the correlation and dependency of two problems. A new algorithm has been presented which solves aircraft recovery and crew recovery problems sequentially and in interactive manner, in the paper [62] and this could be the optimal solution. The subject algorithm takes into account the dependency of two problems, represents the correlation between them without integrating the two recovery problems.

Moreover, to reply at the substatement four, one complete section is dedicated for that, in the chapter six. The MAS architecture, the multi-agent system is really interesting and taken into account in this field of investigation. The agent and service model were the outputs of this process and the base for this architecture. Moreover, it could be iterated for all the agents with the exception of the Supervisor agent.

It is important to capture the costs of delaying or cancelling a flight, from the point of view of the passenger and not only from the point of view of the airline company. The connected works that consider the cost of delaying a flight, assign a cost to each minute of delay. In the authors' opinion, this only captures the cost from the point of view of the airline company because that cost is defined by the airline and it is valid for all flights, without considering the profiles of the passengers in the specific flight being affected by a disruption. The authors' approach uses quality costs that considers the opinion of the passengers on the specific flights and that is one of the biggest differences regarding the related work published so far.

To reply at the substatement six, there is all the chapter five that briefly says that the Air Transport Association has estimated that there were a total of 116.5 million delay minutes in 2006, resulting in a $7.7 billion increase in direct operating costs to the U.S. airline industry. Nonetheless, also in the United States, the introduction in 2006 of airspace flow program (APPs) enabled the FAA to target more precisely, en route, flights affected by weather. Because unaffected flights could easily be excluded from ANSP interventions, this capability is estimated to have reduced delay costs by $ 190 million over the first 2 years of implementation. Determining more specifically which flights should be subject to, and which exempt from, a ground-holding action triggered by reduced airport capacity remains an open research question. Moreover, with the increase in air traffic is not impossible to run into the resulting delays also due to the crowding airports. The total direct operation costs in 2006 amounted $ 7,663 per minute ($ millions) and

it is composed from fuel, crew, maintenance, aircraft ownership and others.
The cost scenarios are derived from independently concurring sources on total passenger costs during 2003 . Two airline sources have also been used to rationalise the equal split between hard and soft costs and we show that in total are 0.16, 0.36, 0.42 respectively for low base and high cost in percentage. Overall, the total base cost scenario for 2008 is 20% higher than the value of 2003.

Finally, the discussion about the last sub-statement, the number seven, is developed in the chapter eight. In it is underlined the influence of the new trends in the overall airline industry, and in what way they should be changed also the disruptions management and the manage of the delays.
There are three main changes to adopt to ATM. The first one is to utilize a new 4D principal trajectoryb. The second is a system wide information management and the latest is the automation.
In that way it will be possible to enable EU skies to handle 3 times more traffic than nowadays, at the same time improving safety by a factor of 10, reducing the environmental impactper flight by 10 % and also cutting ATM costsby 50 %.

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