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A Predictive Model to Evaluate and Improve Punctuality of Fleet of Wide-body Aircraft Maintenance and Reliability

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Abstract

This research was carried out in Martinair M&E department with the aim of analyzing its impact on the network performance and providing an efficient tool to predict delays and the On-Time Performance (OTP). To develop the predictive model, two research questions had to be previously answered:

1. What are the biggest M&E delays and unplanned ground time (UGT) drivers?
2. What are the factors that influence each driver?

The methodology undertaken in this research is based on conventional analytical methods to identify the 'real' delay root causes and their relative importance. Historical data is extracted from Martinair's delay database for the fleet under analysis (Boeing 767 and McDonnel Douglas MD11). After that, in order to have an overview of the growth of the flight delays and UGT, several graphs are plotted with relevant information such as: rate and average time of delays and UGT per quarter; rate and average time of delay and UGT per station of departure; and rate and average time of delay and UGT per Maintenance Delay Categorization Groups (MDCG). Some interviews to people working every day in the key processes were made and fishbone diagrams were drawn to completely identify and understand completely the root causes. Statistical analysis (Binomial Logistic Regression and GLM-ANOVA) is applied to investigate the significance of the factors and their interactions and to build a regression equation which allows the development of the predictive model.

The predictive model gives valid OTP results and enables managers and engineers to take preventive measures in order to enhance punctuality.

Keywords: Aircraft Delay, Punctuality, On Time Performance, Dispatch Reliability, Aircraft Maintenance

Resumo

Este estudo foi desenvolvido no departamento de Manutenção e Engenharia (M&E) da companhia aérea holandesa, Martinair, com o objectivo de analisar o impacto deste departamento nos atrasos dos voos e fornecer uma ferramenta que possibilite a previsão dos atrasos de aviões e do *On-Time Performance (OTP)*.

A metodologia adoptada, nesta pesquisa, foi baseada em métodos convencionais de análise para a identificação das causas 'reais' do atraso de aviões e sua importância relativa. Foram utilizados dados históricos, da base de dados de atrasos da Martinair para a frota em análise: Boeing 767 e McDonnel Douglas MD11. Para ter uma ideia da evolução dos atrasos dos voos e dos UGTs, foram elaborados vários gráficos com informação relevante, como por exemplo: taxa e tempo médio de atraso e de UGT por trimestre; taxa e tempo médio de atraso e de UGT por aeroporto de partida; e taxa e tempo médio de atraso e de UGT por Grupo de Categorização de Atrasos de Manutenção. Foram, ainda, feitas algumas entrevistas a trabalhadores que estão envolvidos nos processos chave e elaborados diagramas *fishbone* para conseguir identificar e perceber as causas dos atrasos. Foi aplicada análise estatística (Regressão Logística Binomial e GLM-ANOVA) para investigar a significância dos factores de manutenção e suas interacções. Esta análise permitiu construir uma equação de regressão linear que possibilita o desenvolvimento do modelo de previsão. Este modelo fornece resultados válidos para o OTP e para o número esperado de atrasos, facilitando o trabalho dos gestores e engenheiros na construção de medidas de prevenção para melhorar a pontualidade das partidas.

Palavras chave: Atraso de aviões, Pontualidade, *On-Time Performance*, Manutenção de Aeronaves, *Dispatch Reliability*

List of Acronyms

A/C	Aircraft
ACARS	Aircraft Communication Address and Reporting System
ADT	Average Delay Time
AMOS	Integrated IT software for Maintenance & Engineering
AOG	Aircraft On Ground
APU	Auxiliary Power Unit
ATA	Air Transport Association
ATC	Air Traffic Control
AUR	Aircraft Utilization Rate
AUT	Average time of UGTs
BITE	Build-In Test Equipment
BOW	Bill of Work
DR	Delay Rate
FH	Flight Hour
FIM	Fault Isolation Manual
FOD	Foreign Object Damage
GSE	Ground Support Equipment
HIL	Hold Item List
IRS	Inertial Reference System
LLL	Log-likelihood
LRU	Line Replacement Unit
M&E	Maintenance Engineering Department
MAREPs	Open Maintenance Reports
MCC	Maintenance Control Centre
MDCG	Maintenance Delay Categorization Group
MEL	Minimum Equipment List
MMEL	Master Minimum Equipment List
MP	Maintenance Program
MPA	Manpower
MPH	Martinair Holland
MRB	Maintenance Review Board

MRO	Maintenance Repair and Overhaul
MTBF	Mean Time Between Failure
NIL	Not In List
NTO	Non-Technical Objection
OTP	On-Time Performance
PIREPs	Open Pilot Reports
PMDU	Predictive Model for Delays and Unplanned Ground Times
RTS	Release to Service
SPL	Schiphol - Amsterdam Airport
TOA	Technical Operation Advice
TTA	Time to A-check
UGT	Unscheduled Ground Time
US	Unserviceable

Content

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Chapter 1

Introduction

Since the past decades, the airline business has been growing fast as travelling for business and leisure purposes increased strongly worldwide. As a result, the aviation industry senses a harsh competition between its members. Carriers need to be more demanding with their service each day, in order to fulfil their valuable high-yield costumer expectations. Thus airlines have to become more efficient if they want to invest in the service quality. The first logical solution is flying their aircraft as much as possible: an aircraft on the ground means real profit losses.
Nonetheless, it cannot be forgotten that airplanes are huge machines that normally transport more than one hundred people. Therefore, along with costumers' satisfaction and profitable revenues, the enterprises in this field are required to have a major concern about safety. An operator is liable for flying its aircraft in the safest condition which means in the most reliable and airworthy condition. The Maintenance & Engineering Department (M&E) of an operator is in charge of Maintenance, Repair and Overhaul (MRO) activities and it is responsible for release aircraft to service within a limited time, so it plays a key role in aircraft availability
Punctuality has become the daily concern inside the airline industry. It can be seen as a key performance indicator and a valuable differentiator in customer services. In fact, researches show that an improvement on On-Time Performance (OTP) is positively correlated with operating profit as it helps to accomplish considerable cost savings, according to Niehues et al [1].

This research is conducted into the context of the Reliability Engineering of Martinair M&E. The present document is the report of the graduation project carried out for 8 months in Martinair Holland N.V. to fulfil the degree of MSc in Aerospace Engineering.

Nowadays with the financial crisis, an airline with a well-known reputation as Martinair, has to strive between achieving sufficient returns for the continuity of the company and to keep improving the company processes to offer its customers the high quality services they are used to.
It is extremely important for M&E to be in control of the dispatch punctuality and to be able to steer the maintenance processes to reach the punctuality targets. Therefore, the M&E of Martinair wants to find out what are the bottlenecks of its department in order to be able to control and to reduce, if possible, the number of aircraft delays. This research investigates potential maintenance drivers for aircraft delays based on historical data from the last three years. Moreover, it is developed a tool to predict the number of delays in a time period set by the user. To accomplish this objective a careful investigation is conducted within M&E department and regression analysis theory is applied to the historical data to build up the Predictive Model for Delays and Unplanned Ground Times (PMDU).

1.1 Background

1.1.1 Martinair General Facts

History

Martinair Holland N.V. is a Dutch airline based in Schiphol, Amsterdam, which operates to several destinations all over the world in both cargo and leisure carrier markets, for more than fifty years. The aviation pioneer Martin Schröder established the airline under the name of Martin's Air Charter on May 24, 1958. The airline's operations and fleet have expanded gradually through the years. *Your choice* is Martinair's company slogan. It offers a quality product based on service, high frequency to destinations, direct flights and year round operations within a worldwide network. Martinair is pride of distinguishing itself as a carrier that has grown from a small charter company to an *intercontinental leisure and 'family, friends and relatives' carrier*, as they like to call themselves. Besides the passenger service to far away vacation destinations, Martinair has established an international reputation as the biggest transporter of perishables, such as, fresh flowers, vegetables and fruit. Although the cargo market is specialized in the previous kind of goods, it also transports other sort of cargo such as computers, cars, cows to the Middle East or horses to international events.

Operations

The Martinair's wide-body fleet under analysis in this study is a relatively old fleet and constitutes two aircraft types: Boeing 767-300ER and McDonnell Douglas MD11. The B767 fleet is mainly used for passenger flights to holidays' destinations in Central America and Africa, such as Curaçao, Cancun or Mombasa. The MD11 fleet also does cargo transports to several destinations in America and Africa, like Miami, Nairobi or Bogota.

A/C Type	Number of A/C in the Fleet	Oldest A/C Age (years)	Newest A/C Age (years)
Boeing 767 (passenger transport)	6[1]	2	16
McDonnell Douglas MD 11 (cargo transport)	7	18	11

Table 1.1 - Martinair wide-body fleet under analysis

Two of the passenger aircrafts which have more than one hundred thousand flight hours (PH-MCG and PH-MCH) have been phased out since July 2009. As a result, it leads to reduce flexibility, and to reserve capacity not readily available. The operator will feel some limitations when dealing with disruptive events such as delays. Therefore, as stated by Diederik Pen, the Chief Operations Officer of Martinair,

"It is of prime importance to keep our (Martinair) *operational process under 'firm' control"*

Moreover, M&E wants to be ready for the economic recovery that has started to give some positive signals. The airline market slight improvements give an incentive to continue working to achieve better network performances.

Maintenance

Maintenance & Engineering department is responsible for maintain and overhaul both Boeing 767 and MD11 fleet. The maintenance procedures can be divided into two main groups: line and base maintenance. These two types of maintenance are defined as follow.

Line Maintenance is the combination of technical and administrative handling, needed to keep or to restore the aircraft in a serviceable, airworthy and to the customers' satisfactory condition, in order to have the aircraft operational for the purpose of its next flight.

Base Maintenance is the combination of technical and administrative handling needed to inspect, rectify, repair, overhaul or modify the aircraft to an approved standard, to be carried out during a planned period of time for which the aircraft will be out of service.

The base maintenance activities are always carried out in Hangar 32 at Schiphol-East while line maintenance activities are handled at the gate at Schiphol Centre.

The base maintenance consists mainly of schedule maintenance (letter checks). Martinair has a policy of performing only A-, C- and D-checks on its aircrafts. M&E department is responsible for the planning and execution of B767 and MD11 A-check. The C- and D-check are outsourced. The Martinair interval between A-checks is set as 700 flight hours for MD11 and 770 flight hours for B767. However, the actual performed date can be delayed by the operator for several reasons. Normally, a check task can be extended up to 10% according to the flight hours or flight cycles. Although there are some tasks that are not extendable, they have higher interval than the average A-check interval. Thus, Martinair is able to perform the A-check within a 110% interval, if not the aircraft must be on ground until it is performed. The A-check is divided in 12 parts concerning different tasks (A1-A12). It is possible to split the A-check because there are check tasks that have a bigger interval than the A-check one. The downtimes of an A-check are normally around 1 day and

[1] Since July 2009 only 4 aircrafts have been in the B767 fleet. Two of them were phased out while this research was being conducted.

7 hours for B767 and 1 day and 3 hours for MD11, when an aircraft receives heavy maintenance (C- and D-check) the downtimes are longer. It must not be forgotten that there are also some inspections of the A-check preformed during C- and D-check.

1.1.2 Relevant Definitions

Before moving on, it is given general definitions of the items listed below that are referred in this thesis [4]:

Airworthiness
Base Maintenance
Chargeable Event
Condition Serviceable
Critical Task
Defect
Human Factors
Delay
Event
Flight Time
Ground Time
Incident
Line Maintenance
Line Replacement Unit
Maintenance Occurrence
Maintenance Program
Master Minimum Equipment List (MMEL)
Minimum Equipment List (MEL)
No-Go items
No Fault Found (NFF)
Non-chargeable Event
Outstation
Turnaround
Service Bulletin
Scheduled Maintenance
Rotable
Repairable
Repair
Pre-flight Inspection
Unscheduled Maintenance
Unscheduled Ground Time (UGT)
Work Order

Airworthiness

The condition of an item (aircraft, aircraft system or part) that meets its type designs in that the item operates in a safe manner to accomplish its intended purpose.

Base Maintenance

The combination of technical and administrative handling needed to inspect, rectify, repair, overhaul or modify the aircraft to an approved standard, to be carried out during a planned period of time for which the aircraft will be out of service.

Chargeable Event

An event is chargeable when it is caused by a known or suspected aircraft basis malfunction of a system or component and requires necessary corrective action.

Condition Serviceable

Equipment or parts of equipment that are in condition to return to the operational status or to an aircraft.

Critical Task

A maintenance task involving some element of disassembly/re-assembly of several aircraft components of the same type fitted to more than one system on the same aircraft. If an error is repeated on more than one system of same type, it would jeopardise the airworthiness or safe operation of the aircraft.

Defect

A finding on the aircraft noticed en-route by either the flight crew or cabin crew or during a(n) (Pre-flight) inspection by authorized maintenance personnel

Delay

A technical delay occurs when a malfunctioning of an item, the checking of same or necessary corrective action, causes the final departure to be delayed by more than a specified time after the programmed departure time in any of the following instances:

- ✓ An originating flight departs later than the scheduled departure time,
- ✓ A through service or turnaround flight remains on the ground longer than the allowable ground time,
- ✓ The aircraft is released late from maintenance.

Event

An event indicates any kind of problem, incident, occurrence, etc. that is reported to Maintenance Control (MC).

Flight Time

The total time from the moment aircraft first moves for the purpose of taking off (i.e. off blocks) until the moment it finally comes to rest at the end of the flight on the designated parking position and all engines are stopped[2].

Ground Time

The total time from the moment the aircraft is on-blocks after flight, and all engines are stopped, until the aircraft is off-blocks for the purpose of flight.

Human Factors

Body of scientific facts concerning the human characteristics (the term includes all psychosocial and biomedical considerations).

[2] All engines are considered stopped, even when one engine has to be kept running for ground purposes.

Incident

It is any event of technical nature which may be considered too significantly to affect the potential airworthiness of an aircraft.

Line Maintenance

The combination of technical and administrative handling, needed to keep or to restore the aircraft in a serviceable, airworthy and to the customers satisfactory condition, in order t have the aircraft operational for the purpose of its next flight.

Line Replacement Unit

A Line Replacement Unit (LRU) is a unit of an assembly (e.g. engine) that can be removed from aircraft as a single component and does not require removal of the complete assembly. The same for installations: an LRU component can be installed in an aircraft independently after the installation of the assembly.

Maintenance Occurrence

Any situation on the aircraft, or in the near vicinity of the aircraft, observed during the flight and which is maintenance related or observed during ground-time, which affects or could affect the airworthiness or safe operation of the aircraft, or could result in an unsafe situation for personnel working in that maintenance environment.

Maintenance Program

The Maintenance Program (MP) contains the complete set of taskcards for a specific aircraft-type. The initial maintenance program for an aircraft-type is issued by the aircraft-manufacturers. These Maintenance Review Board (MRB) reports contain the minimal requirements to operate the aircraft safely. Each operator can then adapt the MRB reports to meet the requirements of the national authorities.

Master Minimum Equipment List (MMEL)

The MMEL is compiled by the manufactures in concert with the airworthiness authority. The MMEL serves as general basis to allow operators to utilise an aircraft when some systems or components are inoperative, and it gives the specific conditions and time limits, to ensure an acceptable level of safety. The MMEL is the minimum required basis, to guard the aircraft safety.

Minimum Equipment List (MEL)

To dispatch an aircraft safety when repairs of an inoperative system or component are not possible without considerable impact on the flight schedule or when spares or tools are not available.

No-Go items

A defect for which maintenance action-according MEL must be taken before the aircraft can be released for further flight.

Non-Chargeable Event

Events that are caused by circumstances that are not due to airplane failure. The aircraft non-chargeable items are defined by the Reliability Exchange of Airline Data International (READI) group. The READI non-chargeable items are, as follows:

- ✓ Servicing (oil, structures, de-icing, water, tire pressure, etc.);
- ✓ Precautionary Maintenance (repairing when an aircraft could be released per MEL;
- ✓ Normal Wear Maintenance (re-lamping, tires, brakes, normal battery replacement);
- ✓ Scheduled Maintenance Activities (letter checks, etc.)
- ✓ Logistics (parts, tools, personnel, facilities, documents, etc.)
- ✓ Damage (directly or indirectly induced by outside force)
- ✓ Known Human Factors
- ✓ Secondary or Down Line Delays

No Fault Found (NFF)

It is a figure in component reliability statistics. Rotables are marked with NFF when it was suspected to be failed, removed from aircraft for that reason, but during testing, it is found to be in a serviceable condition. It is equal to the number of unscheduled removals minus the number of failures divided by the number of unscheduled removals.

Outstation

All stations except home base and/or main base.

Pre-flight Inspection

The inspection carried out by the crew before flight to ensure that the aircraft is operational for the intended flight.

Repair

The restoration of an aircraft/aircraft component to a serviceable condition in conformity with an approved standard.

Repairable

Material with a part number, but no registered serial number and no registered maintenance history. A repairable is a consumable that can be repaired based on economical limits.

Rotable

Material with a part number and serial number. Rotable parts have a computer registered maintenance history and can be repaired as long as repair costs do not exceed economical limits.

Scheduled Maintenance

Maintenance performed to retain an item in a serviceable condition by systematic inspection, detection, prevention of failures, replacement of wear-out items, adjustment, calibration, cleaning, etc. (A, B, C checks, weekly's, 150 hours, etc., modification programs, aircraft painting and major scheduled component changes such as landing gears or engines).

Service Bulletin

Service Bulletin contains information issued by the manufacturer of an aircraft, aircraft engine or component that details maintenance procedures that will enhance safety or improve the performance of the product.

Turnaround

The execution of the line maintenance work package.

Unscheduled Maintenance

Maintenance performed to restore an item to a satisfactory condition by correction of a known or suspected malfunction and/or defect.

Unscheduled Ground Time (UGT)

Treatment of aircraft defects or malfunctions not being 'scheduled maintenance' causing the aircraft to be 'out of service' for a certain period of time and overnight time. This includes AOG's, unscheduled (planned or unplanned) maintenance, damages, extended scheduled maintenance, technical delays and repairs.

Work Order

For all maintenance events which are carried out on an aircraft, a work order has to be issued in the system. No matter whether the technical staff has to perform a check, a time removal or to rectify a snag, the document which proves that a certain action has been completed is always the work order.

1.2 Research Problem

As stated before, in airline business there is an urge to measure the effectiveness of the maintenance process in order to find the best trade-off between safety and costs. According to

Niehues et al [1], delay costs can be from 0.6% to up as much as 2.9% of airlines revenues and one way to increase the operating profit is to pay more attention to On-Time Performance (OTP).
For this purpose, the M&E main objective is to maximize the operational reliability and aircraft availability. Therefore, Martinair has already a *Reliability Program* with the aim of reducing the number of chargeable delays and unscheduled ground times (UGTs). However, the analysis of the chargeable delays is not sufficient if Martinair wants to be in control of its punctuality. It is essential to find out the bottlenecks of the processes. In other words, the next step for the Reliability Engineering is to analyze the impact of M&E on the network performance and implement measures to enhance OTP.
Hence, the objective of this thesis can be formulated as follows:

Develop a predictive model to perform analysis of Martinair M&E processes effectiveness with the aim of controlling/improving punctuality.

Other questions that cope with this objective need to be addressed:

1. What are the drivers for the delays and UGTs?
2. How can delays and UGTs be reduced?

1.3 Report Outline

The thesis report is strutted in five Chapters and its outline is as follows.

Chapter 1 provides the reader a brief background of this research and the problem statement and main objectives.
Chapter 2 describes the theoretical framework and it is divided in two parts: Literature Review and Research Methodology. The Literature Review discusses aspects such as reliability engineering, flight delay and dispatch reliability and some delay predictive models. The Research Methodology introduces each phase of the project from the data collection to the development of the predictive model.
Chapter 3 presents the analysis and results. This chapter shows the results for the two different analysis carried out during the research: descriptive statistics and statistical analysis of delays and unplanned ground times.
Chapter 4 discusses the implementation of the model. The tool developed is also validated and tested in this chapter.
Chapter 5 synthesises the results and gives recommendations.

Chapter 2

Theoretical Framework

This chapter presents the literature review concerning the subject described above and the methodology followed in the research.

2.1 Literature Review

In this research, it was done a literature review about general concepts of *Reliability Engineering* (section 2.1.1), definition and factors of *Flight Delay and Dispatch Reliability* (section 2.1.2) and previous approaches of *Delay Predictive Models* (section 2.1.3).

2.1.1 Reliability Engineering

Reliability is defined as the probability of the equipment or a process functioning without failure, when operated as prescribed for a given time of interval under stated conditions [2]. Nevertheless, the failure could be described as the inability of a system, subsystem or component to perform its required function [3]. According to Bazovsky, reliability is a yardstick of the capability of equipment to operate without failures when put into service. Reliability predicts the behaviour of equipment mathematically under expected operating conditions. Moreover, reliability can express in numbers the chance of equipment to operate without failure for a given length of time in the environment for which it was designed [4].

The performance of a component or system can be accessed with RAMS (Reliability, Availability, Maintainability and Supportability) and it is often express in terms of probability [5]. Each of these factors is closely related to each other and influences each other in a positive or negative way.

- Reliability has already been defined in the previous paragraph.
- Availability performance is the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given interval, assuming that the required external sources are provided [6].
- Maintainability is the inherent characteristic of an item related to its ability to be restored when the specified maintenance task is performed as required. In other words, maintainability measures certain parameters to monitor the performance and to find out trends that can help to adapt the maintenance process [5].
- Supportability is the inherent characteristic of an item related to its ability to be supported by the required resources for the execution of the specified maintenance task [7].

The main objective in the development of such system (specified by operation and maintenance requirements) is to be cost-effective [8].

2.1.2 Flight Delay and Dispatch Reliability

A complex chain of events occurs before aircraft departure and some of them may cause an unexpected delay. Sometimes a delay results from a single reason, but most delays come from multiple causes. The departure delay has increased significantly in the past decade due to several factors such as the increasing demand of air transport [9]. The International Air Transport Association (IATA) created the *IATA Delay Codes* to help airlines standardize the reason of a flight late departure. More information about these codes can be found in Appendix A. According to IATA, the delays can be caused by:

- ✓ Passengers and Baggage Handling (code 11-18)
- ✓ Cargo and Mail (code 21-29)
- ✓ Aircraft and Ramp Handling (code 31-39)
- ✓ Technical and Aircraft Equipment (code 41-47)
- ✓ Damage to Aircraft and Automated Equipment Failure/EDP (computer system) (code 51-57)
- ✓ Flight Operations and Crewing (code 61-69)
- ✓ Weather (code 71-77)
- ✓ Air Traffic Control Restrictions and Airport or Governmental Authorities (code 81-89)
- ✓ Reactionaries Reasons and Miscellaneous (code 91-99)

Furthermore, it is possible to group the delay factors under controllable and uncontrollable and also by airline activity as presented in the chart below [11]. This helps airlines to understand how they can take effective measures to be in control of their On-Time Performance (OTP).

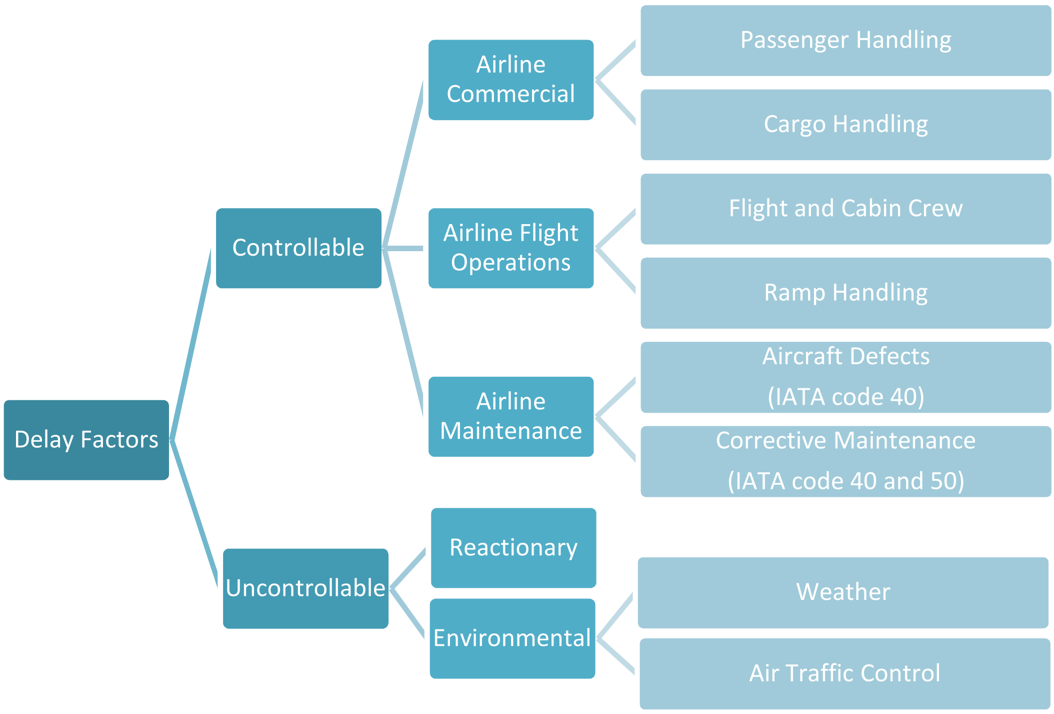


Figure 2.1 – Delay Factors based on the Boeing Seminar "Delay: How to Mitigate it"

The Maintenance & Engineering (M&E) department of an airline is directly responsible for the IATA delay codes 40 and 50 which can be grouped as controllable factors. Therefore, it is important for M&E to find the root causes of the *Airline Maintenance* delay factors.

The On-Time Performance (OTP), also known as, *Dispatch Reliability* is defined as the percentage of revenue departures which do not incur a delay because of technical problems [10]. It is a measure of the overall effectiveness of the airline operation with respect to on-time departure. The dispatch reliability can be calculated using equation 2.1 or it can be equal to 100% minus *Delay Rate* [14].

$$Dispatch\ Reliability = OTP = \left(1 - \frac{\#\ of\ delays}{\#\ departures}\right) x\ 100 \qquad (2.1)$$

Sridhar [11] mentioned that there are also influencing factors that can affect the *Dispatch Reliability.*

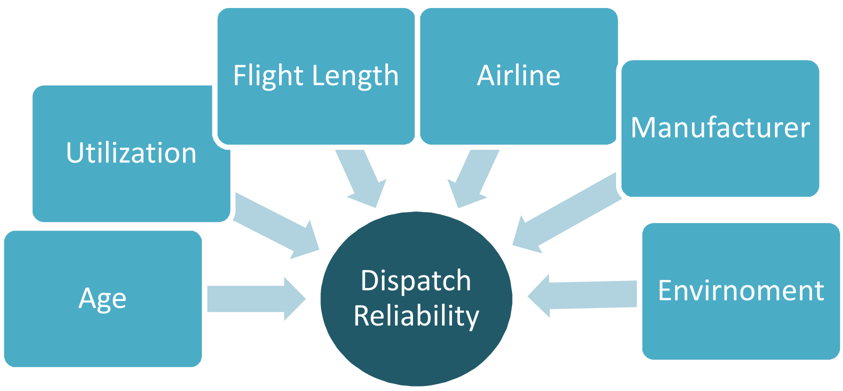


Figure 2.2 – Influencing Factors Affecting Dispatch Reliability

From the six influencing factors displayed in Figure 2.2, the ones that are related to M&E and are interesting for further analysis are: *Age, Flight Length, Utilization* and *Airline*.

AGE

Ageing aircraft can be described as a process through which the aircraft experiences the effects of an increasing age [12]. Aircraft age is a combination of several factors such as chronological age, the number of flight cycles, or the number of flight hours. Besides, maintenance on an aircraft, the type of aircraft operations, and the operational environment also affects the ageing process. It is further complicated to determine the age of an aircraft by the fact that individual aircraft components age differently depending on those factors. It was chosen in the current study not to take into account the age as a factor of On-Time Performance (OTP). A careful examination of the relation between aircraft age and dispatch reliability could be the subject for another research.

FLIGHT LENGHT

In aviation business, flight length is defined as the airborne time during a flight. Depending on the flight hours, the flight can be categorized into short-, medium- and long-haul flight. As the name suggests, long-hauls are journeys that involve long distances typically beyond six and half hours.[3] This factor is not taking into account in the current research because the airline under study, Martinair, operates mainly cargo and passenger long-haul flights to Africa and America.

UTILIZATION

Aircraft utilization is the average daily airborne flying hours or cycles for one aircraft. A daily utilization can be calculated for the entire fleet or for a single aircraft. In this research, the aircraft utilization is calculated by the following equation:

$$Aircraf\ Utilization\ Rate\ (AUR) = \frac{Totalflying\ hours}{Number\ of\ days} \qquad (2.2)$$

This factor is one of the chosen to study the probability of a delay in the statistical analysis. The Aircraft Utilization Rate (AUR) represents the average daily utilization of an aircraft for the past 7 days.

AIRLINE

The operator plays a decisive role in controlling the dispatch reliability. As shown in Figure 2.1, the controllable factors can be related with the different airline departments: *Commercial, Flight Operations* and *Maintenance*. The *Airline Maintenance* factors will be analysed for this research purpose.

[3] Defined by Thomas Cook Airline

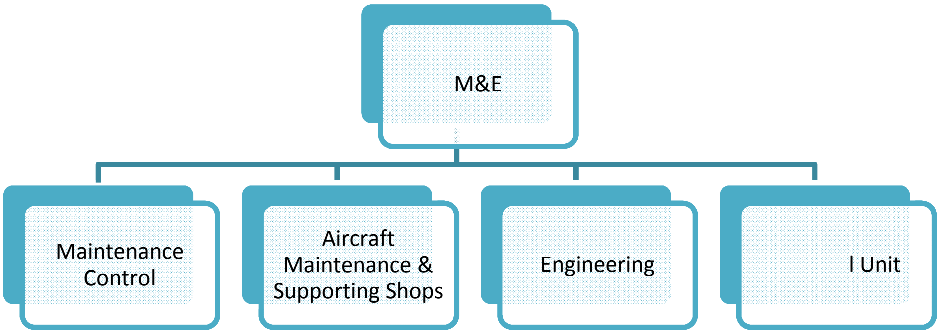


Figure 2.3 – Basic Structure of Maintenance and Engineering

The basic structure of Martinair Maintenance & Engineering (M&E) is shown in Figure 2.3. The *Maintenance Control Centre* (MCC) is responsible for keeping track of all vehicles in operation. Vehicle location, maintenance servicing needs, and others requirements are monitored by MCC. Moreover, to minimize delays and down time, Maintenance Control Centre coordinates operations, maintenance and engineering activities. It is also responsible for daily technical operation. The *Aircraft Maintenance & Supporting Shops* is responsible for Line and Base maintenance at Schiphol and worldwide. Its duty is also the initial and recurrent training for certifying staff and the organization of all other training activities for M&E organization. The primary purpose of *Engineering* is to establish the initial maintenance program from manufacturer's maintenance manual and other documents and to continually upgrade the program over time. *Engineering* will also provide technical assistance in troubleshooting and equipment problem. *Material Unit* is responsible for the availability of contracts and components worldwide which means: negotiation and monitoring the vendor performance within the agreed M&E budget business contacts; keeping vendor relations; establishing and keeping contracts; and maintenance and capital cost for stockholding [13] and [14].

2.1.3 Delay Predictive Models

The On-Time Performance is a key factor of airline schedules to maintain the customer satisfaction and to attract new ones. However, flight schedules often suffer from irregularities, leading to unreliable services [15].

In the literature, it is possible to find some studies that develop prediction model for the delays. Most of them are related to: prediction of delay propagation in the flight scheduled [16], [17], [18], aircraft rotations between airports [19], [20], [21], or prediction of delays from delay statistics of airports [22], [23]. The focus of these models is in airline and airport operation rather than in maintenance.

Mueller and Chatterji [23] used 12 variables to describe the distribution of delay. The Normal and Poisson distribution were used to compare with historical data and the Least Square method was also applied to good-fit the parameters. Yufeng et al [22] also developed a model for estimating the departure delay distributions using nonparametric methods for daily and seasonal trends. They use flight data from United Airlines and Denver International Airport to build a strategic departure delay prediction model.

Wu and Caves [21] explored the inherent delays of airline schedules resulting from limited buffer times and stochastic disruptions in airline operations. The results show that airline schedules must consider the stochastic nature of daily operations. One way of improve schedules reliability is to embed and design buffer times in airline schedules. Also Wu and Caves [20] investigated the relationship between tight schedule punctuality and aircraft turnaround efficiency at airports. Again, they developed a cost minimization model to optimize the scheduling of aircraft rotation by balancing the use of schedule time and delay costs [19].

Another approach by Sachon and Pate [24] developed a model to assess the effects of an airline maintenance policy on delays, cancellation and in-flight safety. They propose a probabilistic risk analysis model which consists of three tiers: management policies ad decisions (Decision tier), maintenance and delays (Ground model tier) and in-flight safety (In-Flight model tier).

Abdelghany et al [18] tried to use the classic shortest path algorithm to model and predict the flight scheduled delay for United Airlines of U.S. The model used a directed acyclic graph containing a series of nodes, which were sorted topologically in a liner time, to represent and simulate the process of scheduled flights operation and delay propagation. This model has been used at United Airlines' Operation Control Centre to monitor the daily schedule operation. AhmadBeygi et al [16] and [17] showed how delay propagation can be reduced by redistributing existing slack in the planning process, making minor modifications to the flight schedule while leaving the original fleeting and crew scheduling decisions unchanged. They used data from a major U.S. carrier to present computational results.

2.2 Research Methodology

As mention before, this thesis is designed to find out what are the maintenance drivers that are influencing the delay and how they can be control. In this chapter it is given a description about the different steps followed during this research.

2.2.1 Data Collection

The data collection is focused on data related to the 'delay drivers' analysis. In order to identify the main causes of the delays and Unplanned Ground Times (UGT), it is required to establish a database about these disruption events. Thus, a data collection is extracted from Martinair's database for the fleet under analysis (see Table 1.1).

Currently, Martinair works with two main systems which are related to M&E department:

- AMOS, Aircraft Maintenance and Engineering System, is a complex integrated software package that manages the maintenance, engineering and logistics functions of aviation companies. It allows everyone from the staff to access all type of information.
- MPH Technical Delays and Unscheduled Ground Time is a homemade database with all information about delays and UGTs for use of the Reliability team.

When creating a database, it is important to choose the relevant information for the desire objective. Sridhar [25] suggests that the minimum advisable data elements for evaluating the dispatch reliability are, as follows:

- ✓ Date of the event (when delay occurred)
- ✓ Aircraft identification
- ✓ Station (city where the delay took place)
- ✓ Length of the delay (normally in minutes)
- ✓ Flight number
- ✓ Delay Reason (qualitative measure)
- ✓ ATA code

Furthermore, as we are interested in finding the real root causes of the delays and UGTs, other elements are taking into account as well:

- ✓ Aircraft age
- ✓ Aircraft flight hours
- ✓ Aircraft cycles
- ✓ Date of maintenance checks
- ✓ Pilot and Maintenance complaints (PIREPs and MAREPs)
- ✓ Manpower Available

The data element mention above, *Delay Reason*, uses new categories called Maintenance Delay Categorization Groups (MDCG) which are a combination between the delay reasons used in Martinair and the ones presented by Niehues et al [1] and Shridhar [11]. The *Delay Reason* is divided in eight main groups:

- ✓ A/C Mechanical Fault
- ✓ Ground Activities
- ✓ Down Line
- ✓ FOD (Foreign Object Damage)
- ✓ Maintenance
- ✓ Non-Technical
- ✓ Parts
- ✓ Incomplete Record

Furthermore, each of these 1st Order reasons has several specific reasons (2nd Order reasons) which can be seen in Table 2.1. Further information about each reason can be found in Appendix B.

Reason Group MDCG – 1st Order	2nd Order
A/C Mechanical Fault **(A/C Chargeable Event)**	Adjusted cleaned electrical cycle electrical rerack hydro/mech reset hydro/mech swap Inspected / checked install missing parts incomplete information lubricated no defect re-programmed repaired item replaced LRU replaced non-LRU repositioned servicing (toilet, water, fuel) serviced tightened tires (cut/debris)
Ground Activities **(A/C Non Chargeable Event)**	a/c damage engine air start equipment ground support equipment human factors (e.g. training/skills, wrong procedures/installation) loading (baggage, catering) servicing (toilet, water, fuel)
Down Line **(A/C Non Chargeable Event)**	down line short due delays and cancellations
FOD **(A/C Non Chargeable Event)**	bird strike debris tools
Maintenance **(A/C Non Chargeable Event)**	a/c damage approval required (TOA/NTO) (A/C Chargeable Event) deferred maintenance (HIL/MEL/placarded) documentation human factors (e.g. training/skills, wrong procedures/installation) late out of maintenance no wrong procedures planning (personnel or maintenance) personnel not available precautionary maintenance unscheduled maintenance (A/C Chargeable Event) weather
Non-Technical **(A/C Non Chargeable Event)**	air traffic control communications (human factor) facilities flight crew flight operations MEL extension required MEL interpretation
Parts **(A/C Non Chargeable Event)**	Cannibalization inadequate parts NIL stock parts location unknown tools (not available/ US)
Incomplete Record	no info/ unknown action

Table 2.1 – Delay Reasons divided into the Maintenance Delay Categorization Groups

The delay data was gathered from January 2006 until April 2009, however it should be noticed that data concerning PIREPs, MAREPs and manpower are available only since October 2007. Appendix shows a few examples of Martinair data for the elements listed above.

2.2.2 Descriptive Statistics of Delays and UGTs

The US Department of Transportation [26] described the causes of flight delays and cancellations by their increase and current data on the length and nature of delays. Despite it did not focus on determining the causes incurred by the M&E department of an airline, it provides a good methodology to analyse the data. In this research several graphs are plotted with the aim of getting an overall picture of the growth of the flight delays and UGTs of Martinair.

Before showing these results, which you can find in the coming chapter, let's make clear the difference between *delay* and *unscheduled ground times (UGTs)*. As defined above, a delay occurs when a flight departure is later than the scheduled departure time due to a technical problem. An UGT happens when the period of time for maintenance inspections was not scheduled. In reality, the flight crew should send a list of all defects/alarms noticed during the flight an hour before arrival to the station of arrival and to the Maintenance Control (MC). This way, MC would be able to plan the maintenance slot and provide the necessary manpower, components and tools. This information is transmitted by ACARS (Aircraft Communications Addressing and Reporting System), a digital datalink system for transmission of short, relatively simple messages between aircraft and ground stations via radio or satellite. An UGT is also the time that was not scheduled one hour before the aircraft land. Moreover, it can be related to the extension of planned maintenance and aircraft damage.

As can be noticed, despite technical reasons, both delays and UGTs can arise from the same "maintenance problems", i.e. the maintenance drivers that can influence the time of a delay can also influence the time of an UGT. For that reason, M&E needs to analyse both events to achieve the desire control over the maintenance processes.

The plotting analysis differentiates between delays and UGTs' graphs and, instead of using total numbers it takes into account rates and average time of delays. Thus, it is possible to compare fairly the on-time performance for different months/quarters/years. Otherwise it could lead to wrong interpretation of the data. As an example, consider there were more delays in August than in October, you cannot jump to the conclusion that Martinair's performance has decreased during August. A simple explanation could be that the departures have also increased due to external factors, like the peak seasons in that month. As mention before, this problem is solved by using rates instead of total numbers. The definitions of *Delay Rate (DR)*, *Average Delay Time (ADT), UGT Rate (UR)* and *Average UGT (AUT)* are as follows:

$$Delay\ Rate\ (DR) = \frac{number\ of\ delays\ for\ a\ specific\ period}{number\ of\ departures\ for\ the\ same\ period}\ x\ 100 \quad (2.3)$$

$$Average\ Delay\ Time\ (ADT) = \frac{total\ time\ of\ delay\ for\ a\ specific\ period}{number\ of\ delays\ for\ the\ same\ period} \quad (2.4)$$

$$UGT\ Rate\ (UR) = \frac{number\ of\ UGTs\ for\ a\ specific\ period}{number\ of\ departures\ for\ the\ same\ period}\ x\ 100 \quad (2.5)$$

$$Average\ UGT\ (AUT) = \frac{total\ time\ of\ UGT\ for\ a\ specific\ period}{number\ of\ UGT\ for\ the\ same\ period} \qquad (2.6)$$

This analysis looks not only for the departure in Amsterdam Airport Schiphol, which is Martinair's major station, but also for the worldwide business (including outstations).

The next step of this phase is to understand which the most significant MDCG (Maintenance Delay Categorization Group) reasons are. This time the graphs for *Delay Rate* and *Average Delay Time* are plotted quarterly and monthly for the 1st Order and 2nd Order reasons. As there are several reasons it must be applied a criteria to decide the most relevant that should be studied.

After some advices from Martinair's reliability engineers, the reasons chosen are the ones that satisfied one of the following criteria:

1. Delay Rate > 5% OR
2. UGT Rate > 5%

The rate mention above take into account an average of all months considered in the data set specified in the section 2.2.1. The results of this analysis are discussed further on in Chapter 3.

2.2.3 Root Causes and Statistic Analysis

After an extensive analysis of the main groups and the 2nd Order reasons of the MDCG that are causing the majority of the delays/UGTs, the research tries to find out and to proof statistically other possible root causes that might be related to the delays/UGTs.

Root Causes

Normally, airlines utilize delay codes which give a good quantitative knowledge on the delays. However, according to Niehues et al [1] and Sridhar [27], it is good practice to apply cause effect diagrams (CAED), also called fishbone diagrams, to identify and understand the root causes and factors. Yufeng et al [22] used these diagrams to investigate the factors that influence the departure delay. The CAED approach is accomplished with information from people working in the key processes.

A fishbone diagram is drawn to put together all the possible logical factors that might be influencing the delays. As not all of this information is reported, it is necessary to talk directly with the Project Supervisors and Team Leaders. This approach allows the proper choice of the maintenance delay factors to use in the statistical analysis. These factors are shown and explained in Chapter 3.

Statistical Analysis

Statistic analysis interprets quantitative data to consider underlying causes, patterns, relationships and trends. The analysis is based on the proposition that the behaviour of a dependent variable can be explained by a model that takes a form of an algebraic equation that involves other independent

variables that describe the experimental conditions [28]. One of the most interesting parts of statistical analysis is the ability to analyze the interaction effects of certain variables [29].
It is necessary to identify the appropriate type of statistical analysis which is going to investigate if the independent variables have an effect on the dependent variable (response variable) and which is going to estimate the parameters of the model. There are several methods that can be applied depending on the type of variables used. For a data analysis, after obtaining the parameters estimates, it is very important to understand how well the model actually fits the observed data

Variables

As explained before there are dependent variables called response variable and independent variables called as factors or predictors. These variables can be from two types: *categorical variables* or *continuous variables.* The first ones, *categorical variables*, are variables that can only assume a limit number of possible values known as factors levels. *Continuous variables* are, as the name suggests, variables of a continuous function that can assume any value between a lower and upper limit. Miles and Shevlin [29] suggested that in the case of mixed data set of continuous variables and categorical variables, the continuous variables can be transformed into categorical ones. They also pointed out that by transforming the continuous variables into categorical variables one important aspect is the loss of detailed information.

Regression Analysis

Regression Analysis is a statistical tool for the investigation of relationships between variables. In its simplest form regression analysis involves finding the best straight line relationship to explain how the variation in the dependent variable depends on the variation in the independent variable. Thus, regression analysis is the technique most used to analyze quantitative data and make forecast [30]. This kind of analysis can be applied for a single or multiple independent variables but only for a single continuous dependent variable [29]. In general, the multiple regression procedures will estimate a linear equation of the form [32]:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m + \varepsilon \quad (2.7)$$

where

y dependent variable

x_i independent variables with i=1,..., m

m number of independent variables

β_0 intercept (value when all the independent variables are zero)

β_i i^{th} regression coefficient with i=1,..., m

ε error of prediction with mean zero and variance σ^2

General Linear Model – Analysis of Variance

An extension of the simple and multiple regression is the *General Linear Model (GLM)*. The general purpose of GLM is the same as the multiple linear regression. A *General Linear Model* can be developed when it is applied an *Analysis of Variance (ANOVA)*. The ANOVA is used to investigate the significance of factors and their interactions. It explains the variation attributable to the various experimental factors and their interactions. In the case of ANOVA-GLM, it is possible to work with mixed variables formats, i.e., categorical and continuous variables [31]. Furthermore, with this analysis it is possible to use *unequal cells*, i.e. when the data is unbalanced and this occurs if the number of observations for all factors-level combinations are not all equal. The model which uses independent variables as categorical variables is described by the following equation (using only three independent variables A, B and C) [33].

$$y_{ijk} = \mu + a_i + b_j + c_k + ab_{ij} + ac_{ik} + bc_{jk} + abc_{ijk} + \varepsilon_{l(ijk)} \qquad (2.8)$$

where

y_{ijk}	dependent variable
a_i, b_j, c_k	independent categorical variables
i, j, k	factor level of its categorical variable
μ	intercept (value when all the independent variables are zero)
$ab_{ij}, ac_{ik}, bc_{jk}, abc_{ijk}$	interactions between the independent variables
ε	error of prediction with mean zero and variance σ^2

Binominal Logistic Regression

Logistic Regression analysis extends the techniques of multiple regression analysis to research situations in which the outcome variable is categorical like a binary response variable. A binary variable has only two possible values, 0 and 1. If it is applied a multiple regression analysis, the predicted values would spread out over an interval. The logistic regression analysis assumes that the response variable, Y, is dichotomous, but it does not model this variable directly. Instead, it is based on probabilities associated with the values of the response [34]. In theory, the hypothetical, population of cases for which Y=1 is defined as *p*=P (Y=1). Then the theoretical proportion of cases for which Y=0 is 1-*p*=P(Y=0). In absence of other information, *p* could be estimated by the sample proportion of cases for which Y=1. However, in regression context, it is assumed that there is a set of predictor variables $X_1,..., X_m$ (*m* independent variables) that are related to Y and, therefore, provide additional information for predicting Y.

In statistics, logistic regression is used to predict the probability of occurrence of an event by fitting data to a logistic curve. Then, this type of analysis is based on a linear model for the natural logarithm of the odds. Odds are more familiar to most people and represent the relative frequency with which the outcome occurs. Odds are directly related to probabilities and can be translated back and forth using the following relation [29].

$$Odds\ ratio = \frac{p}{1-p} \qquad (2.9)$$

where *p* is a conditional probability of the form $P(Y=1|\ X_1,..., X_m)$.

The logit transformation used in this analysis is done by taking the natural log of the odds [32]. A logit transformations is *link function* which means that it maps the interval (0, 1) onto the entire real number [33]. Then, the Logistic Regression analysis model is identical to the multiple regression analysis one, as shown in equation 2.10.

$$Log_e\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m \qquad (2.10)$$

This analysis will find out the coefficients for the equation 2.10. After that it is possible to convert from a log-odds ratio to a probability by using the equation 2.11

$$p = P(Y = 1|\mathrm{X}_1, \ldots, \mathrm{X}_\mathrm{m}) = \frac{e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m}}{1 + e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m}} \qquad (2.11)$$

<u>Statistical Significance</u>

A sample statistic is statistically significant if a hypothesis test proves it to be too unlikely to have occurred by chance. The *null hypothesis* is the hypothesis we wish to test. Rejection the null hypothesis always leads to accepting the alternative hypothesis [32]. In the regression analysis, the hypothesis test proves if the model estimated is significant. Therefore, the hypothesis test is applied to each parameter estimate. In this case, the null hypothesis is "the parameter estimate is not accepted". An *acceptance region* has to be defined where all values will fail to reject the null hypothesis. *Alpha (α)* is the maximum acceptable level of risk for rejecting a true null hypothesis and it is expressed as a probability ranging between 0 and 1. Alpha is frequently referred to as the level of significance [35]. Alpha should be set in the beginning of the analysis and then compare to *p-values* to determine the significance. The most commonly used levels are 0.05 and 0.01. At these levels, the chance of incorrectly reject the null hypothesis is only 5% and 1%, respectively.

The statistical software will give the *p-value* for each parameter estimate. The *p-value* determines if we reject the null hypothesis. If the p-value is less than alpha, the null hypothesis must be rejected. The smaller the p-value, the smaller the probability that rejecting the null hypothesis is a mistake.

As mention in Chapter 1, this thesis tries to find out the maintenance delay drivers that can be control by M&E department of Martinair. Therefore, it is chosen to perform a GLM-ANOVA analysis using as response variable the *delay time* and as predictors the *maintenance factors* chosen in the root causes analysis. Moreover, it is applied a binominal logistic regression to the data set, coding the response variable as 1 in case of delay or 0 in case of on-time departure, and using as predictors variables the *maintenance factors*. For this purpose, it is used the statistical software package Minitab.

2.2.4 Delay and UGTs Predictive Model

As explained in the previous section, after a proper statistical analysis, it is possible to find out the significant delay and unplanned ground times (UGTs) *maintenance factors*. The statistical software package, Minitab, will give the parameter estimate for the regression model chosen and its statistical significance. To chose the best model several tests (analysis) are done with different combination of the predictors, different types of predictors (categorical and continuous) and different types of interactions between predictors. The decision about the best model will depend on the type of analysis it is used.

<u>Regression Model Choice</u>

For the GLM-ANOVA analysis, which will use the *delay time* as a dependent variable, we must check the value of the R^2 and *Adjusted* R^2. According to Miles and Shevlin [29], the R^2 represents the total amount of variance accounted for in the dependent variable by the independent variables. It is expressed as a percentage of the response variable variation that is explained by its relationship with one or more predictor variables. In general, the higher the R^2, the better the model fits our data. There is the need to adjust this value because if another independent variable is added, the R^2 will always increase. Therefore, a model with more terms may appear to have a better fit simply because it has more terms.

The Binominal Logistic regression analysis estimates the regression coefficients based on the *maximum likelihood principle*. As the name suggests, the estimator will be the value of the parameter that maximizes the likelihood function, *L*. This function is the product of the probabilities for delay (coded as 1) or for on time (coded as 0).

$$Likelihood = \prod_{i=1}^{n} P(Y_i|\mathrm{X_{i1}},\ldots,\mathrm{X_{im}})$$
$$= \prod_{i=1}^{n}\left[\left(\frac{e^{\beta_0+\beta_1x_1+\beta_2x_2+\cdots+\beta_mx_m}}{1+\ e^{\beta_0+\beta_1x_1+\beta_2x_2+\cdots+\beta_mx_m}}\right)^{Y_i} x\left(\frac{1}{1+\ e^{\beta_0+\beta_1x_1+\beta_2x_2+\cdots+\beta_mx_m}}\right)^{1-Y_i}\right]$$

(2.12)

The statistical software compute the regression coefficients which allows the calculation of the likelihood value. If it is considered the logarithm of equation 2.12, the likelihood function changes from products of terms involving the parameters into sums of logarithms of these terms which makes the calculations easier.

$$log - likelihood = \sum_{i=1}^{n}\left[Y_i \log(p_i) + (1+Y_i)\log(1-p_i)\right] \qquad (2.13)$$

where $p_i = \left(\frac{e^{\beta_0+\beta_1x_1+\beta_2x_2+\cdots+\beta_mx_m}}{1+e^{\beta_0+\beta_1x_1+\beta_2x_2+\cdots+\beta_mx_m}}\right)$ and Y_i is the real value of the response.

The objective is to discover the model that maximizes this value. As this value is always negative, we are looking for the closest number to zero.

Predictive Model – On-Time Performance

The regression linear model will predict the probability of one delay taking into account the different factors. However, these probabilities are expected to be always low because it is based on historical data and flights normally departure on time (around 90%). Therefore, the model will never give probabilities of delay much higher than 10%.

Nevertheless, this tool can be useful to predict the on-time performance in larger periods. For example, it is possible to forecast how many flights will be delayed under certain conditions in one week (i.e. using different values for the factors - the independent variables). Then, with this information, we can predict the on-time performance. The Delay Predictive Model measures the impact of a certain factor on on-time performance. The user can set a specific value for one factor and simulate how many flights will be delayed under that condition and how good the fleet will perform in a specific period. For instance, imagine it is decided to increase the *aircraft utilization* for a certain month. The tool allows managers and engineers to check how changes in the aircraft utilization rate will impact Martinair on-time performance.

In this study, it was considered appropriated to use *Microsoft Excel* spreadsheet, shown in other studies [31], as practical and sufficient tool for a limited budget. The data set was divided into a “training” set (90% of the data) and a “testing” set (other 10% of the data). The training set was used to estimate the regression coefficients. Forecasts were then made for the testing set. This model works with a prepared dialog box (Microsoft Excel) and runs the calculations of prepared coefficients through an adapted visual basic for applications (VBA).

Chapter 3

Results and Analysis

3.1 Descriptive Statistics of Delays and UGTs

As mention before in Chapter 2 to get a better overview of the Martinair performance, this research starts to look to the growth of the delays and UGTs (Unplanned Ground Times) over the past 3 years worldwide and in the main station in Schiphol. After that, a brief analysis is made for the outstations and for the different Maintenance Delays Categorization Groups. The section 3.1.1 shows the rate of delays/UGTs and their average time for B767 and MD11, the section 3.1.2 presents the results concerning the outstations, section 3.1.3 analyses the main groups of Maintenance Delays Categorization Groups (MDCG) and the section 3.1.4 concludes what are the 2^{nd} Order reasons of MDCG that are causing the delays/UGTs.

The following analysis studies, when it is possible, the delays and UGTs since January 2006 until April 2009.

3.1.1 Delays and UGTs Worldwide and Schiphol

Martinair operates both passenger and cargo flights to several destinations around the world. Its base station is in Schiphol as well as its headquarters. The following analysis is divided per type of operation, or we can say per type of aircraft: B767 and MD11.

Boeing 767 Fleet Analysis

In Figure 3.1, it is possible to evaluate the delay rate and the average time of delay since 2006 to April 2009. The graph 3.1 (a) shows that the delay rate has been decreasing since 2006. In 2006 and 2007 the percentage of departure delayed was around 10.4%. However, since the beginning of 2008 the average delay rate decreased to 5.8% mainly between the first and second quarter of 2008. This can be explained with the introduction of the *Reliability Program* in Martinair in February of 2008. The program showed managers and engineers how M&E has been performing. Since this period, the engineering department has also started to take responsibility for the resolution of technical problems. For the first quarter of 2009 the average delay rate increased slightly although the average rate was 5.4% which corresponds to a dispatch reliability of 96%.

As you can see in Figure 3.1 (b), the average time of delays is quite random and it is not possible to find any trend in it. There were only 6 months with average delay time higher than 3h30 during the past 3 years due to some long AOG's. The average delay time for those 3 years was 2h20. However, from September of 2008 onwards, the average delay time was only around 1h25 most likely thanks to the development of the *Reliability Program* in February 2008 and more responsibility given to engineers.

The Figure 3.2 represents two graphs related to the UGTs: (a) the UGT rate and (b) the average time of an UGT. As you can see in graph (a), the UGT rate varies greatly along the months. However, the linear curve plotted from the historical data points suggests a growth in this rate over the years. In fact, the average of UGT rate increased from 1.2% in 2006 and 2007 to 2.5% in 2008. The average rate raised more than 50% mainly due to a higher number of UGTs in April and May of 2008 (respectively 4.0% and 5.2%). For the first quarter of 2009 the average rate was high as well, 3.8 UGTs per 100 departures. Nevertheless, the UGT rate decreased to 1.1% in last April.

In Figure 3.2 (b) it is possible to see that the average time of an UGT is highly variable going from 1 hour up to 38 hours. Over the 3 years under analysis the average of an UGT was higher than 15 hours for 8 random months. These high averages were due to specific incidents and occurrences which took longer than the normal average time of an UGT for those months. The linear black line shows that the average time of an UGT has been increasing from about 8h30 in 2006 and 2007 to 11h in 2008 and 16h30 in 2009. A carefully analysis of these disrupt events is always carried out by Martinair's engineers who give recommendations to avoid future long UGT. For several times the occurrences are just isolated cases and no recommendations are given.

(a) Delay Rate for B767 since 2006 until April 2009

(b) Average Delay time for B767 since 2006 until April 2009

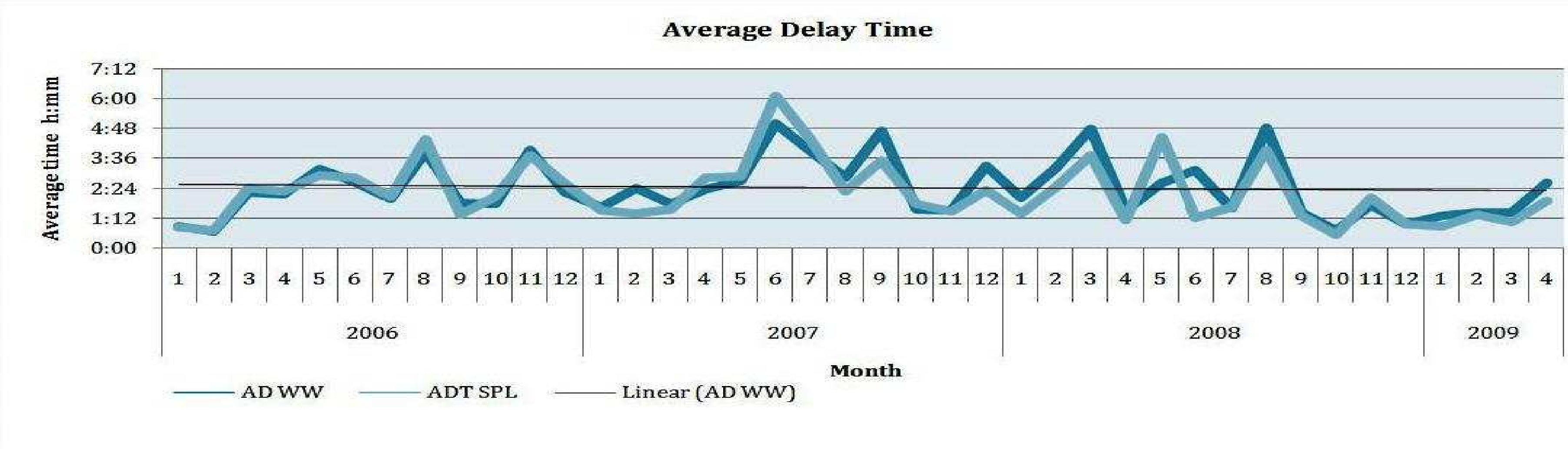
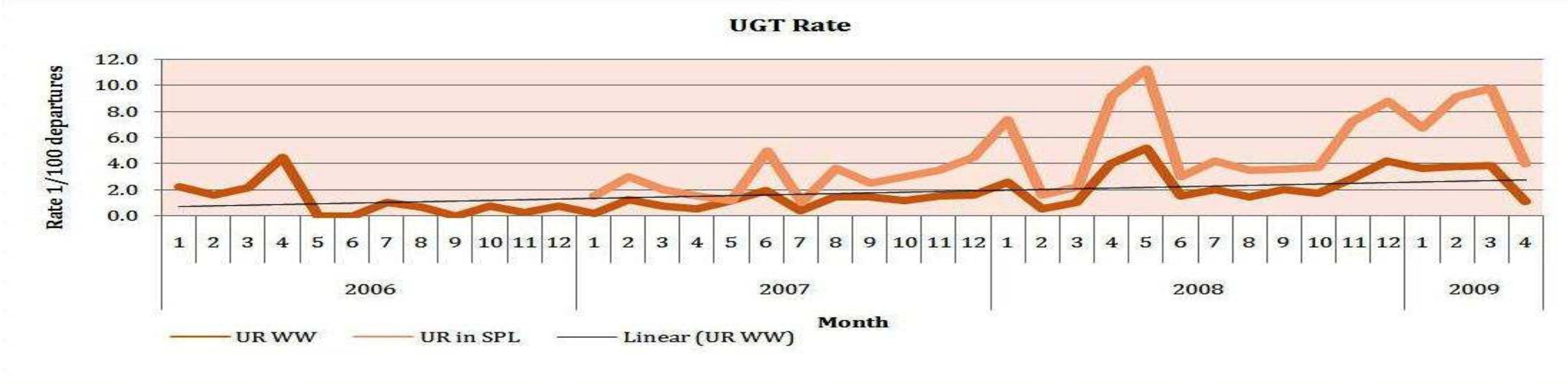


Figure 3.1 - Graphs of the (a) DR and (b) ADT for Boeing 767 since 2006 until April 2009

(a) UGT Rate for B767 since 2006 until April 2009



(b) UGT average time for B767 since 2006 until April 2009

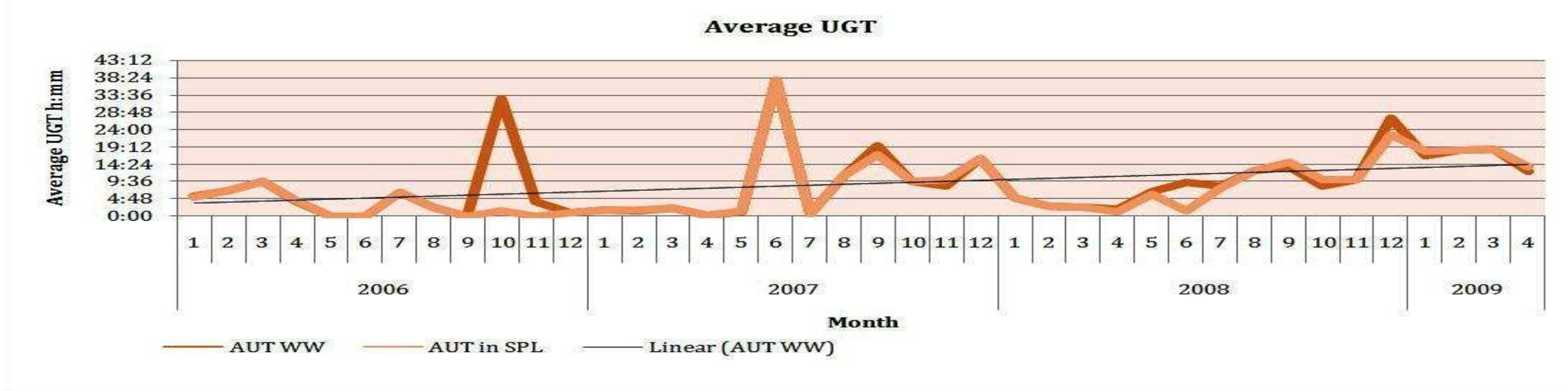


Figure 3.2 - Graphs of the (a) UR and (b) AUT for Boeing 767 since 2006 until April 2009

MD11 Fleet Analysis

In Figure 3.3 it is possible to evaluate the delay rate and the average time of delay for MD11 fleet since 2006 until April 2009. The dark line on the graph 3.3 (a) shows that the delay rate has been fluctuating around 5.7% since 2006. Indeed, in 2006 and 2007 the percentage of departure delayed was around 6.5%, in 2008 this number decreased for 5.93% and for the first quarter of 2009 the average delay rate was 4.62% which corresponds to a dispatch reliability of 95.4%.

As you can see in Figure 3.3 (b), the average time of delays is again quite random and it is not possible to find any logical trend in it. The months with higher average of delay are most likely related to some incident or occurrence that had happened during that particular month. The average delay time for the 3 years under analysis was 2h45. However, it is possible to find a slight decrease if we look to the years average of the delay time. Therefore, in 2006 and 2007 the average time was about 3h30 while in 2008 was 2h54 and in the first quarter of 2009 was 1h50.

These values might give the idea that the delay rate and the average time is decreasing every month but, as explained before, that is not the case. The rates varied between a central value and the average time took random values each month.

The Figure 3.4 represents two graphs related to the UGTs: (a) the UGT rate and (b) the average time of an UGT. As you can see in the dark line of graph 3.4 (a), the UGT rate floated randomly around 2.42% for the different months. The linear curve plotted from the historical data points suggests a constant rate over the years. In fact, the average of UGT rate was about 2.1% in 2006 and 2007, 3.6% in 2008 and 1.93% for the first four months of 2009. Nevertheless, the number of UGTs per 100 departures was above 4.5% for some months.

In Figure 3.4 (b) it is possible to see that the average time of an UGT can go from 6 hours up to 44 hours each year. The linear black line indicates that the average time of an UGT has been always above 12 hours with exception of 2008 (when it was 8h30). For 2006, it was about 13h40 and 14h51 for 2007. For the first four months of 2009 the average time of an UGT was 13h45. Note that the previous values are for years averages and that the real average time per month of an UGT is not at all constant over the years. As said before, a carefully analysis of the incidents and occurrences that lead to a long UGT is always carried out by Martinair's engineers who give recommendations to avoid future long UGT. For several times, the occurrences are just isolated cases and no recommendations are given.

From the analysis of both graphs (a) and (b), it seems that UGTs have been more under control since 2008 which is most likely due to the beginning of the *Reliability Program* and more responsibility give to engineers.

(a) Delay Rate for MD11 since 2006 until April 2009

(b) Average Delay time for MD11 since 2006 until April 2009

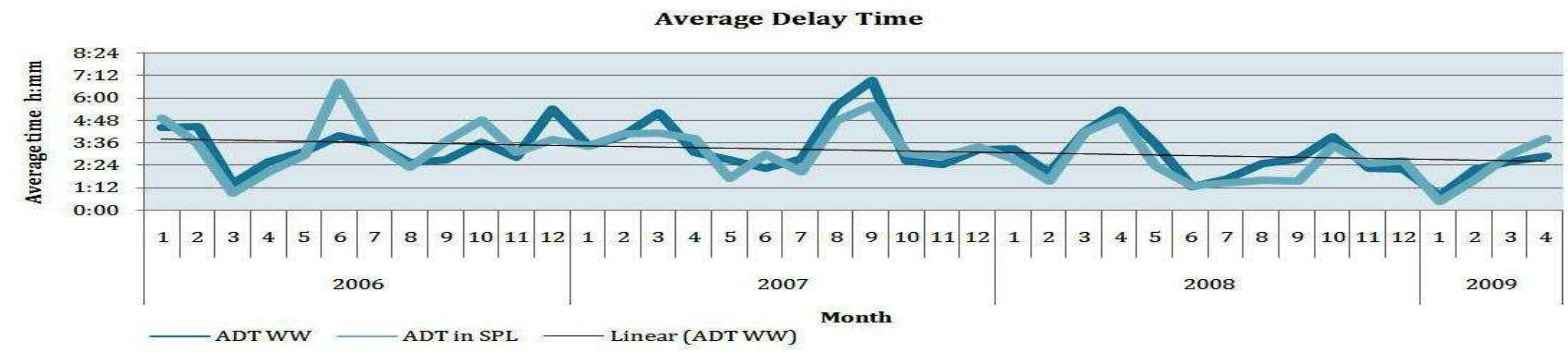


Figure 3.3 - Graphs of the a) DR and b) ADT for MD11 since 2006 until April 2009

(a) UGT Rate for MD11 since 2006 until April 2009

(b) UGT average time for MD11 since 2006 until April 2009

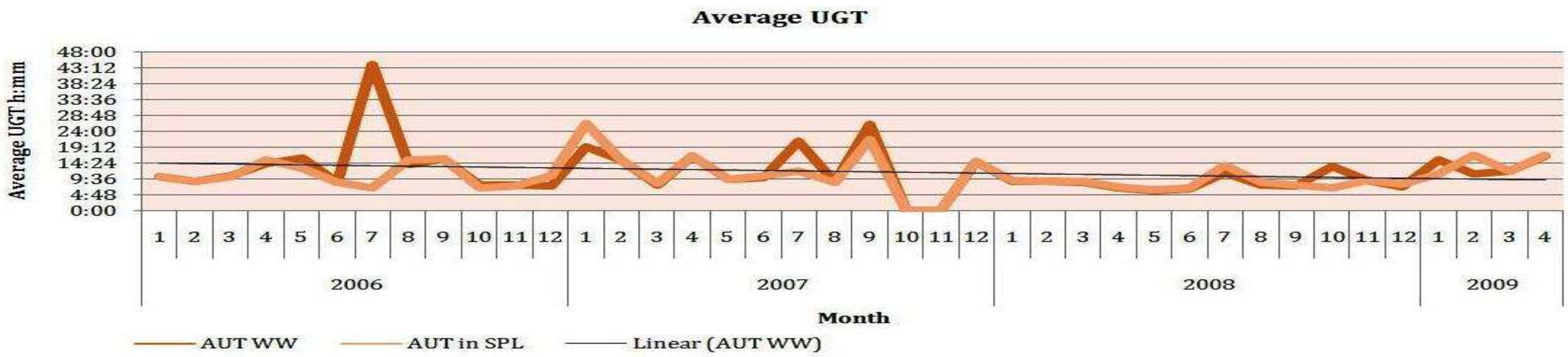


Figure 3.4 - Graphs of the (a) UR and (b) AUT for MD11 since 2006 until April 2009

The comments above are related to the dark line of the graphs of Figure 3.3 and Figure 3.4 which represent the delays/UGTs worldwide. The light lines correspond to the same figures but for departures from Amsterdam Airport, Schiphol (SPL). Owing to lack of data concerning the number of departures from Schiphol, the delay and UGT rates were plotted since February 2007.

As a general rule, the line's shape for Schiphol and worldwide is similar with exception of some particular months. This result is very easy to explain since almost 50% of the departures are from the main station in Amsterdam. The difference between Schiphol and worldwide is mainly for the rate values in both delays and UGTs. The higher rate values in Schiphol are due to the fact that Schiphol is the airline hub and Martinair's most important overhaul station. If we look to the average delay times for the outstations, it is possible to understand which station(s) caused the main differences between the dark and light line. Therefore, we can say that there was a long delay/UGT in the outstations when the light line is below the dark one; or that there were long delays/UGTs in the main station when the light line is above the dark one. For the first case, normally, they were isolated occurrences or incidents in that specific outstation for that particular month. For instance, the Figure 3.4 shows that in July 2006 there was a long UGT in some outstations. In fact, in San Juan (SJU) there was a really long UGT caused by a defect found during inspections. Another example can be seen in Figure 3.2 (b), the average time of UGT is higher for the worldwide curve in October 2008 due to one long UGT in Keflavic Iceland station (KEF).

In the next section a more detailed analysis will be made for the outstations.

3.1.2 Delays and UGTs Outstations

The B767 fleet is used mainly for passenger flights to holidays' destinations in Central America and Africa, such as Curaçao, Cancun or Mombasa. The MD11 fleet does cargo transports to several destinations also in America and Africa, like Miami, Nairobi or Bogota.

Departures from Schiphol Airport represent about fifty percent of all Martinair's flights. Therefore, the other half is spread all over the outstations around the world.

Martinair tries to avoid any kind of AOG in the outstations since these stations do not usually have components, tools and/or qualified personnel available. Nonetheless, there are offices in Miami and in Nairobi responsible for the line maintenance of South America and Africa, respectively.

As Martinair flies to quite different destinations, it was made a previous selection of the outstations to include in this analysis. As a result, the graphs below start to investigate only delays and UGTs (Unplanned Ground Times) for stations that meet the following criteria:

- ✓ number of delays/UGT higher than 4 for the years average OR
- ✓ total delays/UGTs time longer than 20 hours for the years average

Owing to lack of data concerning departures from outstations before 2007, the delay rate has been plotted since that year.

Boeing 767 Fleet Analysis

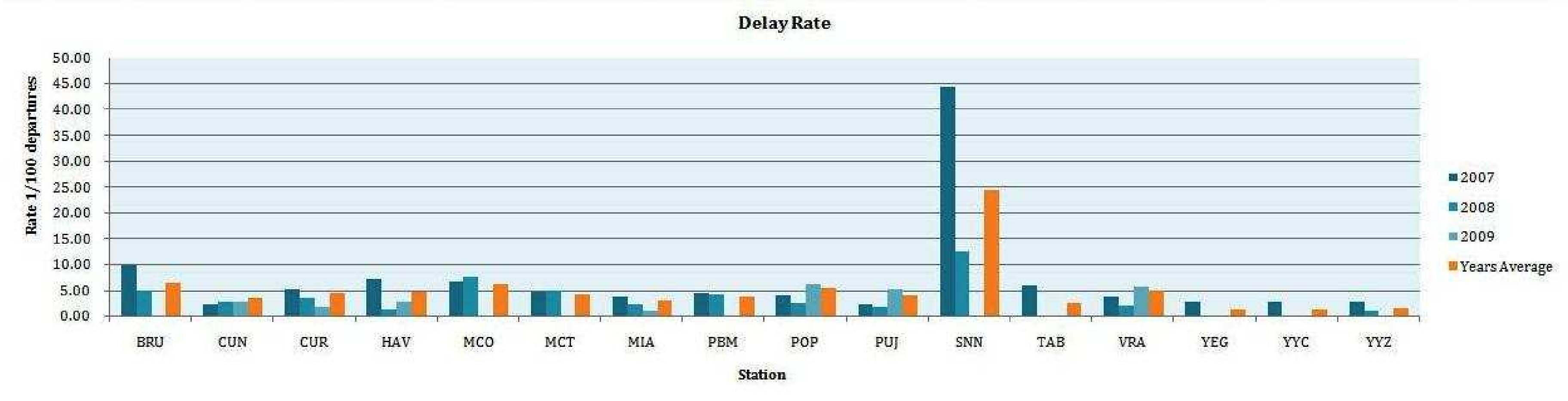
After study the graphs from Figure 3.5, it is possible to point out some stations that revealed higher rates of delays and/or longer average time. Thus, the graph (a) shows that: Brussels (BRU) and Orlando (MCO) stations have an years average of the delay rate of about 6%; Porto Plata (POP) and Varadero (VRA) of about 5%; and Curaçao (CUR), Havana (HAV) and Muscat (MCT) of about 4.5%. In Shannon Ireland station (SNN) the years average rate of the delay was the highest (about 24%), there is no need to concern though since this rate means only a couple of delays. The big value is due to few departures from this station.

From graph (b) it seems that Toronto (YYZ), Edmonton (YEG) and Shannon Ireland (SNN) stations usually had long delays (average time of 5h, 11h and 6h30, respectively) but we must remember that for those stations there were only one or two delays that happened to be long ones. Besides that and considering the date range under analysis, Martinair did not fly to YYZ since October 2008 as well as to YEG since September 2007. Again, there is no need to worry about these results. For the other outstations the average delay time was between 1 and 2 hours except Curacao (CUR), Muscat (MCT), Paramaribo (PBM) and Miami (MIA) that had a year average time around 4 hours.

As stated at the beginning of this section, Martinair tries to avoid UGTs as much as possible in the outstations. Indeed, there were hardly any UGTs for the majority of the outstations. The Figure 3.5 (a) shows the UGT rate for the relevant ones. It can be seen that the rate is always small (less than 1%) and there are some years with no UGTs at all. For Shannon Ireland (SNN) station the average of annual rate was 5.3% but only one UGT occurred for a total of 19 departures, which can be considered not significant.

The average time of an UGT is plotted in graph (b). Despite the averages time of UGTs being always above 17 hours, there were only one or two UGTs per station which means they were isolated cases.

(a) Delay Rate in some outstations for B767



(b) Average Delay Time in some outstations for B767

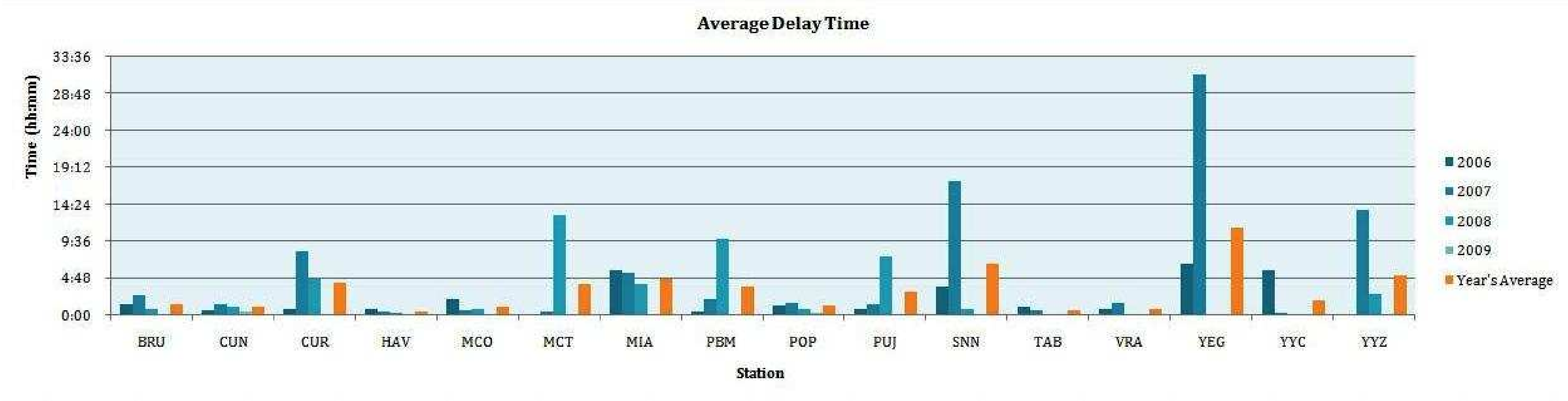
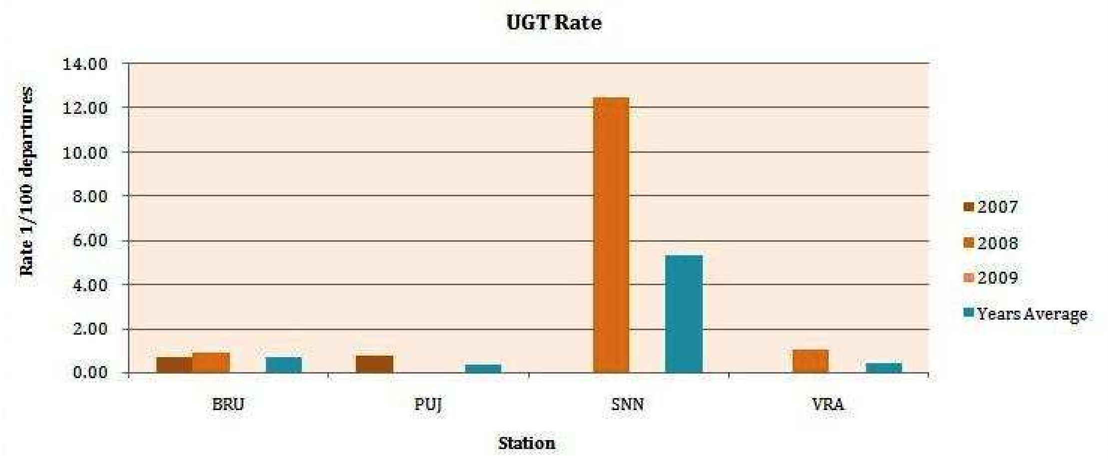


Figure 3.5 - Graphs of the (a) DR and (b) ADT for B767 in some outstations for 2006, 2007, 2008 and the first 4 months of 2009

(a) UGT Rate in some outstations



(b) Average Time of UGT in some outstations

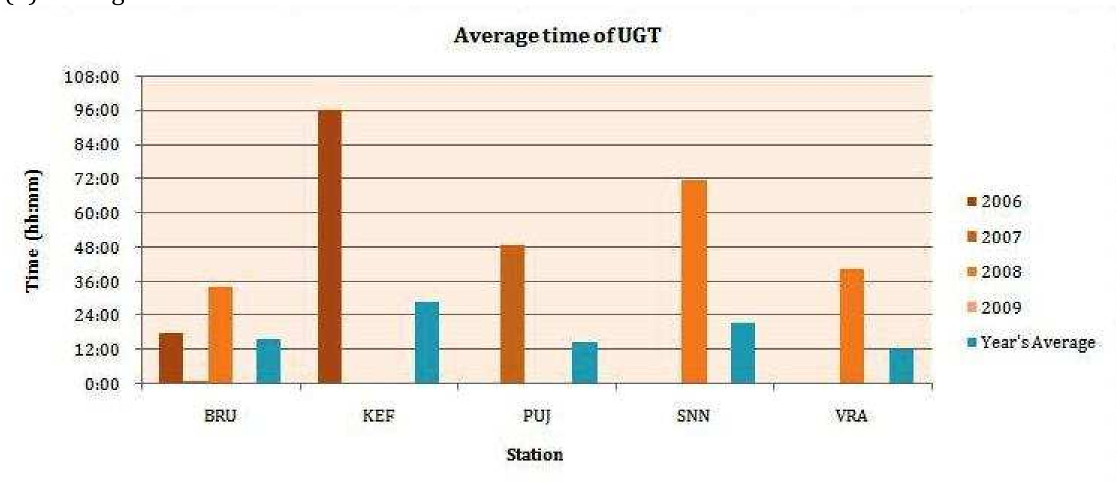


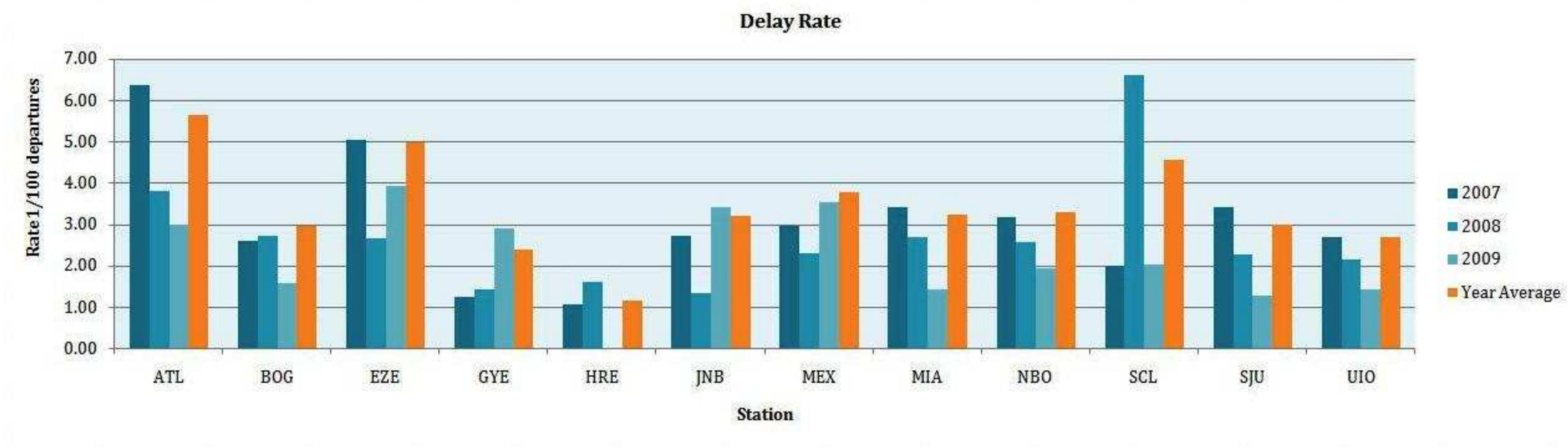
Figure 3.6 - Graphs of the (a) UR and (b) AUT for B767 in some outstations for 2006, 2007, 2008 and the first 4 months of 2009

MD11 Fleet Analysis

After studying the graphs from Figure 3.7, it is possible to point out some stations that revealed higher rates of delays and/or longer average time. Thus, the graph (a) shows that: Atlanta (ATL), Buenos Aires (EZE) and Santiago de Chile (SCL) stations have a years average of the delay rate of about 5% and Mexico (MEX) of about 4%. The delay rate for the outstations with more departures, in Nairobi (NBO), Miami (MIA), San Juan (SJU), Bogota (BOG) and Quito (UIO), was around 3%.

From graph (b) it seems that Harare (HRE) and Johannesburg (JNB) had long delays at least in one of the years under analysis (years average time of 6h and 8h30, respectively) but we must remember that for those stations there were only one or two delays that happened to be really long ones. For the other outstations the average delay time was between 3 and 5 hours except Bogota (BOG), Guayaquil (GYE) and Nairobi (NBO) that had a year average time around 2 hours.

(a) Delay Rate in some outstations for MD11



(b) Average Delay Time in some outstations for MD11

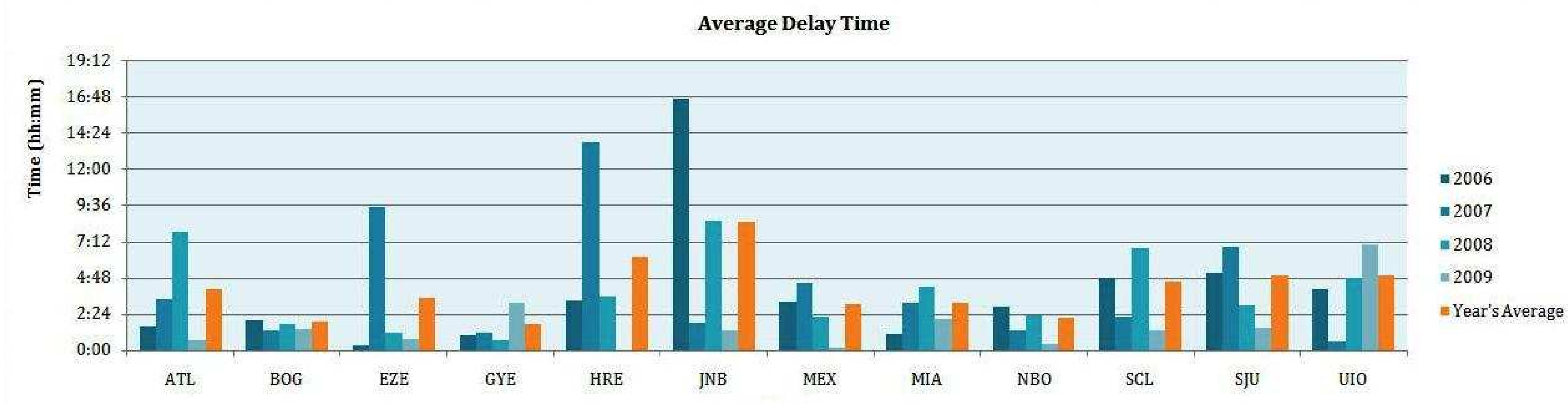
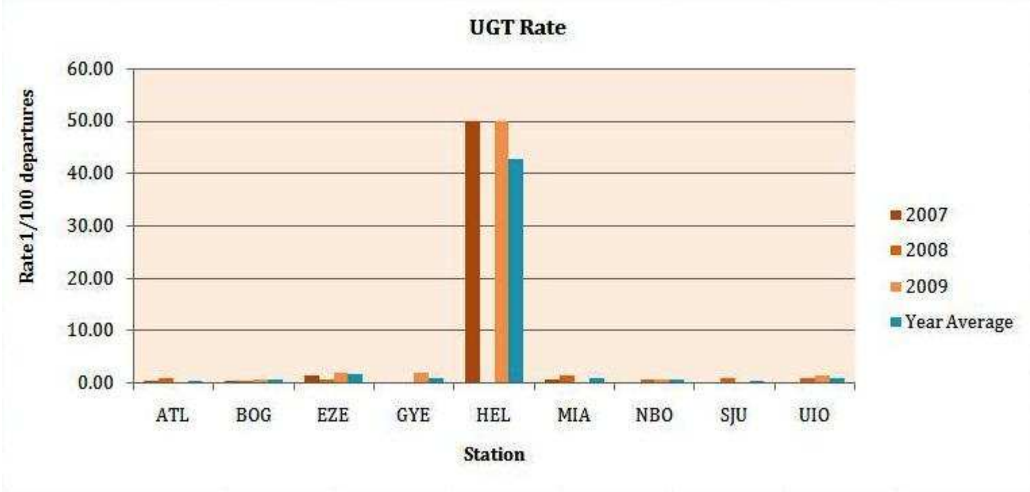
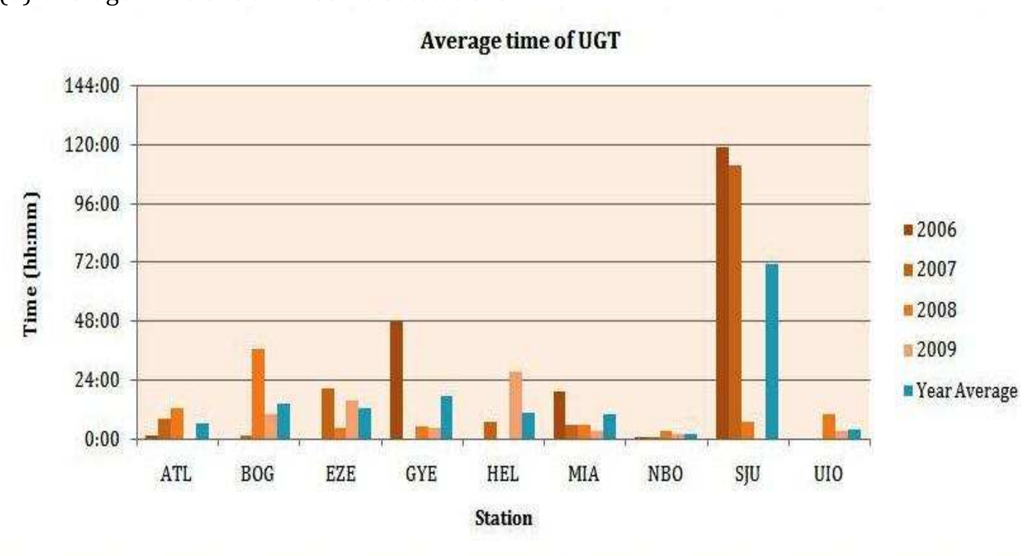


Figure 3.7 - Graphs of the (a) DR and (b) ADT for MD11 in some outstations for 2006, 2007, 2008 and the first 4 months of 2009

(a) UGT Rate in some outstations



(b) Average Time of UGT in some outstations



(c) UGT Rate in some outstations without Helsinki

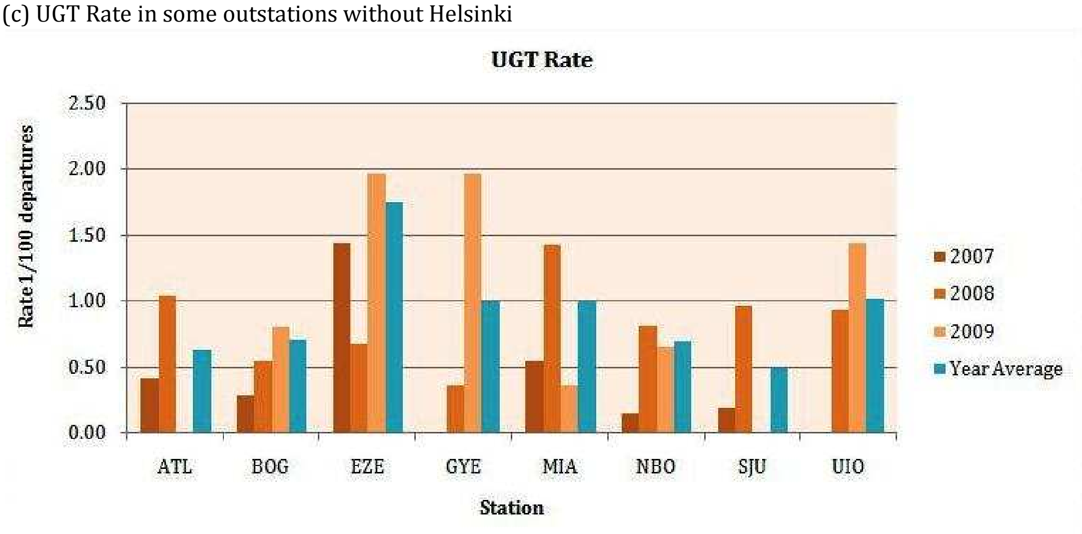


Figure 3.8 - Graphs of (a) UR (b) AUT and (c) UR (except Helsinki station) for MD11 in some outstations for 2006, 2007, 2008 and the first 4 months of 2009

There were hardly any UGTs (Unplanned Ground Times) for the majority of the outstations. The Figure 3.8 (a) and (c) shows the UGT rate for the relevant ones. In graph (a), the outstation in Helsinki, Finland (HEL) had a delay rate of 50%, however there were only 2 departures from this station in 2007 and 4 in 2009, which means only 1 and 2 UGTs respectively. In graph (c), it is possible to have a better look of the rate for the other outstations excluding Helsinki (HEL). It can be seen that the rate is always small (less than 2%) and there are some years with no UGTs at all for some stations.

The average time of an UGT is plotted in graph (b). Although San Juan station had the highest values for the average time of UGTs in 2006 and 2007, it was only one long UGT due to technical problems and tools not available. Despite the average time of UGTs per year being usually above 10 hours, there were only a couple of UGTs per station, which means they were isolated cases.

During this analysis some graphs were plotted for the delays/UGTs rates and average time per quarter for the stations that revealed higher and/or longer delays/UGTs. However, it was decided not to include them in this report because no further information could be extracted, i.e., the conclusions were similar to the ones already presented above. Thus, no deep analysis is made for the outstations as there is no evidence to support the theory that the delays or UGTs might be related to some specific outstation.

3.1.3 Delays and UGTs for the MDCG

As explained in chapter 2.2.1, each event that leads to a delay is categorized with a delay reason by Martinair's A/c Mechanics or Project Supervisor. These reasons were reorganized in the Maintenance Delay Categorization Groups (MDCG) as you can see in Table 2.1 in section 2.2.1. The eight main categories of MDCG (1^{st} Order reasons) give a general idea of the cause of the delay, yet these categories are used after the delay occurred and cannot be considered to predict the delays. Nonetheless, it might help in pinpointing some problematic areas. One shortcoming is the fact that for each delay event it is only attributed a single reason and most of the times (mainly for long delays) there were more factors involved. For example, the reason for a delay can be set as *A/C Mechanical Fault – Replaced LRU*, i.e., the final corrective action was the replacement of a LRU, however the time of delay might not be related only with the time to perform the replacement itself but also with troubleshooting time, waiting time for some Maintenance Control (MC) decision, waiting time for parts, and so on.

Martinair has started to categorize the delays into these qualitative reasons a few months before the beginning of this research. Therefore, firstly it was necessary to read the description of the delay events since 2006 and categorize them according to MDCG; secondly some pie charts were plotted for the eight main MDCG per quarter; and finally it was analysed the 2^{nd} Order delays of the relevant MDCG main groups.

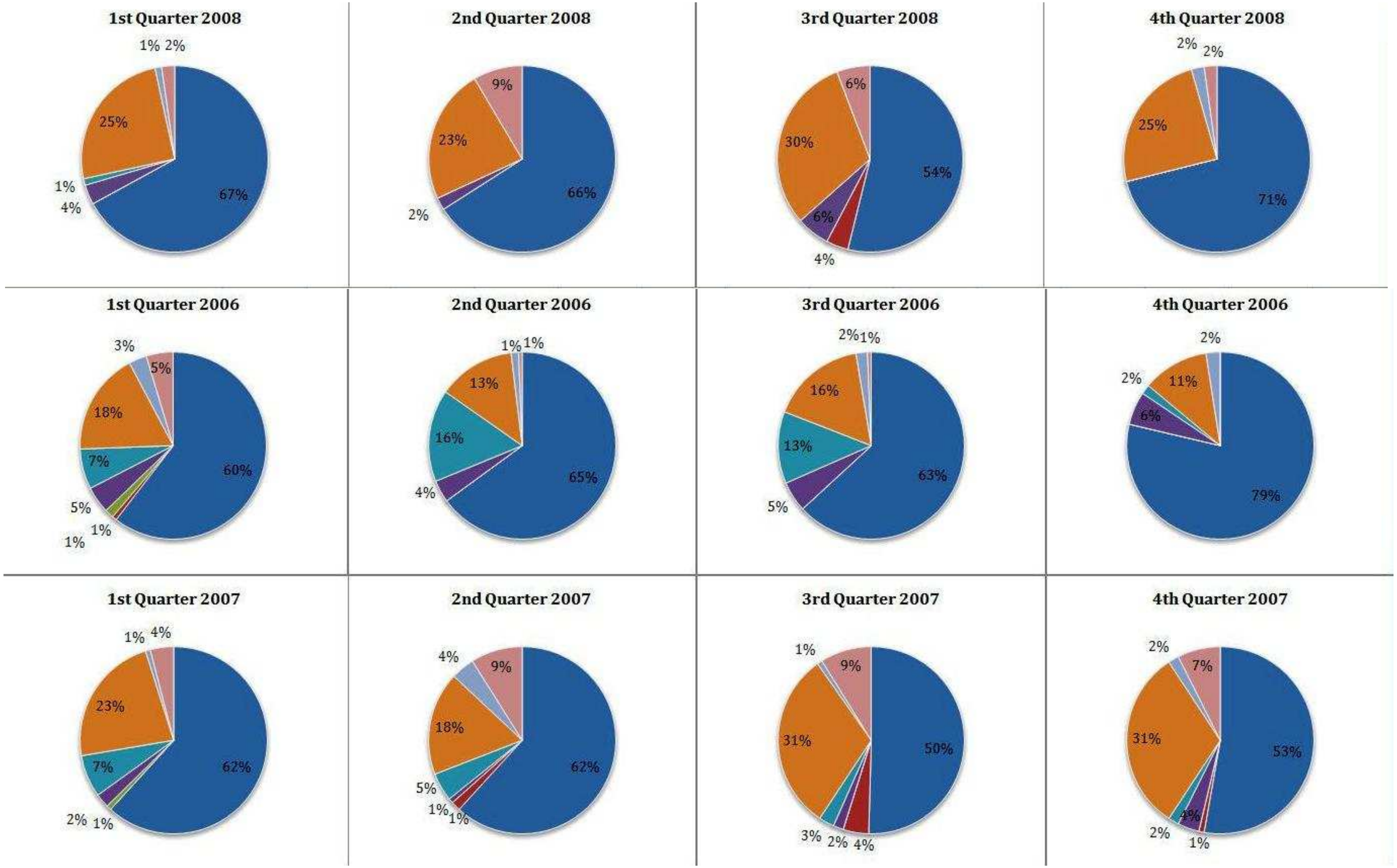
Boeing 767 Fleet Analysis

The following 13 pie charts in Figure 3.9 show the contribution of each 1st Order MDCG to the total number of delays per quarter.

It is clear that the two main reasons causing the delays were *A/C Mechanical Fault* and *Maintenance*. In fact, the latter was responsible for around 20% of the delays each quarter while more than half of the delays were caused by *A/C Mechanical Fault*, normally around 60%. There were delays caused by *Parts* for most of the quarters with an average percentage of 7%. Owing to lack of information about the delay events, there were higher rates of *Incomplete Record* reason in 2006 and at the beginning of 2007 (about 9%). After 2007 the information is more reliable because Martinair has started to use AMOS, a software package, to manage the different aspect of maintenance activities. The other reasons of Maintenance Delay Categorization Groups (*Down line*, *FOD*, *Ground Activities* and *Non-Technical*) were responsible for the 10% of delays left but they are unevenly distributed by each quarter. The rate for these reasons never exceeded the 5% and it was normally around 1-2%.

These results are not surprising. Most of the delays are caused by technical problems (chargeable events) and, as mention before, in most cases A/c Mechanics attributed the cause of the delay to the corrective actions performed.

The average delay time for each main group of MDCG can be seen in Table 3.1. These results are shown by quarter since 2006. The last column takes the quarters average considering only the quarters that had delays. Looking to these values, it is possible to say that *A/C Mechanical Fault, Maintenance* and *Parts* are responsible for the longest delays (2h40, 1h42 and 2h11, respectively). As a matter of fact, *Down Line* is the group that shows a higher value for the quarters average, almost 3h. However, it was caused by only one long delay in July 2007 for the a/c MCJ and MCH due to a defect on MCI. As in section 3.1.1, it is possible to conclude that the average delay time decrease for most of the main groups of MDCG since the first quarter of 2008, especially for *A/C Mechanical Fault*. One explanation is the development of a Reliability Program in 2008 which allowed Martinair to be more in control of the technical delays (chargeable events) and also because since this period, the engineering department has also started to take responsibility for the resolution of technical problems.


1st Quarter 2008
1% 2%
25%
1%
4%
67%
2nd Quarter 2008
9%
23%
2%
66%
3rd Quarter 2008
6%
30%
54%
6%
4%
4th Quarter 2008
2% 2%
25%
71%
1st Quarter 2006
3%
5%
18%
7%
60%
5%
1%
1%
2nd Quarter 2006
1% 1%
13%
16%
4%
65%
3rd Quarter 2006
2% 1%
16%
13%
63%
5%
4th Quarter 2006
2%
2%
11%
6%
79%
1st Quarter 2007
1% 4%
23%
7%
62%
2% 1%
2nd Quarter 2007
4%
9%
18%
5%
62%
1% 1%
3rd Quarter 2007
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3% 2% 4%
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53%
4%
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1%

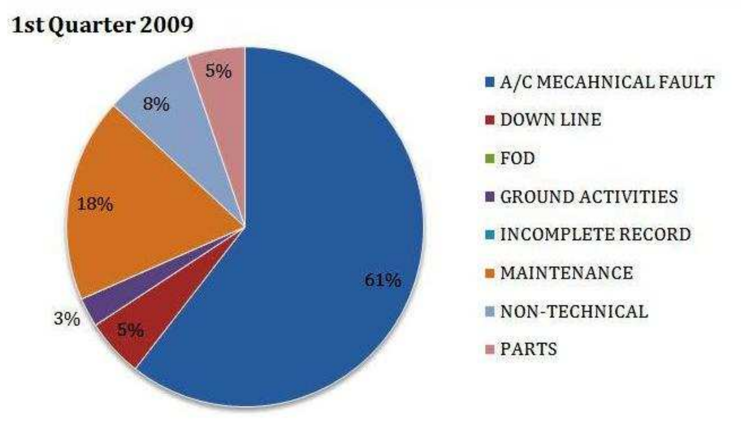


Figure 3.9 – Charts for delay rate of the main groups of MDCG for B767 per quarter from 2006

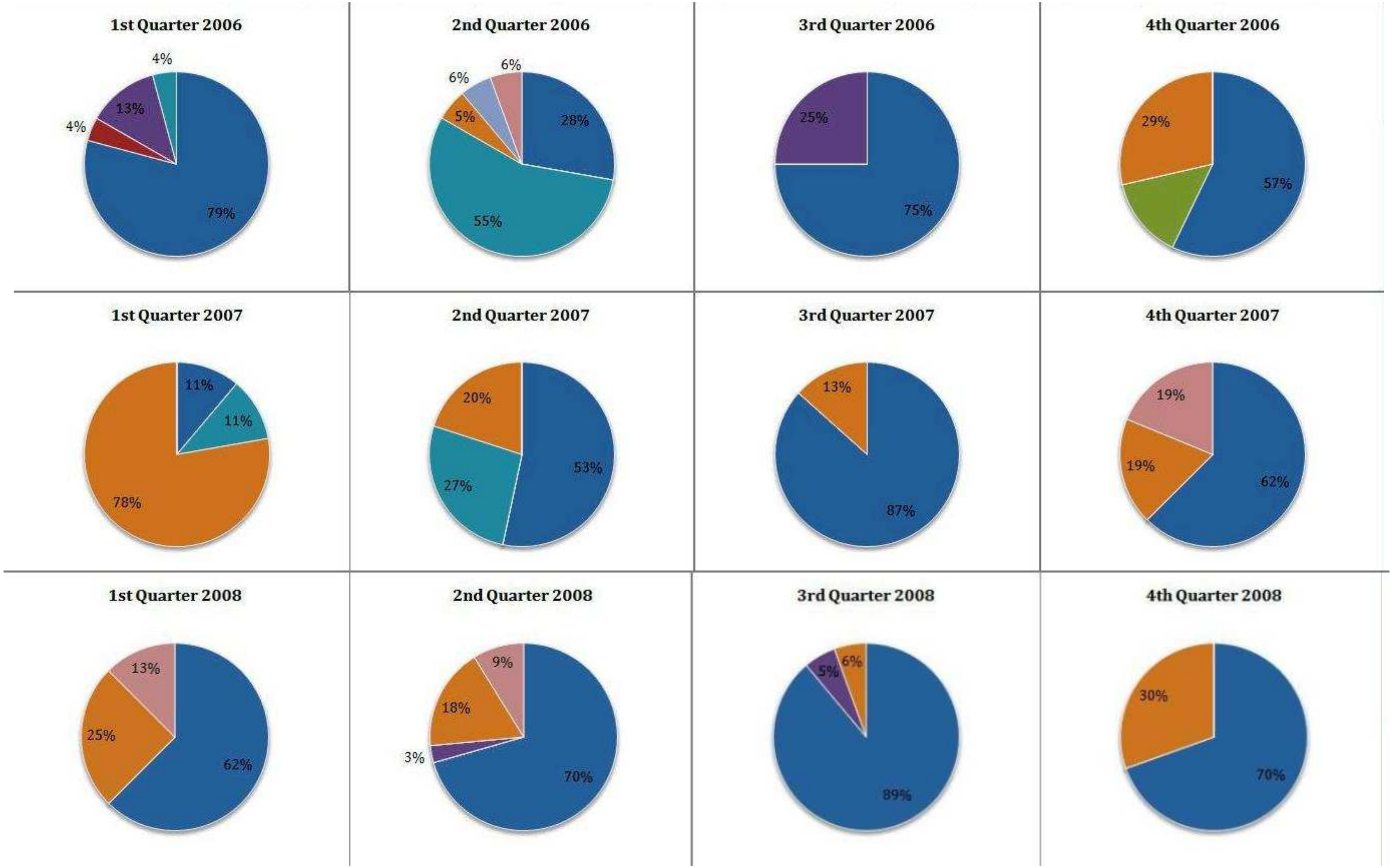
		2006 - Quarters				**2007 – Quarters**				**2008 - Quarters**				**2009**	
AVERAGE DELAY TIME	**PERIOD**	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	**Av. 06-09**
	A/C Mechanical Fault	1:41	3:19	3:28	2:59	2:14	3:19	3:30	1:56	3:39	2:34	2:49	1:23	1:50	**2:40**
	Down Line	1:35	-	-	-	-	0:55	10:05	0:26	-	-	1:50	-	2:00	**2:48**
	FOD	0:58	-	-	-	0:20	-	-	-	-	-	-	-	-	**0:39**
	Ground Activities	1:41	2:42	0:24	1:25	1:18	4:06	0:09	1:30	0:27	-	0:06	-	0:26	**1:17**
	Incomplete Record	0:38	1:03	0:50	0:28	0:22	0:19	0:09	0:23	0:09	-	-	-	-	**0:29**
	Maintenance	0:58	2:34	1:39	0:44	1:56	1:36	3:25	3:22	2:48	0:36	1:30	0:31	0:27	**1:42**
	Non-Technical	0:25	0:29	4:42	0:17	0:28	2:28	0:03	0:51	2:10	-	-	0:40	1:02	**1:14**
	Parts	0:45	1:21	0:14	-	1:28	7:41	6:01	1:12	1:11	5:50	0:14	0:06	0:16	**2:11**

- means no delay

Table 3.1 - Average Delay Time for each main group of MDCG for B767 since 2006 until 1st quarter of 2009

The pie charts in Figure 3.10 confirm that *A/C Mechanical Fault* and *Maintenance* groups were the main reasons for UGTs as well. Notice that the total number of UGTs was much smaller than the total number of delays which led to higher percentage for each MDCG. As a result, percentages of 20% can mean only 2 or 3 UGTs for that quarter. In any case, it is obvious that the UGTs were caused mainly by *A/C Mechanical Fault* and *Maintenance*. As mentioned before for the delays, there was a significant number of *Incomplete Record* in 2006 and at the beginning of 2007. Other reasons that were presented in some quarters were *Parts* and *Ground Activities,* in a small number though.

The Table 3.2 shows the average time of UGT per quarter for each of the eight main groups of MDCG. The last column takes the quarters average considering only the quarters that had delays. Both *A/C Mechanical Fault* and *Maintenance* were responsible for the majority of the longest UGTs with a quarters average of 13h and 8h, respectively. For the other reasons the *Ground Activities* group caused long UGTs of approximately 8h, but only responsible for one or two. *Parts* had a quarters average of 3h30 but for some quarters the average delay time raised to 8h.


1st Quarter 2006
4%
4%
13%
79%
2nd Quarter 2006
6%
6%
5%
28%
55%
3rd Quarter 2006
25%
75%
4th Quarter 2006
29%
57%
1st Quarter 2007
11%
11%
78%
2nd Quarter 2007
20%
27%
53%
3rd Quarter 2007
13%
87%
4th Quarter 2007
19%
19%
62%
1st Quarter 2008
13%
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3rd Quarter 2008
5%
6%
89%
4th Quarter 2008
30%
70%

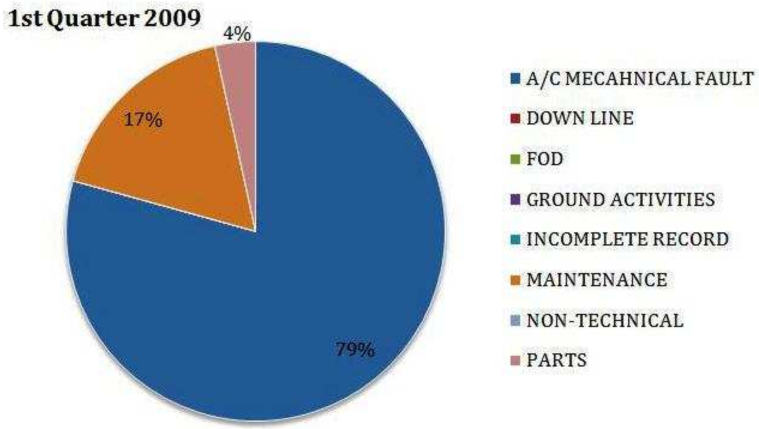


Figure 3.10 - Charts for UGT rate of the main groups of MDCG for B767 per quarter from 2006

		2006 - Quarters				2007 - Quarters				2008 - Quarters				2009	
	PERIOD	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	**Av. 06-09**
AVERAGE UGT TIME	A/C Mechanical Fault	7:16	8:28	3:31	21:33	4:21	37:03	15:13	12:18	4:47	6:14	11:31	18:33	16:21	**12:51**
	Down Line	2:15	-	-	-	-	-	-	-	-	-	-	-	-	**2:15**
	FOD	-	-	-	2:33	-	-	-	-	-	-	-	-	-	**2:33**
	Ground Activities	12:50	-	9:40	-	-	-	-	-	-	1:20	8:30	-	-	**8:05**
	Incomplete Record	3:00	2:34	-	-	1:45	1:22	-	-	-	-	-	-	-	**2:10**
	Maintenance	-	0:23	-	7:52	1:24	2:05	0:52	12:21	4:08	5:43	11:00	16:36	26:54	**8:07**
	Non-Technical	-	2:55	-	-	-	-	-	-	-	-	-	-	-	**2:55**
	Parts	-	0:19	-	-	-	-	-	8:43	1:01	1:00	-	-	7:00	**3:36**

- means no UGT

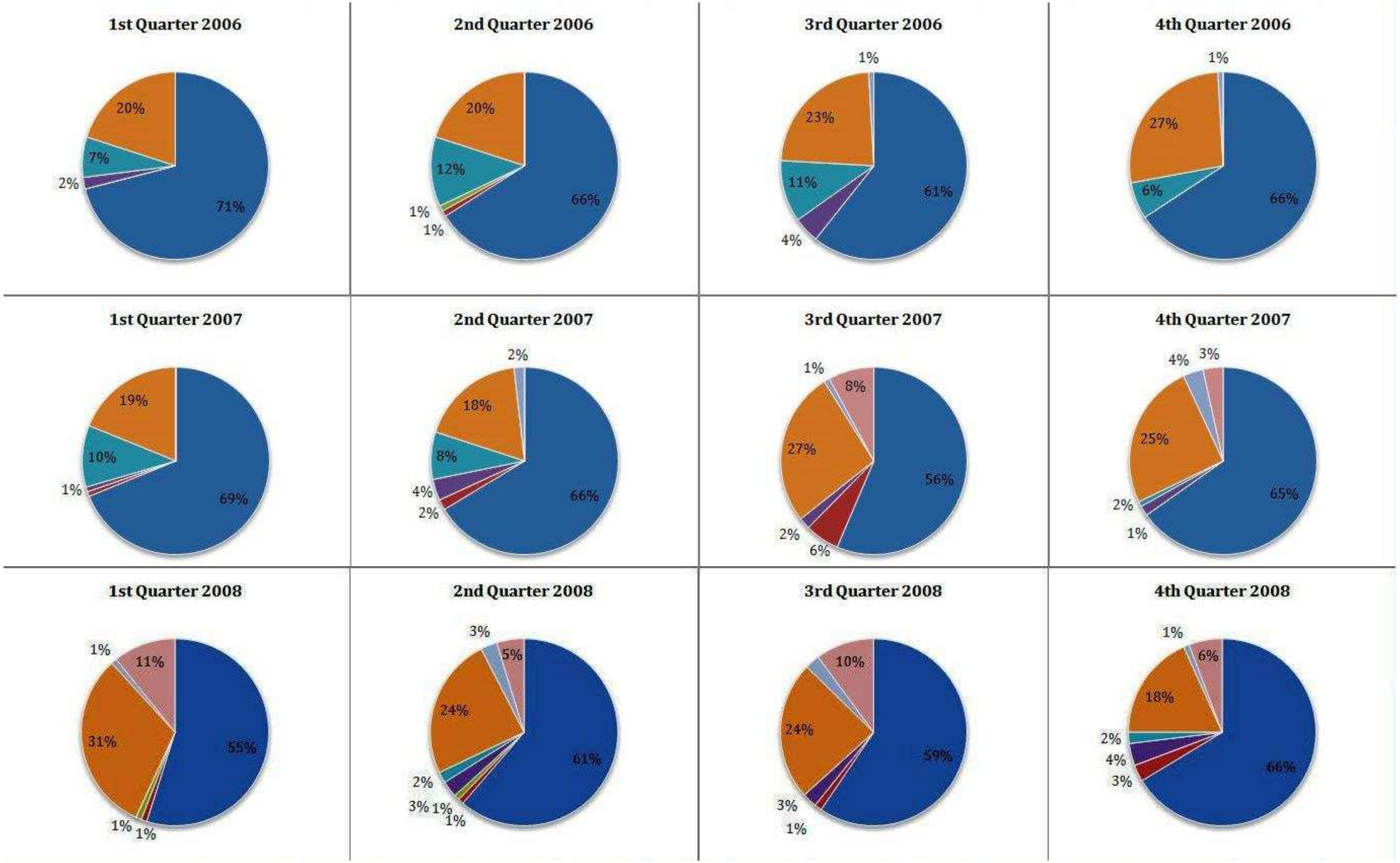
Table 3.2 - Average Time of UGT for each main group of MDCG for B767 since 2006 until 1st quarter of 2009

MD11 Fleet Analysis

The following pie charts of Figure 3.11 show the contribution of each main group of MDCG to the total number of delays per quarter for MD11.

The conclusions for MD11 are very similar to B767. Therefore, it is also clear that the two main reasons causing the delays were *A/C Mechanical Fault* and *Maintenance*. In fact, the latter was responsible for about 20% of the delays each quarter while more than half of the delays were caused by *A/C Mechanical Fault*, normally around 65%. There have been delays caused by *Parts* every quarter since the middle of 2007 with an average of 7.5%. Normally, when the cause of the delays was *Parts,* there was also some kind of *A/C Mechanical Fault* involved, which makes the categorization highly dependent of staff on duty. Before the middle of 2007, it can be assumed that there were not any delays caused by *Parts* because ground engineers always attributed it to *A/C Mechanical Fault*. Owing to lack of information about the delay events, *Incomplete Record* appeared with a contribution of about 9% from 2006 to the middle of 2007. As mention before, after 2007 the information is more reliable because Martinair has started to use AMOS, a software package, to manage the different aspect of maintenance activities. The others MDCG reasons (*Down line*, *FOD*, *Ground Activities* and *Non-Technical)* were responsible for the 8% of the delays left but they were unevenly distributed by each quarter. The rates for these reasons never exceeded the 4% and it was normally around 1-2%. Once again, these results are not surprising. As mentioned before for B767, most of the delays are caused by technical problems (chargeable events) and in most of the cases the ground engineers attributed the cause of the delay to the corrective actions performed.

The average delay time for each main group of MDCG can be seen in Table 3.3. These results are shown by quarter since 2006. The last column takes the quarters average considering only the quarters that had delays. *Down Line* is the group that shows a higher value for the quarters average, almost 8h. However, it was caused by only a couple of long delays. Indeed, when *Down Line* is the cause of the delay, they tended to be long ones. *FOD* also shows a quite high average delay time (3h36), and again it was only due to one long delay caused by a bird strike. Moreover, *Parts* had a quarters average time of 6h. Despite *A/C Mechanical Fault* and *Maintenance* were the causes of the majority of delay their average time were about 3h20 and 2h30, respectively. As in section 3.1.1, it is possible to conclude that the average delay time was quite random and it is not possible to find any logical trend in it. The quarters with higher average delay time are most likely related to some incident or occurrence that happened during that particular month.


1st Quarter 2006
20%
7%
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71%
2nd Quarter 2006
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1%
66%
3rd Quarter 2006
1%
23%
11%
4%
61%
4th Quarter 2006
1%
27%
6%
66%
1st Quarter 2007
19%
10%
1%
69%
2nd Quarter 2007
2%
18%
8%
4%
2%
66%
3rd Quarter 2007
1%
8%
27%
2%
6%
56%
4th Quarter 2007
4%
3%
25%
2%
1%
65%
1st Quarter 2008
1%
11%
31%
1%
1%
55%
2nd Quarter 2008
3%
5%
24%
2%
3%
1%
1%
61%
3rd Quarter 2008
10%
24%
3%
1%
59%
4th Quarter 2008
1%
6%
18%
2%
4%
3%
66%

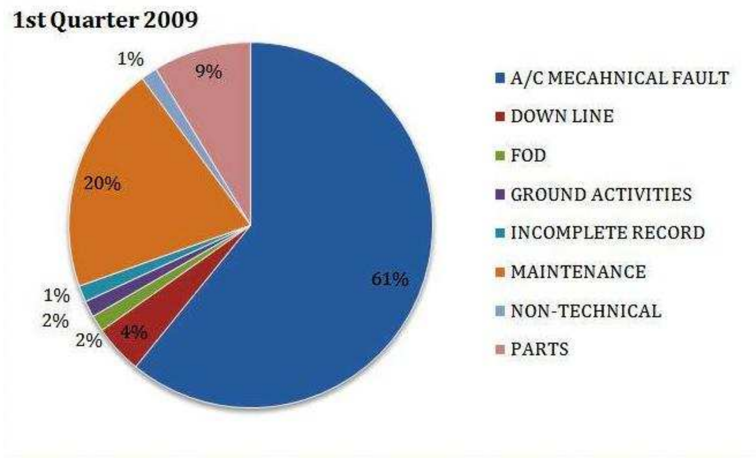


Figure 3.11 – Charts for delay rate of the main groups of MDCG for MD11 per quarter from 2006

		2006 - Quarters				2007 – Quarters				2008 - Quarters				2009	
AVERAGE DELAY TIME	**PERIOD**	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	**Av. 06-09**
	A/C Mechanical Fault	2:52	3:01	2:59	4:54	5:12	2:56	5:22	3:26	2:10	3:45	1:34	3:03	1:46	**3:18**
	Down Line	-	1:53	-	-	0:24	2:58	5:11	-	21:05	28:40	2:48	4:59	1:58	**7:46**
	FOD	-	2:02	-	-	-	-	-	-	0:32	1:09	-	-	10:43	**3:36**
	Ground Activities	2:08	-	2:23	-	0:48	1:01	0:19	0:32	-	0:23	3:00	0:21	0:21	**1:07**
	Incomplete Record	9:11	3:10	4:43	3:34	3:10	4:06	-	0:10	-	10:29	-	1:18	1:44	**4:09**
	Maintenance	4:23	3:17	1:59	2:40	1:39	1:27	5:42	1:50	3:18	1:52	1:20	1:53	1:46	**2:33**
	Non-Technical	-	-	0:17	3:00	-	1:14	0:46	1:24	0:10	1:35	0:33	2:30	0:12	**1:10**
	Parts	-	-	-	-	-	-	8:15	1:40	8:28	7:37	9:22	4:44	3:22	**6:12**

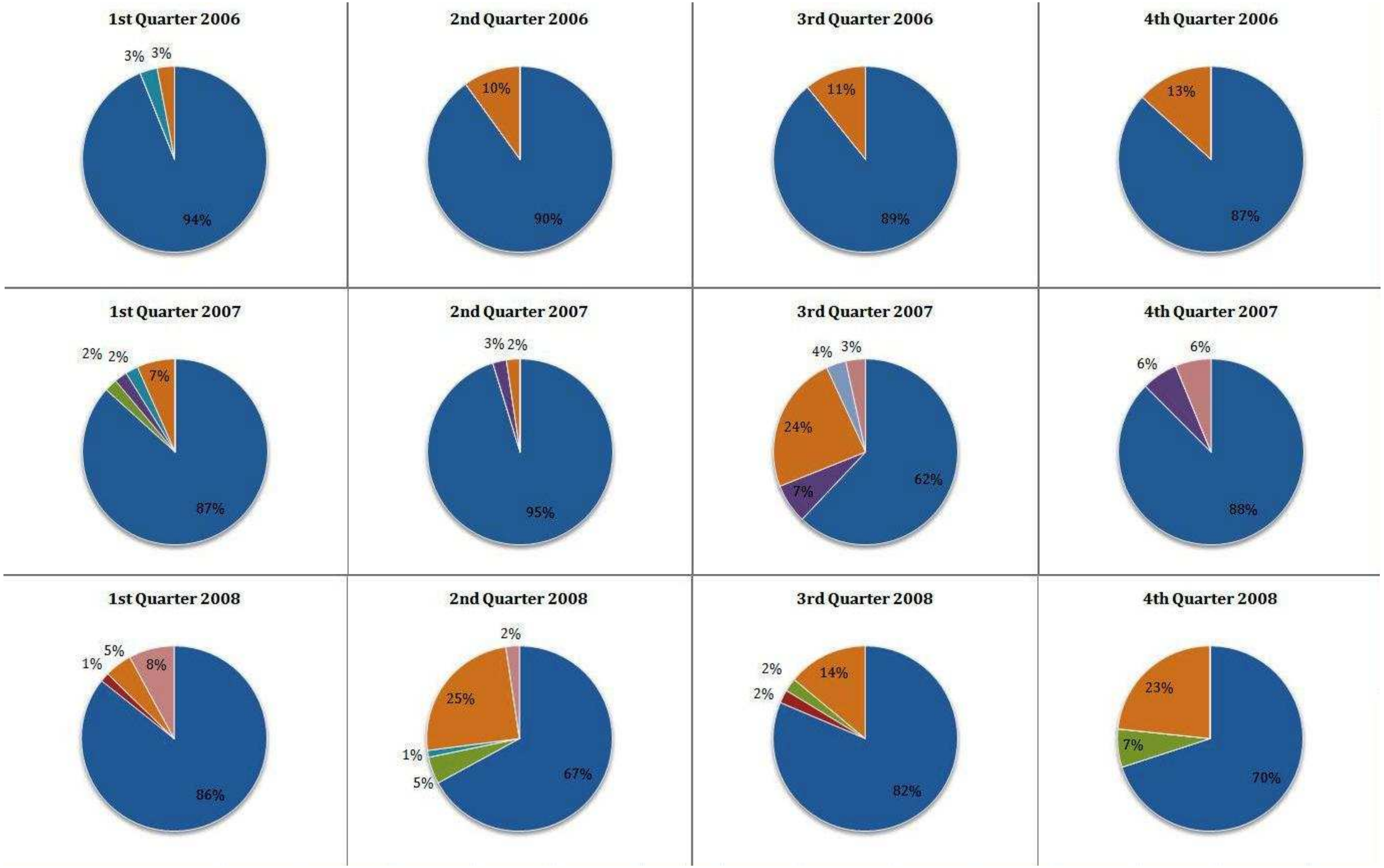
- means no delays

Table 3.3 - Average Delay Time for each main group of MDCG for MD11 since 2006 until 1st quarter of 2009

The pie charts of Figure 3.12 confirm that *A/C Mechanical Fault* and *Maintenance* groups were the main reasons for UGTs (Unplanned Ground Times) as well. Similar to B767, the total number of UGTs was much smaller than the total number of delays which led to higher percentage for each group. As a result, percentages of 20% can only mean 2 or 3 UGTs for that quarter. In any case, it is obvious that the UGTs were mainly caused by *A/C Mechanical Fault* (average of 80% of all UGTs). *Maintenance* group was also responsible for about 15% of the UGTs for various quarters. The other reasons appeared randomly and always with small contributions.

The Table 3.4 shows the average time of UGT per quarter for each of the eight main groups of MDCG. The last column takes the quarters average considering only the quarters that had delays.
Most of the MDCG groups caused long delays. However, both *A/C Mechanical Fault* and *Maintenance* were responsible for the majority of the UGTs with a quarters average of 12h and 9h, respectively. For the other reasons, *Ground Activities* and *Parts* groups also caused really long UGTs with a quarters average of 17h and 15h. *Down Line* and *FOD* had a high average as well (8h). Nonetheless, the latter pair of reasons caused only one or two long UGT in the period under analysis.

Summing up, it is possible to draw general conclusions for the eight main groups of MDCG. Hence, most of delays and UGTs for both B767 and MD11 have been caused by *A/C Mechanical Faults* and *Maintenance* reasons. *Parts* group has also been responsible for a relevant amount of delays. The others MDCG caused randomly delays and UGTs over the years which do not seem to be significant.
The average time of both delays and UGTs were highly dependent of specific events. In general the highest averages were due to a few long delays/UGTs that occurred in that particular quarter and do not seem to be related to any specific MDCG. The average delay time for B767 is slightly lower than for MD11 but both look to be more dependent on *Maintenance* and *A/C Mechanical Fault* groups. *Parts* group is normally responsible for long delays as well. It can be said that, except specific occurrences, *Maintenance, A/C Mechanical Fault* and *Parts* have been responsible for the longest delays and UGTs


1st Quarter 2006
3% 3%
94%
2nd Quarter 2006
10%
90%
3rd Quarter 2006
11%
89%
4th Quarter 2006
13%
87%
1st Quarter 2007
2% 2%
7%
87%
2nd Quarter 2007
3% 2%
95%
3rd Quarter 2007
4% 3%
24%
7%
62%
4th Quarter 2007
6%
6%
88%
1st Quarter 2008
1%
5%
8%
86%
2nd Quarter 2008
2%
25%
1%
5%
67%
3rd Quarter 2008
2%
2%
14%
82%
4th Quarter 2008
23%
7%
70%

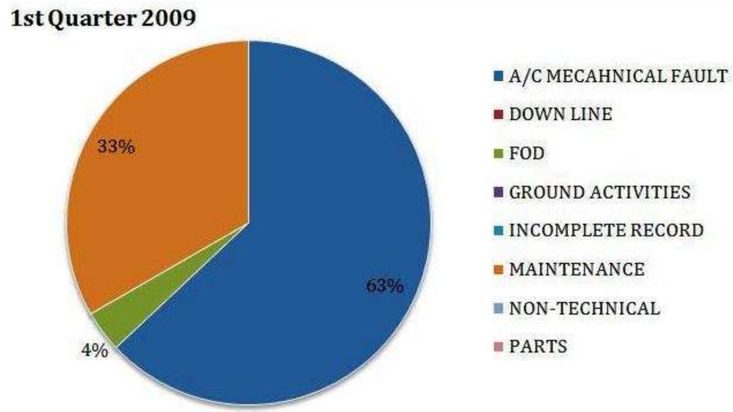


Figure 3.12 - Charts for UGT rate of the main groups of MDCG for MD11 per quarter from 2006

		2006 - Quarters				2007 - Quarters				2008 - Quarters				2009	
AVERAGE UGT TIME	**PERIOD**	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	**Av. 06-09**
	A/C Mechanical Fault	10:02	14:22	23:09	7:41	13:38	11:34	18:45	14:54	8:48	6:56	8:20	8:46	10:46	**12:08**
	Down Line	-	-	-	-	-	-	-	-	7:30	-	10:00	-	-	**8:45**
	FOD	-	-	-	-	4:00	-	-	-	-	2:26	19:45	7:52	4:15	**7:39**
	Ground Activities	-	-	-	-	3:00	41:00	8:00	16:00	-	-	-	-	-	**17:00**
	Incomplete Record	3:00	-	-	-	8:00	-	-	-	-	8:00	-	-	-	**6:20**
	Maintenance	10:30	9:19	12:56	6:04	7:44	3:00	9:09	-	2:35	6:24	7:53	13:08	16:59	**8:48**
	Non-Technical	-	-	-	-	-	-	4:00	-	-	-	-	-	-	**4:00**
	Parts	-	-	-	-	-	-	30:00	12:30	11:30	5:09	-	-	-	**14:47**

- means no delays

Table 3.4 - Average Time of UGT for each main group of MDCG for MD11 since 2006 until 1st quarter of 2009

3.1.4 Delays and UGTs for 2nd Orders of MDCG

In the section above it was only analysed the 1st Order groups of the MDCG. It would be interesting to see how the 2nd Order reasons of the MDCG are related to the delay/UGT rates and average times even though it can lead to an extensive analysis as there are more than fifty 2nd Orders reasons. Thus, this report will only focus on the three 1st Order MDCG that revealed to be the most important for both B767 and MD11:

- ✓ A/C Mechanical Fault
- ✓ Maintenance
- ✓ Parts

Reason Group MDCG – 1st Order	2nd Order
A/C Mechanical Fault **(A/C Chargeable Event)**	adjusted cleaned electrical cycle electrical rerack hydro/mech reset hydro/mech swap Inspected / checked install missing parts incomplete information lubricated no defect re-programmed repaired item replaced LRU replaced non-LRU repositioned servicing (toilet, water, fuel) serviced tightened tires (cut/debris)
Maintenance **(A/C Non Chargeable Event)**	a/c damage approval required (TOA/NTO) (A/C Chargeable Event) deferred maintenance (HIL/MEL/placarded) documentation human factors (e.g. training/skills, wrong procedures/installation) late out of maintenance no wrong procedures planning (personnel or maintenance) personnel not available precautionary maintenance unscheduled maintenance (A/C Chargeable Event) weather
Parts **(A/C Non Chargeable Event)**	cannibalization NIL stock parts location unknown tools (not available/ US)

Table 3.5 – 2nd Order reasons for three relevant groups of Maintenance Delay Categorization Groups (MDCG).

In Table 3.5, you can find the MDCG 2nd Order reasons that will be analysed. Further information about each 2nd Order reason can be seen in Appendix B.

This section tries to find out the main 2nd Order reasons that were set as the cause of the delays/UGTs both for B767 and MD11. The 2nd Order reasons will give us a better perspective of the *real* cause of the delays/UGTs but there are still some limitations. As mentioned before, the delay events have only been categorized in one 1st Order and one 2nd Order reasons which might not correspond to the reality. Indeed, the delays/UGTs can be dependent on multiple factors (technical and non-technical faults) and also on the judgement of the ground engineer on duty.

This research comprehended a detailed analysis of all 2nd Order reasons per month. However, the results and conclusions are similar when analysed per year or per month. Hence, in this report, the results are presented per year to reduce the complexity of the graphs and make it easier to understand. Moreover, the graphs above show the contribution of the 2nd Order reasons to the delays/UGTs of their main MDCG, according to the following equations:

$$Contribution\ Delay\ Rate(CDR) = \frac{total\ number\ of\ delays\ caused\ by\ the\ 2^{nd}\ Order\ Reason}{total\ number\ of\ delays\ caused\ by\ its\ 1^{st}\ Order\ \ MDCG} x\ 100 \qquad (6)$$

$$Contribution\ Delay\ Time\ (CDT) = \frac{total\ time\ of\ delays\ caused\ by\ the\ 2^{nd}\ Reason}{total\ time\ of\ delays\ caused\ by\ its\ 1^{st}\ Order\ MDCG} x\ 100 \qquad (7)$$

$$Total\ Contribution\ = \frac{CDR+CDT}{2} \qquad (8)$$

Moreover, not all 2nd Order reasons were represented in the graphs below because several of them were responsible for no more than a few delays/UGTs. Thus, it was only plotted contributions up to 2-5%, the others 2nd Order reasons were merged and plotted as the *Others* category.

After analysing the contribution of the 2nd Order reasons described above, a criteria is applied to choose the most important ones. Using the detailed graphs of Appendix C and with the help of Martinair Reliability engineers it was decided to use the following critical values.

1. Delay rate > 5%[4] **OR**
2. UGT rate > 5%[4]

These rates were calculated by dividing the number of delays/UGTs caused by the 2nd Order reasons by the total number of delays/UGTs.

Boeing 767 Fleet Analysis

In Figure 3.13, it is possible to analyse the 2nd Order reasons of the *A/C Mechanical Fault* group. There are twenty 2nd Order reasons for this main group, though the graphs show only 9 of them. For both delays and UGTs, the three main 2nd Order reasons were *Replaced LRU*, *Repaired* and *Replaced Non-LRU*. The *Replaced LRU* had a contribution of more than 45% to the *A/C Mechanical Fault* while *Repaired* had a contribution of about 23%. For the *Replaced Non-LRU*, the contribution

[4] average taking into account all months since 2006

was of about 15% to the delays and 30% to the UGTs. Furthermore, 6.5% of the delays caused by *A/C Mechanical Fault* were due to *Adjusted* and *Electrical Cycle* actions. The other reasons had a contribution smaller than 3% or they did not cause a delay/UGT in at least one of the years.

The following graphs of Figure 3.14 are related to *Maintenance* 2nd Order reasons. The most relevant 2nd Order reason is different for the delays and UGTs. Therefore, the delays caused by *Maintenance* issues are mostly due to *Deferred/Placard/MEL/HIL* (about 60%). Moreover the contribution of *Late out of Maintenance* and *Human Factors* reasons seems to be similar to the delays. Actually, last year they were responsible for only a few delays. *Human Factors* has not caused a delay since July 2008 and its high contribution in 2008 was due to faults on one aircraft that led to delays not only for that a/c but also for others (by swapping aircrafts). As studied in section 3.1.3, the UGTs caused by *Maintenance* were about 20% but sometimes that might only mean one or two UGTs. Regarding the 2nd Order reasons, *Late Out of Maintenance* seems to be responsible for the majority of those UGTs. *Deferred/Placard/MEL/HIL* has also contributed with about 20% to the UGTs caused by *Maintenance*, but not during the last year. The other 2nd Order reasons do not have significant contribution since they have only occurred a couple of times.

The Figure 3.15 represents the contributions of the 2nd Order reasons to the delays and UGTs caused by *Parts*. *NIL Stock* means that the part needed was not available in stock and it was necessary to order one. This 2nd Order reason was responsible for the majority of the delays.
Analysing the UGTs graph, all the 2nd Order reasons contribution seem to be very significant at least for one of the years. However, in the period under analysis, there were only 10 UGTs, three caused by *Cannibalization*, *Tools not Available* and *Parts Unknown*, and the others caused by *NIL Stock*. Again, *NIL Stock* reveals to be again the most common one.

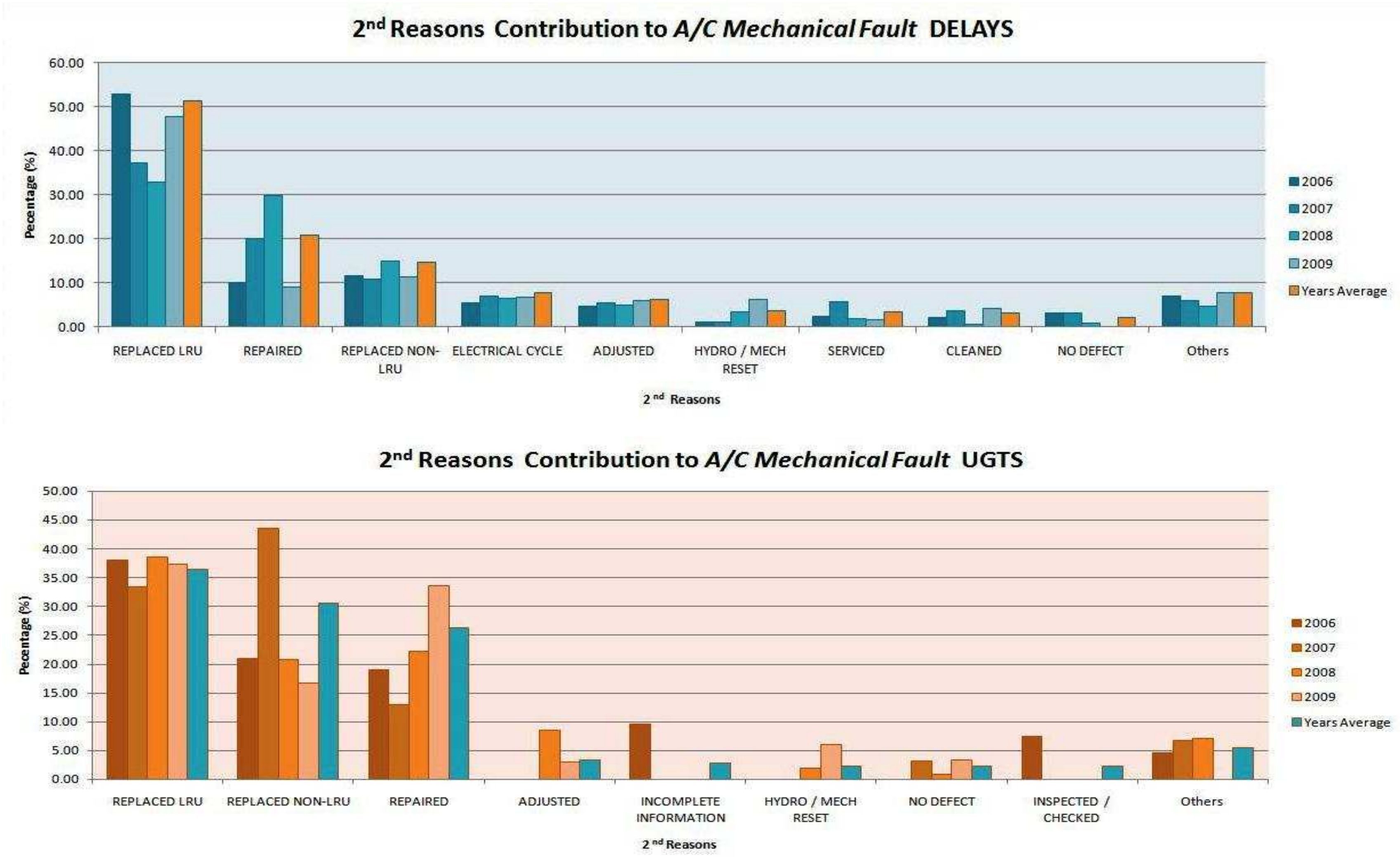


Figure 3.13 –Contribution of the 2nd Order reason to the *A/C Mechanical Fault* delays and UGTs for B767.

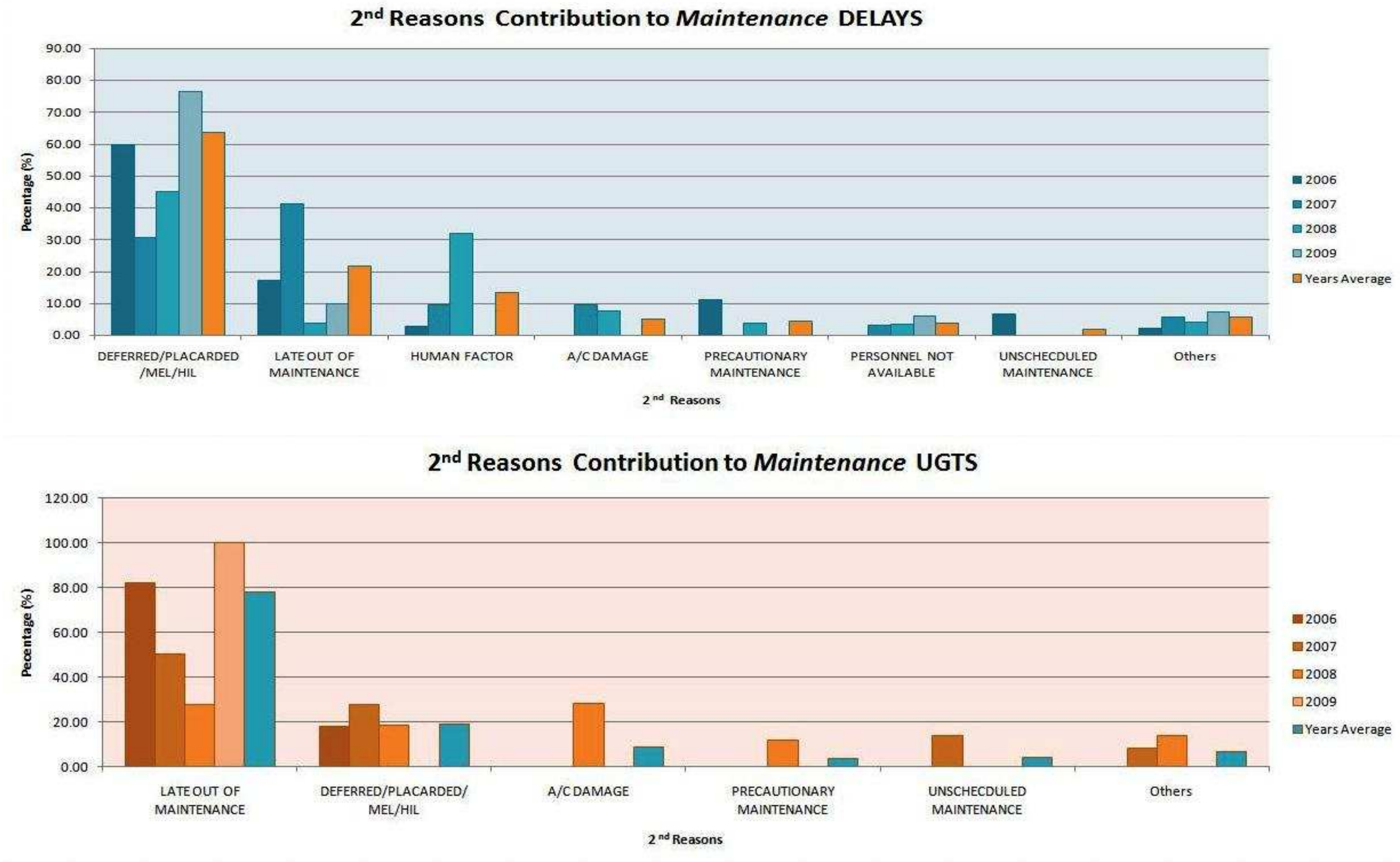
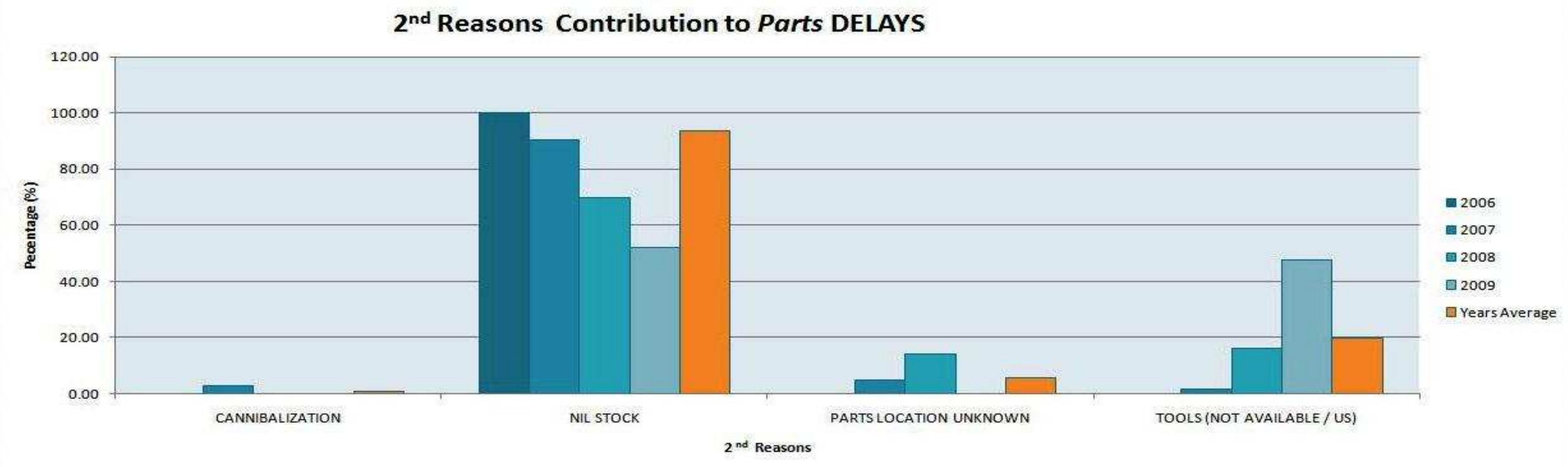


Figure 3.14 - Contribution of the 2nd Order reason to the *Maintenance* delays and UGTs for B767



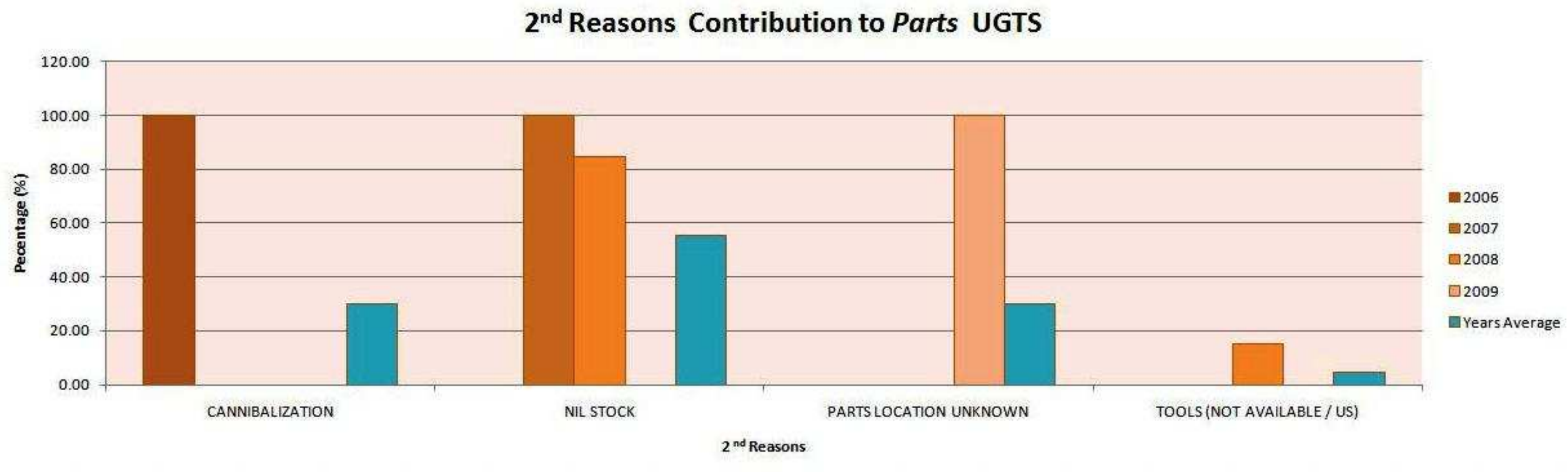


Figure 3.15 - Contribution of the 2nd Order reason to the *Parts* delays and UGTs for B767

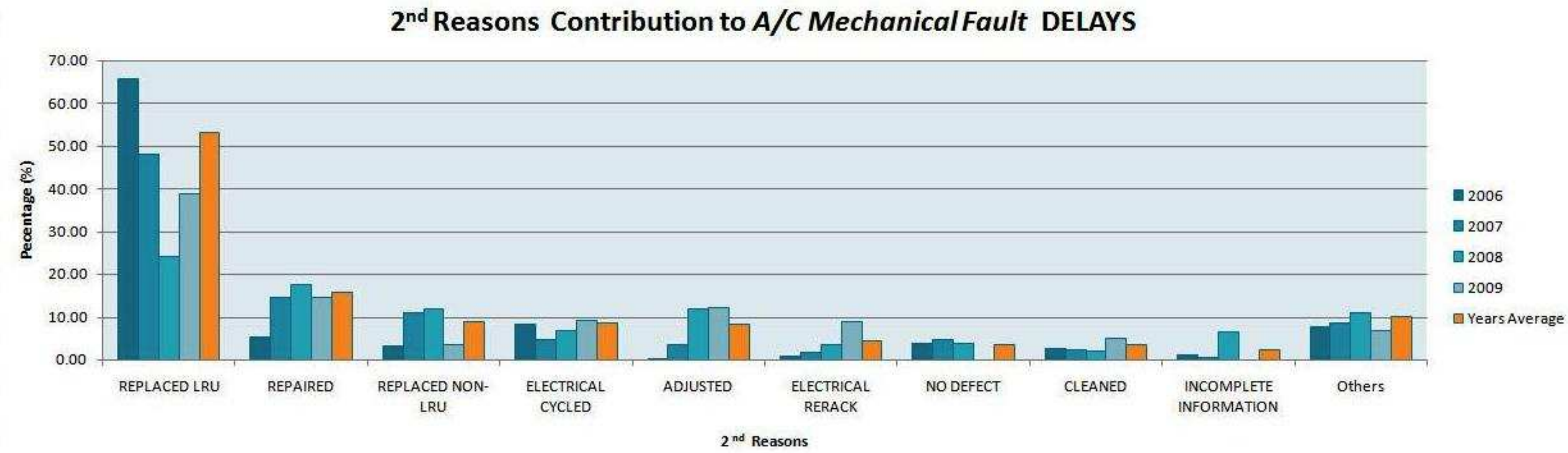
MD11 Fleet Analysis

In Figure 3.16 and Figure 3.17, it is possible to analyse the 2nd Order reasons of the *A/C Mechanical Fault* and *Maintenance* groups, respectively.

As said before, there are several 2nd Order reasons for these main groups, though the graphs show only some of them. For both delays and UGTs (Unplanned Ground Times), the main 2nd Order reason was *Replaced LRU* with a contribution of more than 45%. *Repaired*, *Replaced Non-LRU*, *Electrical Cycle* and *Adjusted* had similar contribution to *A/C Mechanical Fault* delays (between 10-14%). However, *Electrical Cycle* reason was not relevant for the UGTs and *Adjusted* has just caused both delays and UGTs after the middle of 2007. The other reasons had a contribution smaller than 3% or they did not cause a delay/UGT in at least one of the years.

The graphs of Figure 3.17 are related to *Maintenance* 2nd Order reasons and, as can be seen, they are very similar to B767 ones. Again, for this MDCG category the most important reason for the delays and UGTs is different. Therefore, the delays caused by *Maintenance* issues are mostly due to *Defered/Placarded/MEL/HIL* (about 55%). Moreover the contribution of *Late out of Maintenance* was about 30%. *Human Factors* has only caused some delays since the end of 2007. It revealed to have the highest contribution in the first quarter of 2009, although it was the cause of only 3 delays. Once more the UGTs caused by *Maintenance* were about 20% but sometimes that might only mean one or two. Similar to B767, *Late Out of Maintenance* seems to be responsible for the majority of those UGTs (about 60%). *Deferred/Placard/MEL/HIL* has also contributed with about 20% to the UGTs caused by *Maintenance*, not for the first quarter of 2009 though. The other 2nd Order reasons do not have significant contribution since they have only occurred a couple of times.

The Figure 3.18 represents the contributions of the 2nd Order reasons to the delays and UGTs caused by *Parts*. As explained for B767, *NIL Stock* means that the part needed was not available in stock and it was necessary to order one. This 2nd Order reason was responsible for the majority of the delays (about 55%). In the first quarter of 2009 *Cannibalization* was the cause for more than 40% of *Parts* delays. However this means only 4 delays. Notice that if the cause was *Cannibalization*, it also implied *NIL Stock*. Analysing the UGTs graph, only *NIL Stock* and *Tools (Not Available/US)* were responsible for UGT and only in 2007 and 2008. As mentioned in the previous section, there were no UGTs caused by *Parts* since the second quarter of 2008.



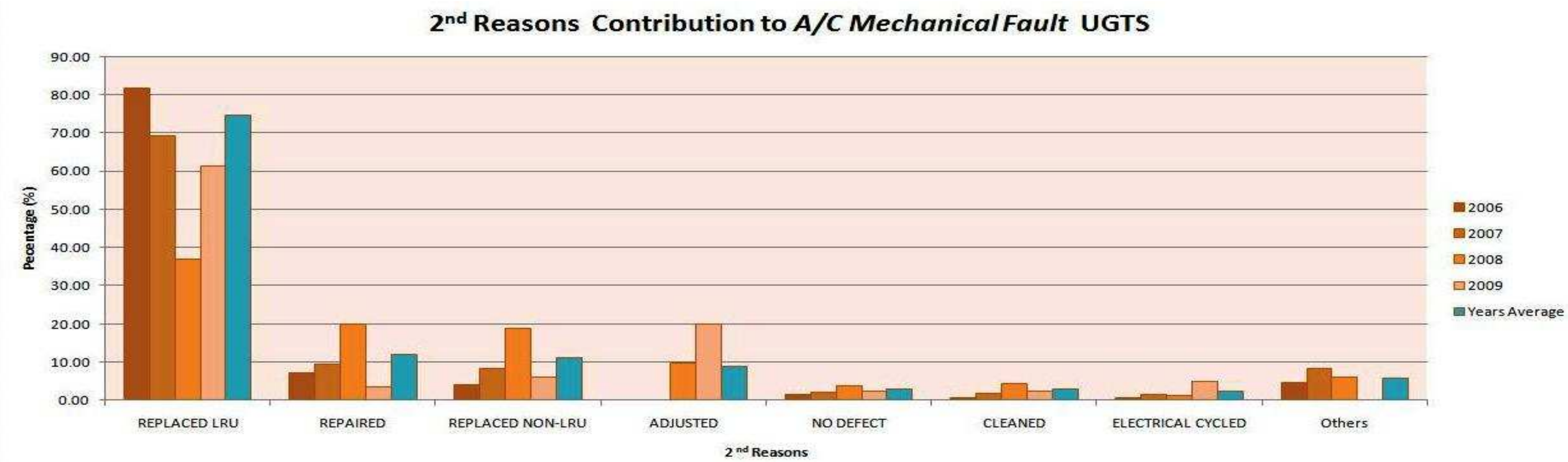
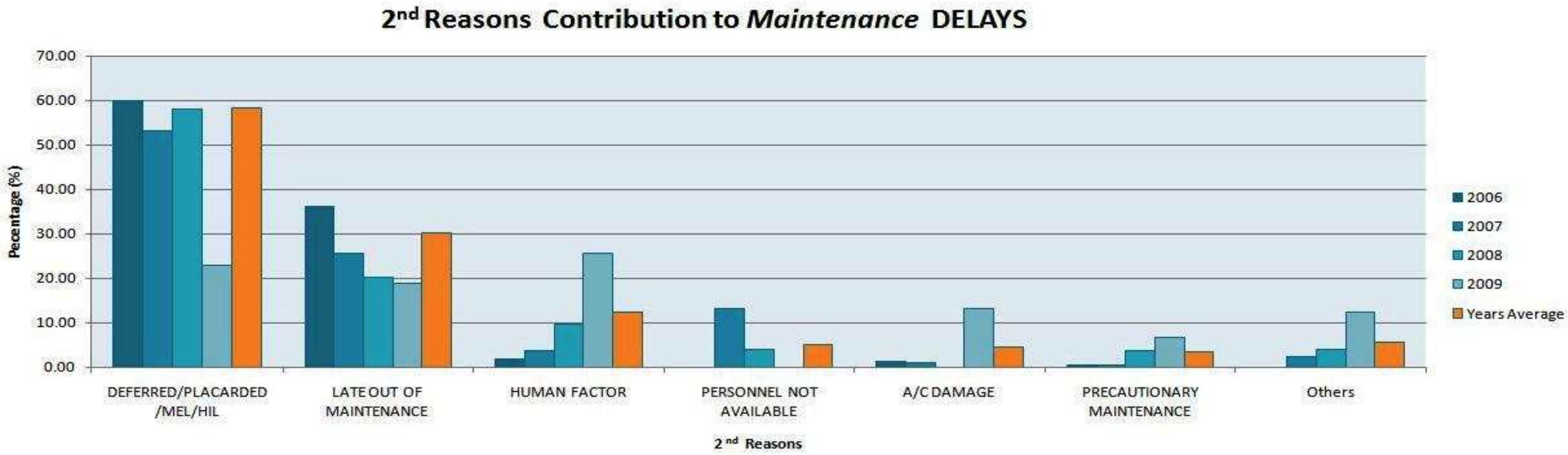


Figure 3.16 - Contribution of the 2nd Order reason to the *A/C Mechanical Fault* delays and UGTs for MD11.


2nd Reasons Contribution to Maintenance DELAYS
Pecentage (%)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
DEFERRED/PLACARDED /MEL/HIL
LATE OUT OF MAINTENANCE
HUMAN FACTOR
PERSONNEL NOT AVAILABLE
A/C DAMAGE
PRECAUTIONARY MAINTENANCE
Others
2nd Reasons
2006
2007
2008
2009
Years Average

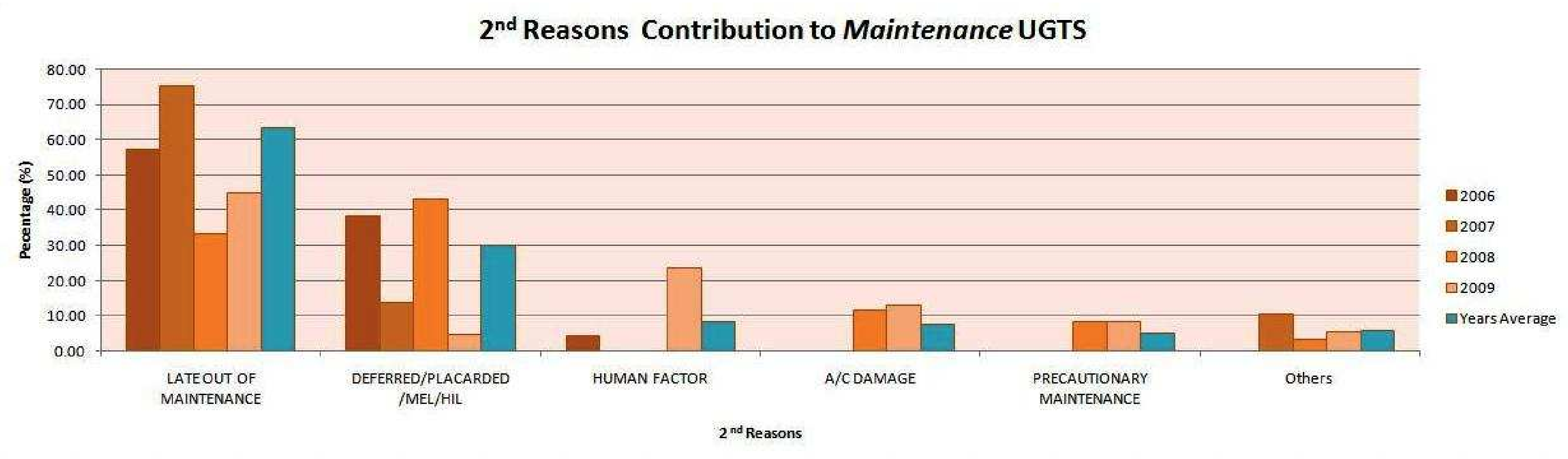
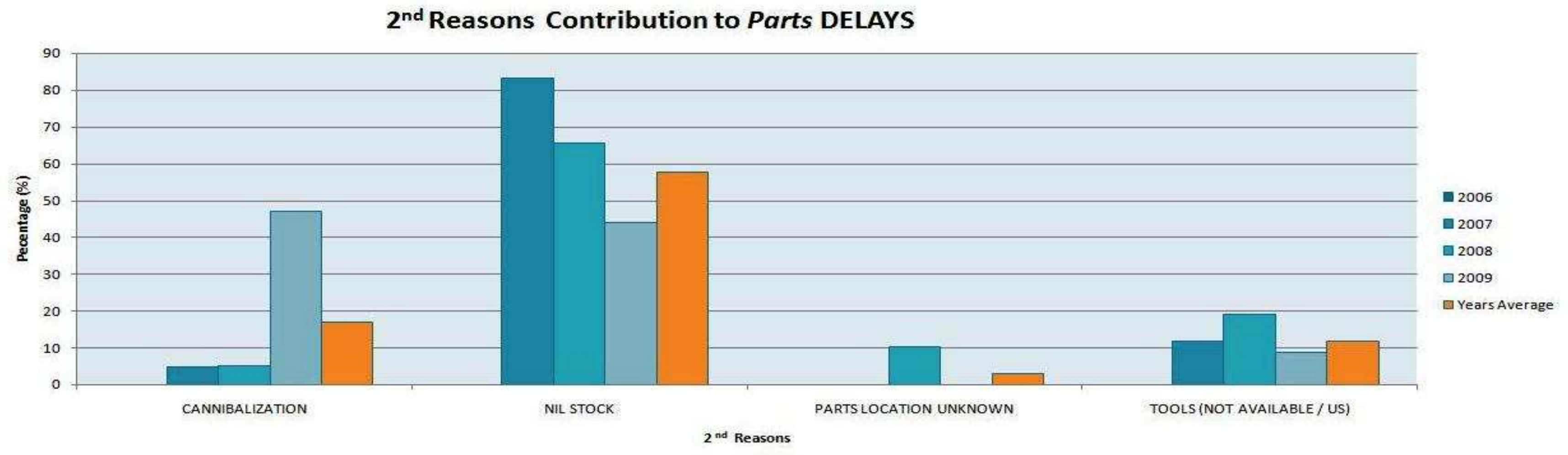


Figure 3.17 - Contribution of the 2nd Order reason to the *Maintenance* delays and UGTs for MD11



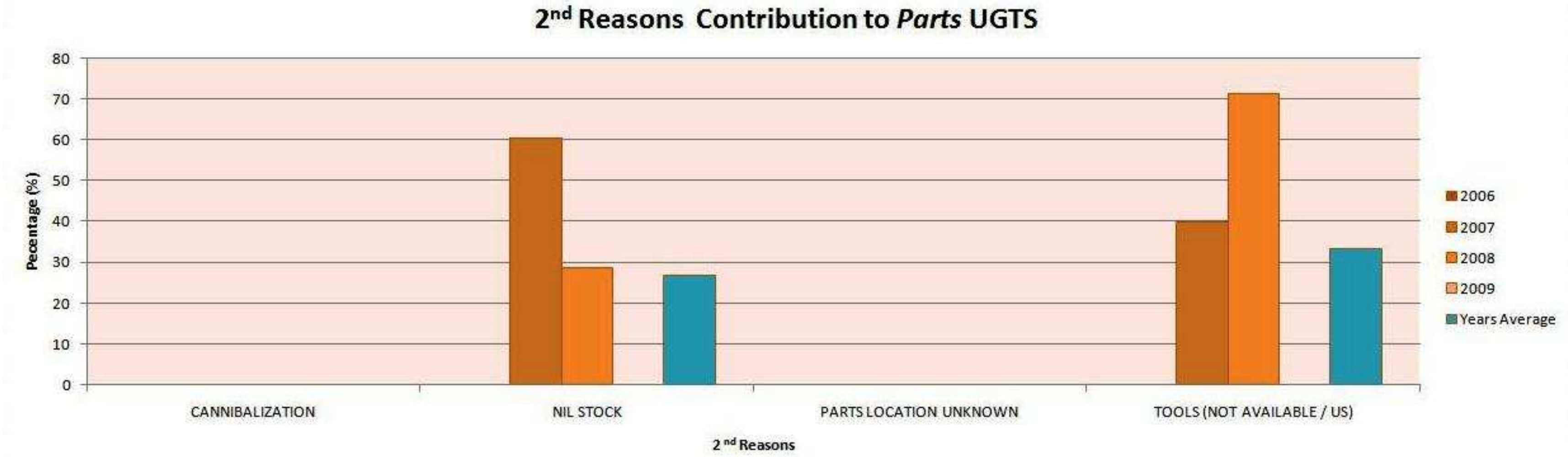


Figure 3.18 - Contribution of the 2nd Order reason to the *Parts* delays and UGTs for MD11

In summary, it is possible to point out the most significant 2nd Order reasons of MDCG. The conclusions and the 2nd Order reason groups mention below revealed to be the same for both B767 and MD11.

Therefore, *Replaced LRU* has contributed with around 40% to *A/C Mechanical* delays and UGTs. In fact, an aircraft has a significant number of LRU and changing these components are most of the time the quickest way to solve a problem. When solving a complaint A/c Mechanics have to perform troubleshooting according to the Fault Isolation Manual (FIM). It will depend on the nature of the complaint what the first step will be in the FIM. It could be a test or it could also be the replace of an LRU. Other relevant 2nd Order reasons of *A/C Mechanical Fault* are *Replaced Non-LRU* and *Repaired*. When the replacement of a LRU does not solve the problem, the next action is, normally, to replace a non LRU or to repair it. The two main corrective actions that can be performed are, indeed, to replace and to repair a component. This fact explains why most of the delays/UGTs are caused by these 2nd Order reasons mentioned above.

Regarding *Maintenance* group, the main reason for the delay has been set as *Deferred/Placard/MEL/HIL*. According to Martinair M&E Business Process, the first step of an A/c Mechanic, when he finds a defect, is to check if it can be deferred or not. Even if the defect is deferred, it can lead to delays because of the time spent, for instance, on troubleshooting, on de-activating a system or on performing a temporary repair. A certified engineer has also to determine if the defect is related to Crew HIL or HIL/MEL (all cat ABCD defects). Moreover, if the defect was at an outstation, the certified mechanic has always to contact the Crew due to possible flight restrictions. At home base, the a/c mechanic has to inform the Crew and the Project Supervisor who will discuss the possible MEL restrictions with Operations to determine if further flight operation is acceptable. UGTs include, among others situations, extended scheduled maintenance. Therefore, it is not a surprising result that *Late Out of Maintenance* has, normally, higher contribution than *Deferred/Placard/Mel/HIL*.

For the four 2nd Order reasons of *Parts* group, the *NIL Stock* reason shows to be the most significant one. Indeed, when the parts that a certified mechanic ordered are not available, he has to determine the seriousness of the defect. If he concludes an AOG situation, he has to inform his supervisor who has to explain the situation to maintenance control. Maintenance control together with the logistics department has to decide which alternatives are possible to create the most economically preferable solution (considering operational consequences, loan costs, and so on). If decided for a Loan part from other company, only Logistics may initiate all necessary steps to get the part released for installation. This process can cause long delays and UGTs.

The Table 3.6 presents the 2nd Order reasons chosen when applying the criteria defined at the beginning of this section. The rates are calculated as the number of delays/UGTs caused by the 2nd Order reason divided by the total number of delays/UGTs in the same period.

(a) Boeing 767 Fleet

MDCG	2nd Order reason	Delay Rate	Av. Delay Time	UGT Rate	Av. Time of UGT
A/C Mechanical Fault	**Replaced LRU**	25%	3h17	27.7%	9h48
	Repaired	8%	4h18	10.2%	22h24
	Electrical Cycle	6.1%	0h41	2.1%	4h09
	Replaced Non-LRU	6.2%	3h58	15.7%	10h41
	Adjusted	3.7% (6.5%[1])	1h59	1.3%	34h11
Maintenance	**Deferred/Placard/MEL/HIL**	10.6%	1h17	4.3%[2]	3h
	Late Out of Maintenance	3.9% (8.2%[1])	3h53	7.7%	12h28
Parts	**NIL Stock**	3% (6.9%[1])	4h35	3%	4h22

(b) MD11 Fleet

MDCG	2nd Order reason	Delay Rate	Av. Delay Time	UGT Rate	Av. Time of UGT
A/C Mechanical Fault	**Replaced LRU**	26.85%	4h18	47.9%	12h48
	Repaired	7.2%	3h57	9.4%	10h16
	Electrical Cycle	6.9%	0h51	1.1%	7h24
	Replaced Non-LRU	3.6% (5%[5])	6h41	8.4%	10h41
	Adjusted	3.5% (7.1%[1])	3h	3.3% (9.1%[1])	14h
Maintenance	**Deferred/Placard/MEL/HIL**	10.4%	1h41	4.7%	5h38
	Late Out of Maintenance	3.5% (5.5%[1])	6h36	5.4%	11h
Parts	**NIL Stock**	2.4% (6%[1])	7h23	1.1 (4.6%[1])	16h30

Table 3.6 – Relevant 2nd Order reason of delays and UGTs for (a) B767 and (b) MD11

It must not be forgotten that the MDCG are the final causes attributed to the delays/UGTs which do not give enough information to determine the actual root cause. These groups can commonly be used at every MRO or airline and have no specific information about the organization, culture or procedures involved. Another shortcoming of this traditional method used in Martinair is the inability to combine reasons. Many chargeable delays have a non-chargeable contribution to the delay duration. Lately, Martinair reliability engineers have started to divide each delays/UGTs into its chargeable and non-chargeable part (including the reason and time contribution). This analysis has been done for the past few months and during the year 2008. However, this information was available in a later stage of the research and it was not possible to include it in this report.

[5] Average excluding the months with zero delays caused by this reason

3.2 Delays and UGT Root Causes – Statistical Analysis

After an extensive analysis of the main groups and the 2nd Order reasons of the MDCG that are causing the majority of the delays/UGTs, the research has tried to find out and to proof statistically other possible root causes that might be related to the delays/UGTs.

3.2.1 Root Causes

Normally, airlines utilize delay codes which give a good quantitative knowledge on the delays. However, according to Niehues et al [1] and Sridhar [27], it is good practice to apply cause effect diagrams (CAED), also called fishbone diagrams, to identify and understand the root causes and factors. Yufeng et al [22] used these diagrams for investigate the factors that influence he departure delay. The CAED approach is accomplished with information from people working in the key processes. As this information was not reported, it was necessary to talk directly with the Project Supervisors and Team Leaders.

Concerning the airline maintenance delays, the fishbone diagram presented in Figure 3.19 tries to put together all the possible logical factors that might be influencing these delays.

- The *Technical Defects* are considered to be in control by the reliability team as every month the delays are analyzed by ATA numbers and the chargeable technical status of the fleet is determined. A Top 5 analysed is made for the ATA codes and recommendations are given.
- The *MDCG* classification was already studied in previous section 3.1.3 and 3.1.4.
- According to the experts opinion the delays are often caused by long time of *Troubleshooting*. Sometimes it can be because of lack of communication between A/c Mechanics, Project Supervisor and MC. Other times, in the Line Maintenance, the delays might be caused by a "Salami Effect". When there is a finding[6] during the turnaround time, the first step is to report to MC and start the troubleshooting. After some time like 1 hour, project supervisor will inform MC of the situation, they might ask for more time for the inspections. After that time they will report back again to MC to give the updated information and according to the status they might need more time for more tests or they can already defined if the defect can be dispatch or not. If it cannot be deferred the Project Supervisor discusses priorities with MC and prioritizes the resources in order to start the defect rectification process. . The previous reporting system can extend for a long period of time until the cause of the complaint is solved or deferred.

[6] Defect on the aircraft noticed en-route by either flight crew or cabin crew or during a inspection by authorised maintenance personnel

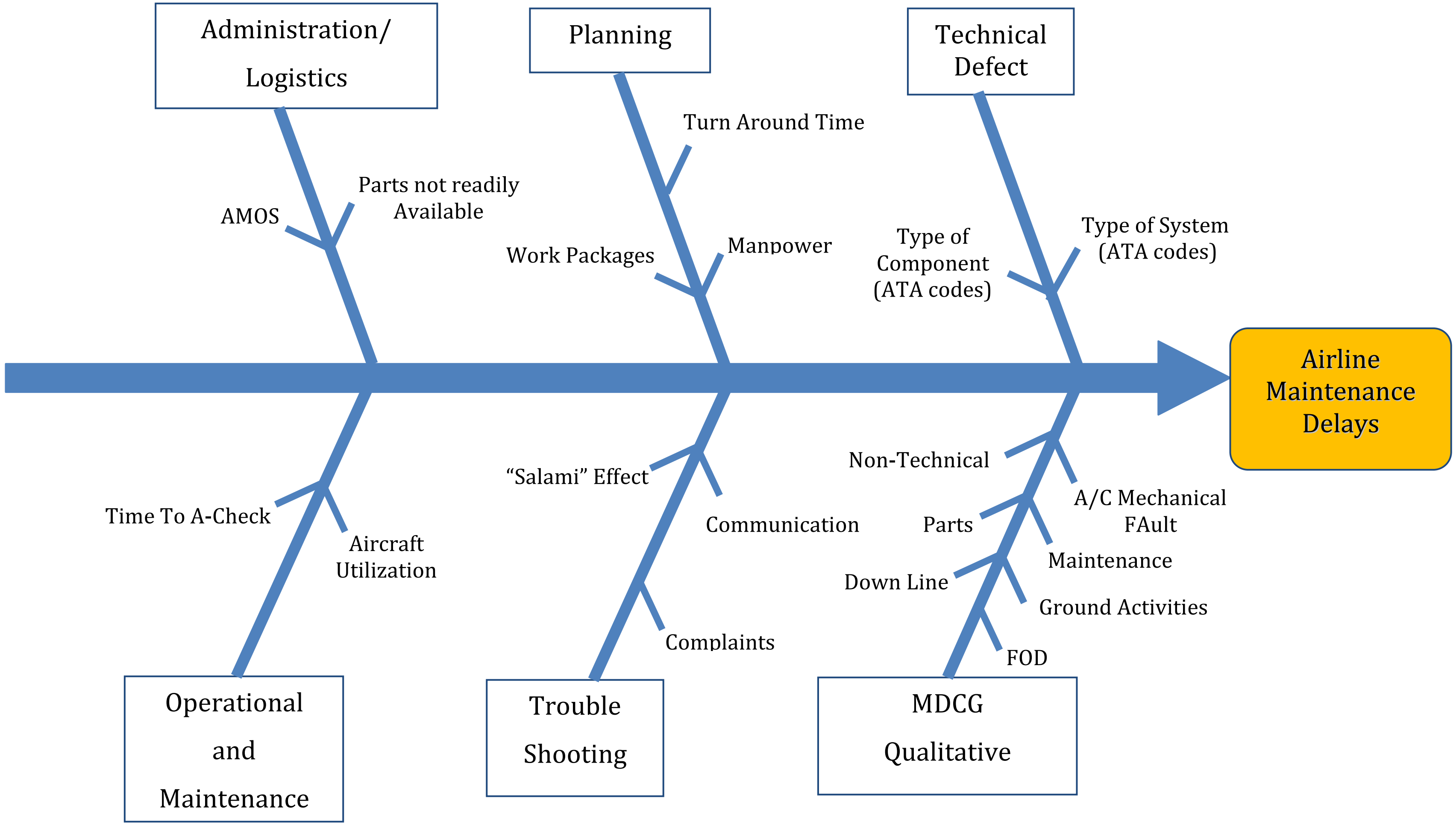


Figure 3.19 – Root Causes for the delays according to experts opinion.

- *Planning* section also represents an important role in the airline maintenance delays as it is responsible for planning all the scheduled maintenance activities, facilities and supplies for these activities. Therefore, the Planner created the task cards and groups them in checks and single running tasks creating basic work packages. Accordingly to the amount of work planned, it is determined the amount of time needed, required man-hours and due dates. Three planning factors were considered to influence the delays: manpower available, turnaround time and estimates of job times in the work packages. In case of findings, the last estimates are given by the A/c Mechanic who has to report in a work order what he needs to solve the defect in terms of manpower, material, tools and ground time. The minimum turnaround time for passenger flights can vary between 1h45-2h depending on the 100% airport control (check for illegal substances). For cargo service, the minimum turnaround time is 3h, which is the minimum time to call the crew. These times are the typical ones used by Planners when planning the flight schedule.
- Experts think that part of the delay can be related to *Administration* and *Logistics* issues. One of them is *Parts not readily available*. Martinair has two ways of handling rotable components: they are always in Matinair's stores or they are available on call at the pool provider (Zurich or Copenhagen). If the pool leader does not have the part available, he is responsible to find a solution as soon as possible. If the parts ordered by the A/c Mechanic are not available, he has to determine the seriousness of the defect and to conclude if it is an AOG situation or not. Moreover, he has to report to his Project Supervisor who informs the MC. Maintenance Control together with the logistics department have to decide which alternatives are possible to create the most economically preferable solution (considering operational consequences, loan costs, and so on). If decided for a Loan part from other company, only Logistics may initiate all necessary steps to get the part released for installation. When a loan part is installed the mechanic has to issue a new work order in AMOS. If decided for robbing a part from another aircraft, the Quick Service Desk has to be informed. Then the A/c Mechanic starts to remove the applicable item from the a/c. He has to report the removed part in AMOS and also the order of the part for the applicable aircraft.
- As it is possible to see other delay factor can be the time spent using *AMOS*. As mentioned before, AMOS is a software package that manages the maintenance, engineering and logistics functions of aviation companies. Despite the clear advantages of using a software that can have all the maintenance, engineering and logistic information updated, the time A/c Mechanics have to spend feeding the AMOS system and all the related order procedures discussed before, can turn out in longer time for corrective action. In fact, findings are reported in paper and AMOS but sometimes to save time A/c Mechanics report them firstly in paper and secondly in AMOS at the end of the shift. This way it is possible to close A-check on time and continue working on findings afterwards. Other problems related to AMOS system are the staff weak training to work with AMOS environment and the awareness of the use.

- Two other factors are believed to be relevant since they can be a root cause of the delay: *A/C Utilization* and *Time to A-Check*. If significant effect is found for those two factors, it might mean that maintenance and operational decisions should be made.
- The report of malfunctions or degradations in aircraft systems can be noticed by maintenance personnel during maintenance actions or by flight crew during the flight. They are called Maintenance Reports (MAREPs) and Pilot Reports (PIREPs), respectively.. These complaints are very important as they can predict early trends in problem areas. The actual number of complaints can be expected to be highly related to the number and time of delays. MAREPs and PIREPs are the official documents to report a finding. This process involving findings was already described above.

There are numerous factors that can cause a delay and influence the delay time. Some of the possible root causes were mentioned in this section.

The *Technical Faults* (aircraft failures) seem to be under control and sufficient data is reported in AMOS system (ATA codes). However, the A/c Mechanics are not aware of the importance of keeping historical data for non-chargeable events and this information cannot be found in a reliable way.

The *MDCG* reasons are categories used to classify the final corrective action performed and themselves cannot be used as predictors in regression analysis. Their frequency and impact on the delays were analysed in section 3.1.3 and 3.1.4.

Aircraft Utilization and *Time to A-check* are factors that can easily be measured and transformed into useful variables. In chapter 2, it was defined Aircraft Utilization Rate (AUR) based on the total flight hours in a particular period and its number of days. The intervals between A-checks are set for each type of aircraft, although they can be subject to change in the very day they are performed. The historical data about the actual performed day of the A-check for all the Martinair's fleet can be found in AMOS system.

The *Administration* and *Logistics* issue might be responsible for an important amount of the delay time. However, it is difficult to quantify its parameters in order to do a statistic analysis. One possible measure could be to check for each delay/UGT event whether the rotable component order was stored in Martinair's store in Schiphol or if it had to be ordered from the pool providers. Owing to several aspects such as lack of time, lack of reliable data and information in Dutch, it was not possible to include any measure in the regression analysis regarding this issue. As explained before, the work packages are composed by the Planner who takes the work orders into account. Concerning *Planning*, it was only assessed the actual manpower available per shift since 2007.

The number of MAREPs and PIREPs seems to be a good indication for the time of troubleshooting and turnaround time.

Summing up, the maintenance factors chosen for the statistical analysis were, as follows:

- ✓ Time to A-check (TTA)
- ✓ Aircraft Utilization Rate (AUR)
- ✓ Maintenance Reports (MAREPs)
- ✓ Pilot Reports (PIREPs)
- ✓ Manpower available (MPA)

3.2.2 Statistical Analysis

The next step is to do an appropriate statistical analysis. For this research, the statistical analysis is done separately for the two aircraft types: Boeing 767 and McDonnell Douglas MD11. Moreover, for each fleet it was also studied delays and UGTs separately. Firstly, it was checked the relation between the time of delay/UGTs and the maintenance factors chosen. Secondly, it was investigated the effect of the independent variables on the probability of a delay/UGT.

Experimental Design and Delay Factors

The main goal of this research is to find out Martinair's maintenance drivers that influence the delay time. As it was mentioned before, there are lots of variable factors that might be the starting point of a delay. Nevertheless, this research focus on maintenance related factors since they are the relevant ones for Martinair's M&E. The following five delay factors were included in this research:

1. Time to A-check (TTA)
2. Aircraft Utilization Rate (AUR)
3. Maintenance Reports (MAREPs)
4. Pilot Reports (PIREPs)
5. Manpower Available (MPA)

The factors above were collected from Martinair database as continuous variables. However, they can be transformed into categorical ones to try to find the best model that fits the data. Despite there is some lost of detailed information when doing this transformation, it is still possible to conclude about the effect of the factor on the response. This way, the factors were split into different levels (bins) to create the categorical variables. The bins lower and upper values were logically chosen according to the range and frequency of the data.

As the wide-body fleet under analysis consists of two different types of aircraft, MD11 and B767, the range values of the continuous variables is slightly different. The Table 3.7 and Table 3.8 summarize the five factors used as continuous and categorical variables, respectively.

(a)B767

Factors	Description	Value	Unit
TTA	Time to A-check	0 to 835	Flight hours (FH)
AUR	Aircraft Utilization	0 to 19h50	Flight hours per day (FH/day)
MPA	Average Manpower available	15 to 46	People per shift (/shift)
MAREPS	Maintenance Reports Rate	0 to 10	Complaints per Take-off (/TO)
PIREPS	Pilot Reports Rate	0 to 12	Complaints per Take-off (/TO)

(b)MD11

Factors	Description	Value	Unit
TTA	Time to A-check	0 to 752	Flight hours (FH)
AUR	Aircraft Utilization	0 to 18h37	Flight hours per day (FH/day)
MPA	Average Manpower available	15 to 46	People per shift (/shift)
MAREPS	Maintenance Reports Rate	0 to 15	Complaints per Take-off (/TO)
PIREPS	Pilot Reports Rate	0 to 8	Complaints per Take-off (/TO)

Table 3.7 – Delay Factors as continuous variables.

Factors	Description	Level	Value	Unit
TTA	Time to A-check	4	0-100, 100-400, 400-600, >600	Flight hours (FH)
AUR	Aircraft Utilization Rate	3	Low (0-7h30), Medium (0-15h), High (>15h)	Flight hours per cycle
MPA	Average Manpower available	4	15-20, 20-30, 30-40, >40	People per shift (/shift)
MAREPS	Maintenance Reports Rate	3	0-2, 2-5, >5	Complaints per Take-off (/TO)
PIREPS	Pilot Reports Rate	3	0-2, 2-5, >5	Complaints per Take-off (/TO)

Table 3.8 – Delay Factors as categorical variables.

TTA: Time to A-check

The Martinair interval between A-checks is set as 700 flight hours for MD11 and 770 flight hours for B767. However, the actual performed date can be delayed by the operator for several reasons. Normally, a check task can be extended up to 10% according to the flight hours or flight cycles. Although there are some tasks that are not extendable, they have higher interval than the average A-check interval. Thus, Martinair is able to perform the A-check within a 110% interval, if not the aircraft must be on ground until it is performed. The A-check is divided in 12 parts concerning different tasks (A1-A12). It is possible to split the A-check because there are check tasks that have a bigger interval than the A-check one. The downtimes of an A-check are normally around 1 day and 7 hours for B767 and 1 day and 3 hours for MD11, when an aircraft receives heavy maintenance (C- and D-check) the downtimes are longer. It must not be forgotten that there are also some inspections of the A-check preformed during C- and D-check. It seems reasonable to consider that the interval between A-checks might have an effect on the occurrence of a delay as more *findings*[7] might appear during the normal pre-flight check as the a/c become closer to its A-check.

The TTA is calculated as the flight hours left of a particular aircraft to its next A-check. When it is used as a categorical variable, it is divided into 4 different levels: 0-100 flight hours, 100-400 flight hours, 400-600 flight hours and 600+ flight hours.

[7] Defect on the aircraft noticed en-route by either flight crew or cabin crew or during a inspection by authorised maintenance personnel

AUR: Aircraft Utilization Rate

Aircraft utilization is the average daily airborne flying hours or cycles for one aircraft. A daily utilization can be calculated for the entire fleet or for a single aircraft. In this research, the aircraft utilization is calculated by the following equation:

$$Aircraf\ Utilization\ Rate\ (AUR) = \frac{Totalflying\ hours\ of\ the\ previous\ 7\ days}{7\ days} \tag{1}$$

The Aircraft Utilization Rate (AUR) represents the average daily utilization of an aircraft for the past 7 days. It is possible to get a zero in the aircraft utilization, for example when an aircraft was in a C-check during the previous 7 days. When it is used as a categorical variable, it is divided into 3 different categories: Low (0-7h30), Medium (7h30-15h) and High (15h+) utilization.

Normally, MD11 fleet has a higher utilization rate and more cycles, which lead to more maintenance times.

MPA: Manpower Available

In general, the manpower is planned at least one/two weeks in advance. The manpower concerns the number of people to perform maintenance actions on the aircraft (A/c Mechanics). Additionally, there are always one Team Manager and 2-4 Project Supervisors per shift. In the beginning of each shift the Team Manager and the Project Supervisor assign work places to the staff. Thus, according to the amount of planned jobs, some of the staff goes to the gate (Line Maintenance) and others stay in the hangar (Base Maintenance). There is always a weekly meeting called Production Evaluation Meeting (PEM) to evaluate the previous A-check and to prepare the next week one. In this meeting, it is checked, among other things, special complaints, licensed staff and man-hours needed and available.

For the statistical analysis, it was taken the average number of people on duty per shift in spite of the normally higher number of people working during the morning (7h-15h). When MPA is used as a categorical variable, it is divided into 4 different levels: 15-20 people, 20-30 people, 30-40 people and 40+ people.

MAREPs and PIREPs: Maintenance and Pilot Reports

All maintenance events, which are carried out on an aircraft, have to be issued in Martinair system as work orders. Sometimes there are unscheduled work orders issued by pilot or maintenance staff. This happens whenever a pilot or an a/c mechanic finds a defect. Each work order corresponds to only one pilot or maintenance complaints (PIREPs and MAREPs, respectively). The defect rectification process has already been explained in the previous section. Therefore, we know that a complaint might not be solved in the same day, indeed many of them are deferred (per MEL or HIL). Even if the complaint is deferred it can cause a delay on that day due to troubleshooting time. It was considered useful to relate the number of PIREPs and MAREPs per take-off with the delays and UGTs. Actually, the flight crew can play a major role in UGTs as the UGT can be defined as the time that is not scheduled 1 hour before the flight arrives. Therefore, the flight crew should send a list of all defects/alarms noticed during the flight an hour before arriving to the station and to the Maintenance Control (MC). This way, MC would be able to plan the maintenance slot and provide the necessary manpower, components and tools. This information is transmitted by ACARS (Aircraft Communications Addressing and Reporting System), a digital datalink system for transmission of short, relatively simple messages between aircraft and ground stations via radio or satellite.

From Martinair work order it was possible to extract the MAREPs and PIREPs per day. A MAREPS and PIREPS rate, to use in the statistical analysis, was calculated according to the following equation:

$$MAREPS\ rate = \frac{number\ of\ MAREPS\ on\ a\ day}{number\ of\ take\text{−}offs\ on\ the\ same\ day} \qquad (10)$$

$$PIREPS\ rate = \frac{number\ of\ PIREPS\ on\ a\ day}{number\ of\ take\text{−}offs\ on\ the\ same\ day} \qquad (11)$$

These rates take the average number of MAREPs and PIREPs before take-off per day. On some days there were only 1 or 2 complaints and more than 2 cycles so these rates can be less than 1. When MAREPs and PIREPs are used as a categorical variable, they are divided into 3 different levels: 0-2 reports/TO, 2-5 reports/TO and 5+ reports/TO.

For this analysis, we tested 4 different models depending on the type of the aircraft and the event:

- Delay for B767 fleet
- Delay for MD11 fleet
- UGT for B767 fleet
- UGT for MD11 fleet

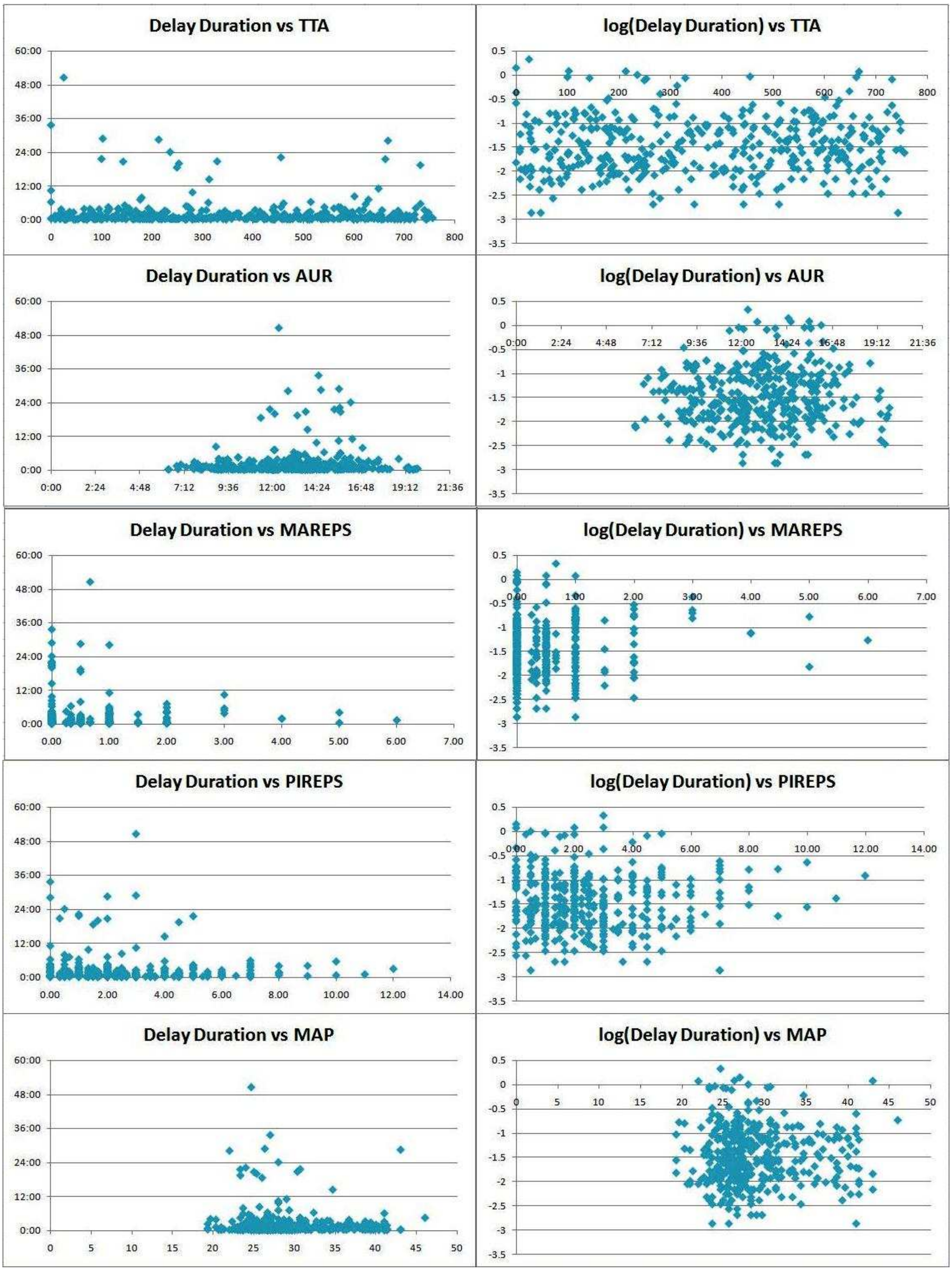
Experimental Result and Analysis - Delay and UGT Duration

At first, we tried to find a correlation between the factors and the duration of the delay and UGT (Unplanned Ground Times) using a Pearson product-moment correlation coefficient. However, none correlation was found between the two responses (Delay and UGT duration) and the independent variables. For all the tests the *p*-value was higher than 0.05. The following graphs show the (a) Delay Duration and (b) UGT duration against the independent variables: TTA, AUR, MAREPs, PIREPs and MPA for B767. For the sake of space, the results for the MD11 are not represented since the graphs were very similar to B767.

The Figure 3.20 demonstrates that none of the independent factors are correlated to the duration of the delays or UGTs even when it was applied a logarithm transformation to smooth the results.

Despite the previous results which evaluated the relation between the single factor and the dependent variable, it was tested several multiple regression models with a GLM ANOVA analysis to check if there was any relationship between the independent variables and the response when studied at the same time. Besides some significance was found for some of the factors, the R^2 for all the tested models was below 10%. The R^2 is the percentage of the response variable variation that is explained by its relationship with the predictor variables. Thus, the low value for R^2 means that the tested model does not fit our data.

(a) DELAY DURATION



(b) UGT DURATION

Figure 3.20 –(a) Delay and (b) UGT duration plotted against the independent variables

Experimental Result and Analysis - Delay and UGT Probability

The second step was to do a Binary Logistic Regression. This kind of regression analysis is used to perform a regression analysis on a binary response variable. A binary variable has only two possible values. In statistics, logistic regression is used to predict the probability of occurrence of an event by fitting data to a logistic curve. It is a generalized linear model used for binomial regression. Because the event (occurrence of a delay/UGT) has been categorized into "yes" (1) or "no" (0), a binary logistic regression analysis is appropriate to investigate the effects of the different factors upon delay.

Table 3.9 represents a summary of the results of Binary Logistic Regression for the Delay and UGT as dependent variable for the two types of aircraft. The model for the B767 Delay used predictors as categorical variables while for the other three models they are continuous variables.

RESPONSE	DELAY		UGT	
FACTORS A/C Type	**B767**	**MD11**	**B767**	**MD11**
TTA	**0.035**[b]	**0.000**[a]	**0.021**[b]	**0.003**[a]
AUR	**0.000**[a]	**0.000**[a]	0.821	**0.000**[a]
MAREPS	0.976	0.059	**0.000**[a]	**0.018**[b]
PIREPS	**0.000**[a]	**0.000**[a]	**0.001**[a]	**0.000**[a]
MPA	**0.002**[a]	0.603	0.650	0.254
TTA*AUR	0.203	**0.000**[a]	0.154	**0.001**[a]
TTA*MAREPS	0.489	**0.000**[a]	0.130	**0.000**[a]
TTA*PIREPS	0.105	**0.000**[a]	0.461	**0.000**[a]
TTA*MPA	0.546	0.751	0.636	0.442
AUR*MAREPS	0.993	0.997	0.146	0.287
AUR*PIREPS	0.258	0.948	0.155	0.873
AUR*MPA	0.213	0.979	0.482	0.526
MAREPS*PIREPS	0.254	0.105	0.782	0.052
MAREPS*MPA	0.726	0.735	0.947	0.418
PIREPS*MPA	0.968	0.666	0.815	0.840

[a] Significant at the 0.01 level
[b] Significant at the 0.05 level
No superscript denotes lack of significance at both levels (0.01 level and 0.05 level)

Table 3.9 – A summary of Binary Logistic Regression results for Maintenance Parameters (*p*-values).

The Time to A-check (TTA) and the PIREPS rate show significance for all models. However, TTA is significant at the level 0.01 for MD11 models while it is at level 0.05 for B767. The MAREPS rate seems to influence only the UGT models both B767 and MD11. However, for the MD11 Delay model the *p*-value is small (p=0.059). The Manpower Available shows significance at level 0.01 only for the B767 Delay model. One explanation might be the fact that the B767 Delay model is the only one using independent factors as categorical variables. Aircraft Utilization Rate (AUR) is highly significant (p=0.000) for all models except B767 UGT (p=0.821). There are significant second order interactions only for booth MD11 Delay and UGT models (between TTA and the other factors). A significant interaction between factor A and B indicates that the effect of A on the mean value of the dependent variable differs for the various levels of B. A significant interaction implies that an appropriate combination of independent variables could be selected in such a way that the performance criterion (probability of delay/UGT) is minimized.

Table 3.10 and Table 3.11 show the coefficients of the significant factors from the Binary Logistic Regression. In Binary Logistic Regression, the estimated coefficients of a predictor are the estimated change in $log\left(\frac{P(event)}{P(not\ event)}\right)$ for each unit change in the predictor (assuming the other predictors remain constant). The probability of event is related to the response of the linear regression by $P(event) = \frac{1}{1+e^{-Y}}$ where Y is the dependent responsible variable of the linear regression.

For continuous variables, positive coefficients mean an increase in the response variable and consequently in the probability while negative coefficients have a reduce effect on probability. For categorical variables, Minitab assigns the first level as the reference one and coded it as 0. So a unit change in a factor refers to a comparison between a certain level and the reference level.

		RESPONSE - DELAY
FACTOR	**Level**	**B767**
TTA	0-100	0
	100-400	0.21272
	400-600	0.37024
	600+	0.52755
AUR	Low (0-7h30)	0
	Medium (7h30-15h)	1.91142
	High (15h+)	1.15185
PIREPS	0-2	0
	2-5	0.50051
	5+	1.31110
MPA	15-20	0
	20-30	0.47420
	30-40	0.27380
	40+	1.45672

Table 3.10 - Coefficients of Fitted Models: Main Effects (categorical variables)

RESPONSE	**DELAY**	**UGT**	
FACTORS **A/C Type**	**MD11**	**B767**	**MD11**
TTA	**-0.00389**	**0.00092**	**-0.00391**
AUR	**-2.47471**	-	**-2.66953**
MAREPS	0.08423	**0.510797**	**0.12187**
PIREPS	**0.87697**	**0.161980**	**1.31727**
MPA	-	-	-
TTA*AUR	**0.00885**	-	**0.00805**
MAREPS*TTA	**0.00234**	-	**0.00173**
PIREPS*TTA	**-0.00179**	-	**-0.00151**

- indicates no significance (not included in the model)
Note: Significant interactions shown in bold.

Table 3.11 – Coefficients of Fitted Models: Main Effects (continuous variables).

Effect of *TTA*

For MD11 fleet, the coefficient is negative and similar for Delay and UGT models. As Time to A-check increases the probability of a delay and UGT reduces. This means that if the aircraft has come out from an A-check the probability of a delay is lower.

The interaction between *TTA* and the other factors are significant only for MD11 fleet and their coefficients are similar for delays and UGTs as well.

Regarding B767, the coefficient of *TTA* is positive for UGT model but it has a relatively small value (0.00092) which can be negligible. For the Delay model, the independent variables are categorical and we need to compare the level coefficients with the reference one (coded as 0). Therefore, it is possible to see a positive effect of *TTA* on the delay. However, the difference between the level coefficients is not very significant.

Effect of *AUR*

For MD11 fleet, the coefficient is negative and similar for Delay and UGT models. As Aircraft Utilization increases the probability of a delay and UGT reduces. Notice that *AUR* is the daily average utilization of the previous 7 days. If *AUR* is higher the probability of delay and UGT reduces maybe due to more control of the components and system failures and more pre-flight checks.

Concerning the B767 Delay model (categorical independent variables), it seems that there is a higher probability of delays when there is a *Medium* or *High* level of utilization. This means that if an aircraft had had a daily average utilization above 7h30 in the past 7 days, the probability of delay would have increased which wouldn't be surprising. In reality, if an aircraft flies more, the components and systems have a higher probability of showing malfunctions which can lead to delays. However, the results show that the probability of delay will be higher if the utilization level is *Medium* instead of *High* (15h+). Once again this result might be due to more maintenance checks (pre-flight checks) for aircrafts with *High* utilization which make possible to be more aware of the problems and planned the corrective actions in a better way.

Effect of *MAREPs rate*

The number of *MAREPs* before take-off is not significant for Delay model both for B767 and MD11. This result is related to lower number of *MAREPs* for delays events. In fact, the delays are mainly caused at the gate (maintenance Pre-flight check and Line Maintenance) where the maintenance actions are not carried out so deeply.

For the UGT models the *MAREPs* rate has a positive coefficient, which means a higher number of *MAREPs* gives higher probability of UGTs. This is logical, if A/c Mechanic finds more unexpected defects (reported as *MAREPs*), more time will be needed to troubleshooting and repair which will cause unplanned maintenance (UGTs).

Effect of *PIREPs rate*

In this study, the coefficient of *PIREPs* is positive for the 4 models which means that this effect increases the probability of delays and UGTs. In fact, for B767 Delay model (categorical independent variables), there is a significant increment of the effect of *PIREPs* between the levels. More than 5 *PIREPs* per take-off cause a higher probability of delay..

This is logical because before a departure all the complaints (defects) enter in the crew maintenance log have to be performed. For the MD11 the impact of *PIREPs* is higher for the UGT model than for the Delay model. It can be explained by the fact that the crew is responsible to report (*PIREPs*) all defects/alarms noticed during the flight before arrival and if they do not send it at least one hour in advance, there will be a UGT situation.

Effect of MPA

The Manpower available seems to be significant only when used as a categorical variable for the B767 Delay model. The coefficients are always positive which means that if there are more than 20 people (reference level), the probability of delay will increase. It will have more impact when the average number of people per shift is higher than 40 but it will have less impact when there are between 30-40 people available. This result is not compatible with reality because it does not make sense that more people available can cause more delays. This result is because the first and the last levels have few observations, probably related to particular days. Therefore, we can infer that the last level (40+) has the higher impact on the delays because, according to the historical data, more people were planned for those critical days. Regarding the first level (15-20), it seems the level with less probability because most of the times there are more than 20 people per shift.

Chapter 4

Predictive Model for Delays and UGTs

This chapter makes a summary of the *Model Description* (section 4.1), shows an *Illustrative Example* of the model (section 4.2), proves the *Model Validation* (section 4.3) and gives *Model Simulation Results* (section 4.4).

4.1 Model Description

As explained in the previous chapters, the predictive model is developed using regression analysis. From the experimental results, the only reliable regression model is the one which can predict the probability of a delay (using a Binominal Logistic Regression). Therefore, this model is able to predict not only the probability of one single event (delay or UGT – unplanned ground times) but also the on-time performance in a certain period.

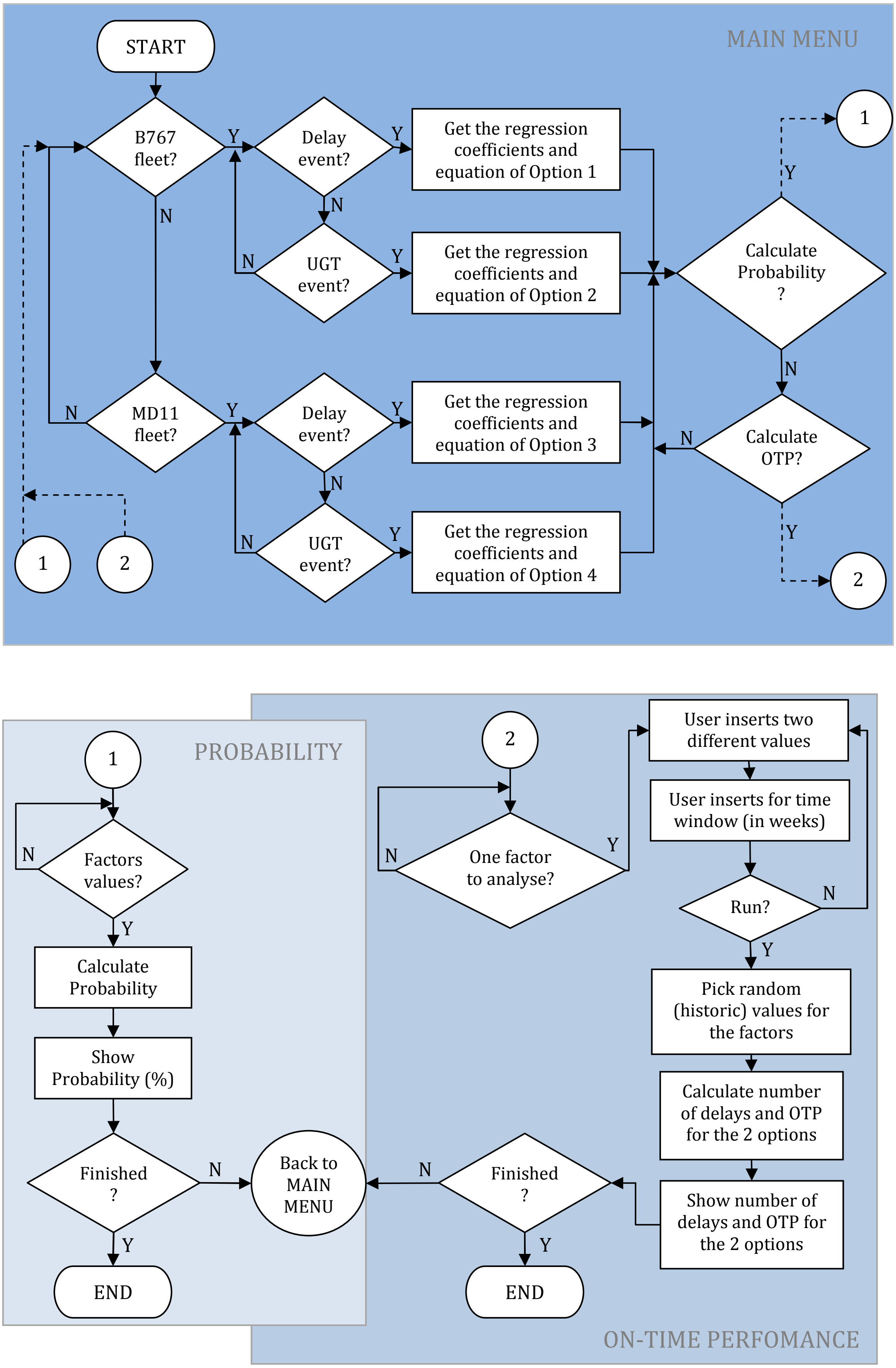


Figure 4.1 – Model Flowchart

4.1.1 Options

The user has to decide what he/she wants to simulate and, then he/she has to set the proper options before running the simulation. This model allows the user to choose between:

1. To predict a *Delay* or *UGT*
2. To predict for *B767* or *MD11* fleet
3. To predict the *Probability of one single event* or *On-time Performance*

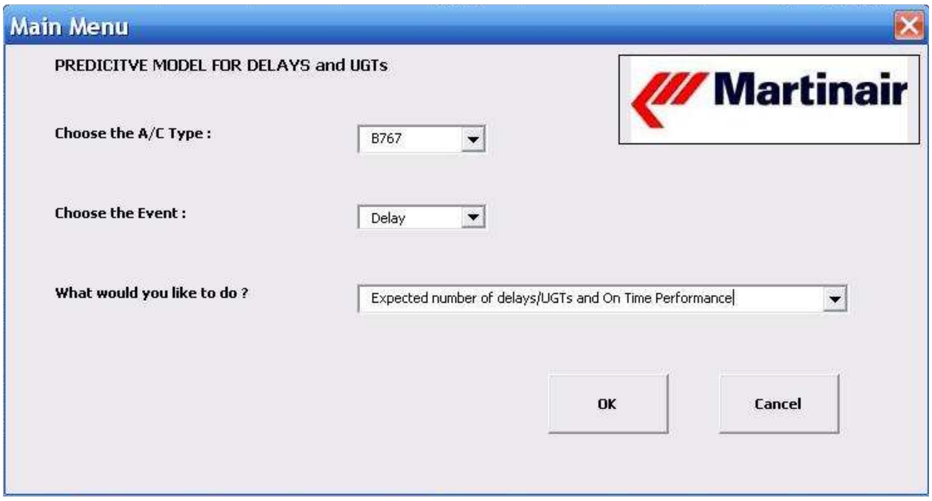


Figure 4.2 – Main Menu: Predictive Model for Delays and UGTs Options

It must be highlighted that the maintenance delay factors will differ according to the setting chosen. This is explained by the regression analysis results which proved that the significance of the factors is slightly different depending on the type of aircraft and type of event.

Therefore, as stated before, there will be four different regression models: B767 fleet Delays, B767 fleet UGTs, MD11 fleet Delays and MD11 fleet UGTs. The regression equation and the coefficients of each model differ, but the calculations for the probability of delay/UGT are the same, as seen in section 2.2.3.

B767 fleet Delays – Option 1

The significant factors found in the statistical analysis that can be manipulated by the user to predict B767 fleet delays are:

- ✓ Time to A-check (TTA),
- ✓ Aircraft Utilization Rate (AUR),
- ✓ Pilot Reports (PIREPS) and
- ✓ Manpower Available (MPA).

This model is the only one that uses categorical independent variables (factors) because it proved to fit the data better and to give more reliable results in the experiments. The Table 3.8 in section 3.2.2 shows the levels of these categorical factors and Table 3.10 shows the regression coefficients for this model.

B767 fleet UGTs – Option 2

The significant factors found in the statistical analysis that can be manipulated by the user to predict B767 fleet UGTs are:

- ✓ Time to A-check (TTA),
- ✓ Maintenance Reports (MAREPs) and
- ✓ Pilot Reports (PIREPs).

This model uses continuous independent variables (factors) because it proved to fit the data better and to give more reliable results in the experiments. The Table 3.7 in section 3.2.2 shows the limits and the units for these factors. The Table 3.11 shows the coefficients for this model regression equation.

MD11 fleet Delay and UGT – Option 3 and Option 4

The significant factors found in the statistical analysis that can be manipulated by the user to predict MD11 fleet are the same for delays and UGTs:

- ✓ Time to A-check (TTA),
- ✓ Aircraft Utilization Rate (AUR)
- ✓ Maintenance Reports (MAREPs) and
- ✓ Pilot Reports (PIREPs).

These models use continuous independent variables (factors) because it proved to fit the data better and to give more reliable results in the experiments. The Table 3.7 in section 3.2.2 shows the limits and the units for these factors. The Table 3.11 shows the coefficients for these models regression equation.

4.1.2 Simulation

As said before, the program developed is able to perform two different types of simulations: predictions of the *Probability of one single event* or predictions of the *On-time Performance*.

Probability of a Single Event

The model can calculate the single probability of one event (delay our UGT) for a certain fleet (B767 or MD11). According to the options selected by the user, the program will ask different inputs (simulation conditions – factors values). The result is shown in percentage and gives the probability of occurrence of a delay/UGT under the selected conditions.

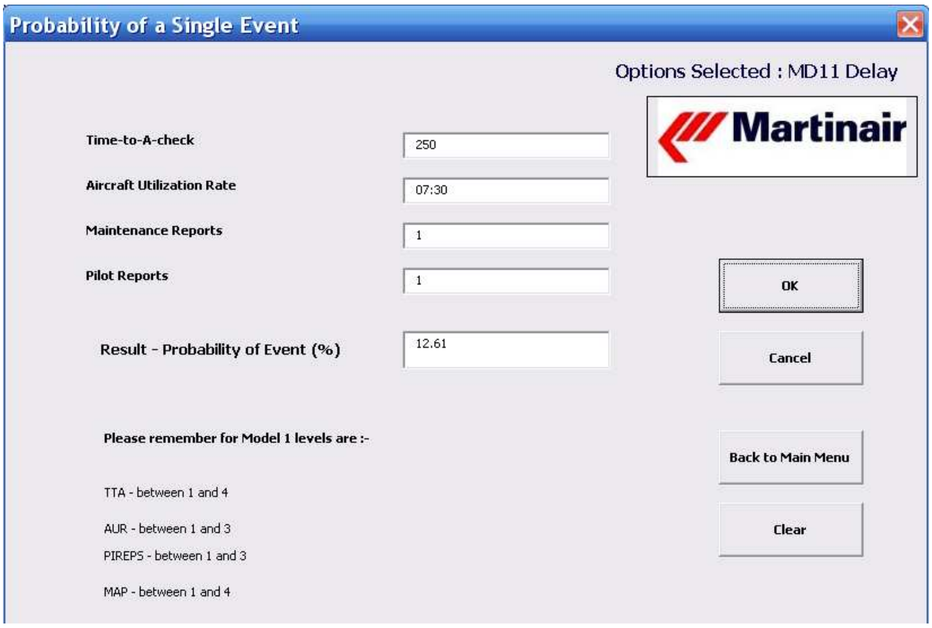


Figure 4.3 – Example of the dialog box for the simulation of the probability of a single event

Expected number of delays/UGTs and On-Time Performance

The other tool available is the possibility of predicting the expected number of delays/UGTs and the on-time performance (OTP) for a certain period. In fact, this tool compares the OTP for two different conditions chosen by the user. The objective is to make a fair comparison between different values of one factor, i.e., manager and engineers can predict the impact of variations on that factor.

Therefore, the user is asked to choose which factor he/she wants to analyse and to insert two different values for that factor. Moreover, the user has to define the time window (in weeks)[8]. The program picks random values from the historical data for the other factors that were not selected. This step is performed for all the departures in the time window selected. Then it calculates the probability of delay/UGT for each departure using the proper regression equation like explained previously. The expected number of delays is basically the sum of all probabilities.

$$END = Expected\ Number\ of\ Delays = \sum_{i=1}^{N} P_i \qquad (4.1)$$

where, N is the total number of departures and P_i is probability of delay for each departure.

The On-Time Performance (OTP) is given by the equation 4.2.

$$OTP = \left(1 - \frac{Expected\ number\ of\ delays}{Total\ number\ of\ departures}\right) x100 \qquad (4.2)$$

[8] The model assumes that in one week there are in average 50 departures for B767 fleet and 130 for MD11.

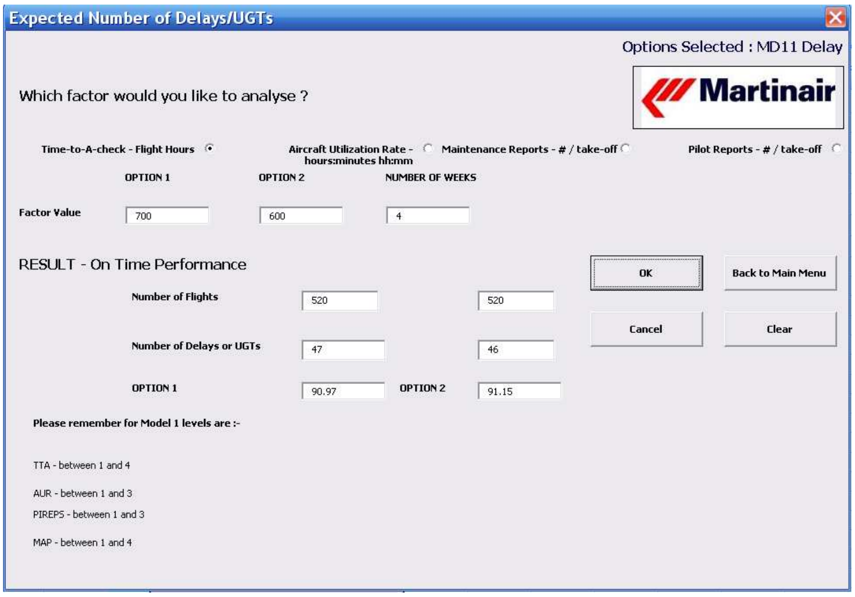


Figure 4.4 - Example of the dialog box for the simulation of the On-Time Performance

The results show the total number of flights (departures) in the time window chosen, the number of delays expected and the on-time performance (dispatch reliability) in percentage.

4.2 Illustrative Example

In this section, it is given an example only for the tool that calculates the probability of delay/UGTs. It is not possible to show all the steps for the tool that calculates the expected number of delays and on-time performance because it needs to choose random values from historical data. For this purpose, it is used a specific random function of Microsoft Excel.

B767 fleet Delays – Option 1

The regression equation and its coefficients for the model that predicts the probability of delay for B767 fleet can be found above.

		B767 DELAY
FACTOR	**Level**	**Parameters**
TTA	0-100	0
	100-400	0.21272
	400-600	0.37024
	600+	0.52755
AUR	Low (0-7h30)	0
	Medium (7h30-15h)	1.91142
	High (15h+)	1.15185
PIREPS	0-2	0
	2-5	0.50051
	5+	1.31110
MPA	15-20	0
	20-30	0.47420
	30-40	0.27380
	40+	1.45672

$$logit\ (delay) = constant\ +\ (TTA)_i + \ (AUR)_j\ + (PIREPS)_k + \ (MAP)_l \qquad (4.3)$$

Consider that an aircraft has to fly more 368 hours to perform the next A-check, the aircraft utilization rate of the previous 7 days was 15h35 and the average number of PIREPS per take-off is assumed to be 3. There is an average of 24 people available per shift to perform maintenance actions.

TTA = 368 = Level 2

AUR = 15h35 = 0.6493[9] =Level 3

PIREPS = 3 = Level 2

MPA = 24 = Level 2

$$logit\ (delay) = -5.2101\ + 0.2127209\ +\ 1.1518514\ + 0.5005089 +\ 0.4741996$$

$$y =\ logit\ (delay) =\ -2.8708$$

According to equation 2.11, the probability of a delay will be:

P = 0.0536 ≈ **5.4%**

B767 fleet UGTs – Option 2

The regression equation and its coefficients for the model that predicts the probability of UGT for B767 fleet can be found above.

$$logit\ (UGT) = -4.6508\ +\ 0.000919.(TTA) +\ \ 0.5108.(MAREPS)\ + 0.16198.(PIREPS) \qquad (4.4)$$

	B767 UGT
Factor	**Coefficients**
Constant	-4.650805
TTA	0.00092
MAREPS	0.510797
PIREPS	0.161980

Consider that an aircraft has to fly more 697 hours to perform the next A-check, the average number of MAREPs per take-off for that day was 1 and for the PIREPS was 2.

TTA = 697

MAREPS = 1

PIREPS = 2

$$logit\ (UGT) = -4.6508\ +\ 0.000919 * 697 +\ \ 0.5108 * 1\ + 0.16198 * 2$$

$$y =\ logit\ (UGT) =\ -3.1755$$

According to equation 2.11, the probability of a delay will be:

P = 0.0401 ≈ **4%**

[9] The regression equation cannot read the format hh:mm, therefore it is necessary to convert it to number format. The application does it automatically

MD11 fleet Delay – Option 3

The regression equation and its coefficients for the model that predicts the probability of delay for MD11 fleet can be found above.

$$logit\ (delay) = -1.9772\ + (-0.0039).(TTA) + (-2.4747).(AUR) +\ 0.0842.(MAREPS) + 0.8770.(PIREPS) +\ 0.0088.(TTA) +\ 0.0023(TTA)(MAREPS) + + (-0.0018).(TTA).(PIREPS) \quad (4.5)$$

	MD11 DELAY
Factor	**Coefficients**
Constant	-1.977161528
TTA	-0.003891751
AUR	-2.474710697
MAREPS	0.084235663
PIREPS	0.876969836
TTA*AUR	0.008849713
TTA*MAREPS	0.002335656
TTA*PIREPS	-0.001795068

Consider that the average aircraft utilization per day from the previous week was 12h41, the next A-check has to be performed in 163 flight hours, the average number of MAREPs per take-off for that day was 1 and of PIREPs was ¾.

TTA = 163

AUR= 12h41 = 0.528[9]

MAREPS = 1

PIREPS = 0.75

TTA*AUR = 86.064

TTA*MAREPS = 163

TTA*PIREPS = 122.25

$$y =\ logit\ (delay) =\ -2.2538$$

According to equation 2.11, the probability of a delay will be:

P = 0.0950 = **9.5%**

MD11 fleet UGT – Option 4

The regression equation and its coefficients for the model that predicts the probability of UGT for MD11 fleet can be found above.

$$logit\ (UGT) = -2.7793\ + (-0.0039).(TTA) + (-2.6695).(AUR) +\ 0.1219.(MAREPS) + +\ 1.3173.(PIREPS) +\ 0.0081.(TTA) +\ 0.0017(TTA)(MAREPS) + + (-0.0015).(TTA).(PIREPS) \quad (4.5)$$

	MD11 DELAY
Factor	**Coefficients**
Constant	-2.7793
TTA	-0.0039
AUR	-2.6695
MAREPS	0.1219
PIREPS	1.3173
TTA*AUR	0.0081
TTA*MAREPS	0.0017
TTA*PIREPS	-0.0015

Consider that an aircraft has to fly more 161 hours to the next A-check, the aircraft utilization rate of the previous 7 days was 15h28, the average number of MAREPs per take-off for that day was 1 and for the PIREPs was ½.

TTA = 161

AUR = 15h28 = 0.6447[9]

MAREPS = 1

PIREPS = 0.5

TTA*AUR = 104.2797

TTA*MAREPS = 161

TTA*PIREPS = 80.5

$$y = logit\ (delay) = -3.35$$

According to equation 2.11, the probability of a delay will be:

$$P = 0.0338 \approx \mathbf{3.4\%}$$

4.3 Model Validation

As explained in section 2.2.4, one way of validating the model is to apply a cross-validation. Cross-validation is mainly used in settings where the goal is prediction, and we want to estimate how accurately a predictive model will perform in practice [38]. Moreover, cross-validation can be used to compare the performances of different predictive models. As suggested in the literature, the sample data was divided into a *training set* to perform the analysis (90% of the sample) and a *testing/validating set* to validate the analysis (other 10% of the sample). To reduce variability, multiple rounds of cross-validation are performed using different partitions and the validation results are averaged over the rounds. The cross-validation was used in two different ways: to choose the best model for each option and to calculate the standard error.

4.3.1 Choosing the Best Regression Model

Before choosing the regression model described above, several tests were performed using different combination of factors and factors interactions. These simulations were done for all the 4 options available (depending on the fleet and on the event type). The log-likelihood function was used to check how good the model in test was performing (more information about likelihood function in section 2.2.4). For this purpose, simple routines were programmed using the software package Matlab.

To know if the different models tested were giving good probabilities, a *reference model* was chosen. A reasonable reference model is the one which attributed to each event the same probability of delay (taking into account the sample data). This is the simplest model that we can consider. The probability of delay for the reference model is equal to the total number of delays in the training set divided by the total number of departures in the same set. As a result, it was possible to calculate the log-likelihood value - LLL_i (where $i=1,...,m$ and m is the number of models in test) for the reference model and for the different models in test (using the validation set). However, the values of LLL_i for the different models in test seemed highly correlated and the difference between them and the LLL_{ref} (log-likelihood for the reference model) did not seem significant (range 2-15 units).
Some simulations were done using the statistical software package *R* to solve the problem above and to understand if it was possible to use any of the models in test for forecasting. Therefore, a program was developed following the next steps:

1. Read from a file the sample data.
2. Initialize the vectors to store the results.
3. Divide the sample data in training set (90%) and validation set (10%).
4. Create a random delay vector (Y) with 1 and 0 with the same size that the sample data (probability of finding 1 is equal to number of delays divided by the number of departures in the sample data).
5. Divide the random delay vector in training set (90%) and validation set (10%).
6. Calculate the regression coefficients using a Binomial Logistic Regression and the training set for all the models in test.
7. Calculate the probabilities of delay/UGT for each departure using the test set and the regression equation of each model in test.
8. Calculate the probability of delay/UGT for the reference model using the test set of the random delay vector
9. Calculate the log-likelihood function using the probabilities (6. and 8.) and the random delay vector (4.) as the “real” delay value.
10. Calculate the value of the variable $Diff = LLL_i - LLL_{ref}$
11. Store the log-likelihood value (LLL_i) for each model in test, the log-likelihood value for the reference model (LLL_{ref}) and the variable *Diff*.
12. Go to step 4 and repeat the procedures as many times you desire so you can have several values for the log-likelihood for each model in test.[10]

[10] In the research the procedure was done 1000 times.

The simulation described above has used random values for the real value of the response. For that reason, it would be expected that the reference model had the highest value for the log-likelihood (negative number closest to 0) because it is the only model which does not take into account any predictor. Surprisingly, the values of the variable *Diff* were not higher than 1. Therefore, it is possible to choose a $Diff_{reference}$ for each model in test to compare with the real difference $Diff_{real}$ between the LLL_i and the LLL_{ref} (using the real response variable). The models in test are statistically significant if $Diff_{real} > Diff_{reference}$. As mentioned before, for all models in test, $Diff_{real}$ was between 2 and 15 units and $Diff_{reference}$ was between 0.5 and 1.2 units.

This statistical result proves that even small differences between the LLL_i and the LLL_{ref} (calculated with real values for the response variable) can be significant and it is possible to use these models for forecasting. Now, it is valid to choose the regression model that presents the highest value for log-likelihood (closest number to 0).

4.3.2 Standard Error

Another way of validating the model is to calculate the standard error. This measure is only applied for the tool that calculates the number of delays and OTP, i.e., it is possible to calculate the standard error for the expected number of delays using equation 4.6.

$$SE = Standard\ Error = \sqrt{\frac{\sum_{i=1}^{N}(END_i - RND_i)^2}{N}} \qquad (4.6)$$

where, *END* is the expected number of delays for 50 departures

RND is the real number of delays for 50 departures

N is the sample number (in this case *N*=1000)

Moreover, it is possible to apply a similar equation for the standard error of the OTP.

$$SE = Standard\ Error = \sqrt{\frac{\sum_{i=1}^{N}(EOTP_i - ROTP_i)^2}{N}} \qquad (4.6)$$

where, *EOTP* is the expected on-time performance for 50 departures

ROTP is the real on-time performance in 50 departures

N is the sample number (in this case *N*=1000)

The standard error results for the different options are presented in Table 4.1. It was simulated 50 flights for each option and the simulation was repeated 1000 times.

	Number of Delays/UGTs		On-Time Performance	
OPTION	Mean	**Standard Error**	Mean	**Standard Error**
1. B767 Delay	4	**± 1.5**	92%	**± 3.0%**
2. B767 UGT	1.5	**± 1.1**	97%	**± 2.2%**
3. MD11 Delay	3	**± 1.6**	94%	**± 3.2%**
4. MD11 UGT	2	**± 1.2**	96%	**± 2.4%**

Table 4.1 – Mean and Standard Deviation for number of delays and OTP

Despite the fact that the standard error for the number of delays is only around 1, it corresponds to a difference in OTP around 2-3% which can make the difference between an acceptable performance for Martinair and a low one. However, it must be noticed that these simulations were done only for 50 departures which corresponds to one week flights for the B767 fleet and half week flights for MD11 fleet.

4.4 Model Simulation Results

This section gives the results of some simulations using the developed predictive model. As the most interesting tool of the program is the prediction of the on-time performance (OTP), the simulations were only done for this tool. In this research two types of events were analysed: delays and unplanned ground times (UGT). The OTP is only related with the delay events because it is based on the number of delays for a certain period. It does not make sense to talk about OTP related to UGT. Therefore, on one hand it will be predicted the OTP for options: B767 and MD11 fleet delays, on the other hand, it will be predicted the number of UGT for B767 and MD1 fleet.

The time window for all simulations was 4 weeks (1 month). As explained before the average number of flights per week for the B767 fleet is 50 and for the MD11 is 130. Thus, these simulations took around 25 seconds to show the results for the B767 fleet and 55 seconds for the MD11 fleet.

Option 1 B767 Delays	TTA		AUR		PIREPS		MPA	
Simulations / Results	Level 3 400-600 FH	Level 4 > 600 FH	Level 2 7:30-15:00 FH	Level 3 >15:00 FH	Level 1 0-2 /TO	Level 2 2-5 /TO	Level 2 20-30 people	Level 3 30-40 people
Number of Delays	14	15	17	9	10	17	14	11
OTP (%)	92.8	92.4	91.4	95.5	94.9	91.5	93.2	94.5

Option 2 B767 UGTs	TTA		MAREPS		PIREPS	
Simulations / Results	550 FH	700 FH	1 /TO	2 /TO	1 /TO	2 /TO
Number of UGTs	6	6	6	10	4	5

Option 3 MD11 Delays	TTA		AUR		MAREPS		PIREPS	
Simulations / Results	550 FH	700 FH	08:00 FH	15:30 FH	1 /TO	2 /TO	1 /TO	2 /TO
Number of Delays	34	32	31	34	54	116	38	57
OTP (%)	93.5	93.8	94.1	93.5	89.5	77.8	92.7	89.1

Option 4 MD11 UGTs	TTA		AUR		MAREPS		PIREPS	
Simulations / Results	550 FH	700 FH	08:00 FH	15:30 FH	1 /TO	2 /TO	1 /TO	2 /TO
Number of UGTs	22	20	15	17	25	42	24	54

Table 4.2 – Results of the simulation for the expected number of delays, OTP and number of UGTs for one month period (200 flights for B767 fleet and 520 flights for MD11).

These simulations allow us to compare the impact of the different factors, i.e., how each factor influences the on-time performance and the number of delays/UGTs. The Table 4.2 shows some of these examples.

Despite showing significance in the statistical results, the factor *Time to A-check (TTA)* seems not to have much influence in the number of delays/UGTs and OTP (on-time performance). In fact, the difference between having 550 flight hours and 700 flight hours left for the next A-check is minimal. This result suggests that there is no benefit in making the A-check intervals smaller.

The *Manpower Available (MPA)* factor was only significant for the B767 fleet in case of delays. In this simulation, it is possible to conclude that the OTP increase 1% if there are more people available.

As expected, the *Maintenance* and *Pilot Reports (MAREPs* and *PIREPs)* factors are strongly related to the on-time performance and number of delays and UGTs since every technical problem is reported as a MAREPs or PIREPs. In these simulations, it is compared the difference between having a rate of 1 and 2 for the average number of MA-/PIREPs per take-off per day (or level 1 and level 2 for the B767 delays case). Although it is only 1 unit (or one level) difference, the results can be quite diverse. For Option 1 (B767 Delay), the on-time performance decreases 3.4% if the number of PIREPS is between 2 and 5 (level 2). For Option 2 (B767 UGTs), MAREPS seems to have a bigger impact in the number of UGTs than PIREPs. In Option 3 (MD11 Delays), the rate of PIREPs has a similar impact of Option 1: a rate 1 unit higher decreases the OTP 3.6%. For this option, the MAREPs factor is also a significant factor and it shows to have a higher impact on OTP. In fact, it is responsible for decreasing OTP 11.7% when the MAREPs rate increases one unit. The number of UGTs of Option 4 almost doubles when the rate of MAREPs or PIREPs increases one unit. It must be highlighted, there are departures that do not have any MAREPs or PIREPs which have not been taking into account in these simulations, i.e., when these factors are under analysis it is considered that the rate of MAREPs and PIREPs is always different from zero. This fact can explain the low OTP and the high number of UGTs.

The *Aircraft Utilization Rate (AUR)* factor is statistically significant for both Options related to delays and for MD11 UGTs. For B767 fleet, the aircraft utilization seems to help the OTP by increasing it 4.1%. This result might be justified by the fact that an aircraft that flies more it is subject to more maintenance inspections (pre-flight checks). On one hand more inspections might help in controlling the technical problems better, on the other hand the technical problems might be easily deferred to the next landing. The OTP and the number of UGTs of MD11 fleet do not seem to be influenced by aircraft utilization. The simulation results suggest that higher utilization will decrease the OTP and the number of UGTs. However, the variation is less than 1% and 1 or 2 UGTs.

Chapter 5

Conclusions and Recommendations

This thesis presented a study handle in Maintenance & Engineering Department of Martinair Holland N.V. into the context of the Reliability Engineering. This research investigated potential maintenance drivers for aircraft delays and it applied regression analysis to historical delay data to build up a Predictive Model for Delays and Unplanned Ground Times. Therefore, the conclusions must be divided in three main topics: the *Descriptive Statistics* results, *Statistic Analysis* and *The Predictive Model*. Then, it is given some recommendations.

5.1 Conclusions

5.1.1 Descriptive Statistic

The first part of this research focused on a descriptive statistics analysis of the growth of delays and UGTs (Unplanned Ground Times) over the past 3 years worldwide and in the main station in Schiphol (chapter 3.1). The relevant conclusions from the results found in section 3.1.1 are summarized as follows.

- For both B767 and MD11 fleet, it is difficult to find out a trend on the rate and average time for both delays and UGTs.
- It is possible to conclude that the introduction of the *Reliability Program* and the management decision of giving engineers more responsibility for the resolution of

technical problems in 2008, allowed more control over delays and UGTs, mainly for B767 fleet and MD11 UGTs.

- As Schiphol station is Martinair's hub and most important overhaul station, the majority of delays and UGTs took place there.

The descriptive analysis of delays and UGTs in the outstations (section 3.1.2) showed that there is no need to make a deeper investigation about any outstations. In fact, the average delay/UGTs rate and the average delay/UGTs time had a similar growth to Schiphol station, with exception of some specific months. The section 3.1.3 and 3.1.4 described and explained the results of the analysis for 1st and 2nd Order reasons of the Maintenance Delay Categorization Groups (MDCG).

- There is no doubt that the *A/C Mechanical Fault, Maintenance* and *Parts* issues have been responsible for the majority and for the longest delays and UGTs.
- The most relevant 2nd Order reasons of the groups mentioned above are, respectively: *Replaced LRU*, *Repaired* and *Replaced Non-LRU; Deferred/Placard/MEL/HIL* and *Late out of Maintenance*; and *NIL Stock.*

It must not be forgotten that the MDCG are the final causes attributed to the delays/UGTs which do not give enough information to determine the actual root cause. These groups can commonly be used at every MRO (Maintenance Repair and Overhaul) or airline and have no specific information about the organization, culture or procedures involved. Another shortcoming of this traditional method used in Martinair is the inability to combine reasons. Many chargeable delays have a non-chargeable contribution to the delay duration. Lately, Martinair reliability engineers have started to divide each delays/UGTs into its chargeable and non-chargeable part (including the reason and time contribution). This analysis has been done for the past few months and during the year 2008. However, this information was available in a later stage of the research and it was not possible to include it in this report.

5.1.2 Statistical Analysis

The maintenance factors chosen for the statistical analysis were *Time-to A-check*, *Aircraft Utilization Rate*, *Maintenance* and *Pilot Reports* and *Manpower Available*. Even if there are other important factors that can influence the occurrence and time of a delay, they were not selected because there was not any historical data available for a statistical analysis. Among these factors are *Troubleshooting*, *Administration*, *Logistic* and *Planning*. Using a statistical software package it was possible to find out some conclusions about delays and UGTs.

- Trying to find a correlation between the maintenance factors selected and the duration of delays and UGTs proved to be useless. No correlation was found between the independent variables (factors) and the dependent one (delay time).
- The factors proved to be significant when using a Binary Logistic Regression to predict the probability of delay and UGT. As it was analyzed four different options (B767 fleet delay, B767 fleet UGT, MD11 fleet delay and MD11 fleet UGT), different combinations of factors were found to be significant.

- Despite, it turned out to be very difficult to predict the delays, the validation test proved that the model is statistical significant and it gives better results than the simplest model of attributing the same probability to each flight.

Another approach to predict the duration of a delay and UGT could have been used. It is possible to find out the regression coefficients for the equation that predict the delay time, assuming that a delay will occur. The statistical software package STAT allows the user to make a regression analysis for two different equations at the same time (one to predict the probability of delay and other one to predict the delay time). In fact, the regression equation for the delay time is multiplied by λ which weights the assumption of delay. To get good results, it is better to use at least one different factor between the probability of delay and delay time. In this research, the previous method was not applied because the statistical software used (Minitab) did not have a tool to perform this test.

5.1.3 The Predictive Model

The predictive model is developed using regression analysis and is able to predict the probability of one single event (delay or UGT – unplanned ground times) and also the on-time performance (OTP) in a certain period (in weeks). The model is validated using cross-validation and the log-likelihood function. The standard error was also calculated for the tool that calculates the number of delays and OTP. It was simulated 50 flights for each of the four options and the simulation was repeated 1000 times. The results showed that the standard error is around 1.5 in 3.5 expected delays and 3.1% in 93% for the on-time performance.

The probabilities of delay and UGTs are, as expected, always low values. For the M&E department this information might not be very useful. For example, knowing that the delay probability of a single flight is 10% instead of 6% may not be a good enough reason for taking measures to avoid the delay because most definitely it would imply some costs.

A powerful tool is to estimate the number of delays and the on-time performance for the next week, month or year using the maintenance factors. The model is able to predict how good Martinair's fleet (B767 or MD11 fleet) will perform for the desire period. The tool also allows engineers and managers to evaluate how changes in the *maintenance factors* will impact Martinair's performance in a long term period.

Some simulation results showed that *Time to A-check (TTA)* for both B767 and MD11 fleet do not have much influence in the OTP which suggests that there is no benefit in changing the A-checks intervals. The *Maintenance and Pilot Reports (MAREPS and PIREPS)* are, as expected, highly correlated to the number of delays for both B767 and MD11 fleet. However, it is difficult to control these factors, anyway if M&E estimates the rate of PIREPS and MAREPS before take-off, it is able to control better its performance. The *Aircraft Utilization Rate (AUR)* seems to have some impact only for the B767 fleet increasing the OTP by 4.1% when the Aircraft Utilization rate is higher than 15 flight hours per day. This result might be justified by the fact that an aircraft that flies more it is subject to more maintenance inspections (pre-flight checks). On one hand more inspections might help in controlling the technical problems better, on the other hand the technical problems might be easily deferred to the next landing. For the MD11 fleet, a higher AUR affects the OTP by 1% which cannot be taking into account because of the associated standard error.

The maintenance factors chosen revealed to be statistical significant and allow a valid prediction of the number of delays and OTP. However, the information that can be extracted for a single factor might not be good enough for M&E to take actions on that maintenance factor and control the number of delays.

5.2 Recommendations

The following suggestions are made to Martinair M&E.

- In order to understand how the Martinair network processes might be influencing the time of delay and UGTs, it is important to continue categorizing them in useful groups and mainly in more than one reason.
- Moreover, it is important to understand where is M&E wasting time when trying to solve a defect that can lead to delay. According to expert opinions, delays are often caused by troubleshooting as explained in section 3.2.1. However, this information it is not automatically reported. It would be a good idea to try to report this issue in AMOS system or to do an intensive investigation in the hangar 32 and at the gate in Schiphol to be able to draw some conclusions.
- The a/c mechanics should be more aware of how the delay data is used by reliability engineers so they can describe the events and categorized them in an appropriate way.
- As *Replaced LRU* was one of the mainly reasons for the cause of delays, it might be interesting to study the *No-Fault Found*, i.e., sometimes a Rotable component was suspected to be failed and removed from aircraft for that reason, but during testing, it is found to be in a serviceable condition.
- As the *Aircraft Aging* is another factor for the delays and unplanned ground times, it should be considered another research on this single topic.
- In order to get better predictions of the on-time performance and number of delays, it might be a good idea to do a similar statistical analysis using technical maintenance factors, as the ATA chapters. This was not developed in this research because we were looking for non-chargeable delays.
- Martinair should find out how much it costs one minute of delay to be able to perform cost benefit analysis regarding the delays and maintenance factors.

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Appendix A

IATA Delay Codes

Others			
6	OA	No Gate/Stand Available	Due to own airline activity
9	SG	Scheduled Ground Time	Planned turnaround time less than declared minimum

Passenger and Baggage			
11	PD	Late Check-In	Check-in reopened for late passengers
12	PL	Late Check.In	Check-in not completed by flight closure time
13	PE	Check-In Error	Error with passenger or baggage details
14	PO	Oversales	Booking errors – not resolved at check-in
15	PH	Boarding	Discrepancies and paging, missing checked in passengers
16	PS	Commercial Publicity/Passenger Convenience	Local decision to delay for VIP or press; delay due to offload passenger following family bereavement
17	PC	Catering Order	Late or incorrect order given to supplier
18	PD	Baggage Processing	Late or incorrectly sorted baggage

Cargo and Mail			
21	CD	Documentation	Late or incorrect documentation for booked cargo
22	CP	Late Positioning	Late delivery of booked cargo to airport/aircraft
23	CC	Late Acceptance	Acceptance of cargo after deadline
24	CI	Inadequate packing	Repacking and/or relabeling of booked cargo
25	CO	Oversales	Booked load in excess of saleable load capacity (weight or volume), resulting in reloading or off-load
27	CE	Documentation, Packing	Incomplete and/or inaccurate documentation
28	CL	Late Positioning	Late delivery of mail t airport / aircraft
29	CA	Late Acceptance	Acceptance of mail after deadline

Aircraft and Ramp Handling			
31	GD	Late/ Inaccurate Aircraft Documentation	Late or inaccurate mass and balance documentation, general declaration, passenger manifest
32	GL	Loading / Unloading	Bulky items, special load, lack loading staff
33	GE	Loading Equipment	Lack of and /or breakdown, lack of operating staff
34	GS	Servicing Equipment	Lack of and/or breakdown; lack of operating staff
35	GC	Aircraft Cleaning	Late completion of aircraft cleaning
36	GF	Fuelling/De-Fuelling	Late delivery of fuel; excludes late request
37	GB	Catering	Late and/or incomplete delivery; late loading
38	GU	ULD	Lack of and/or unserviceable ULD's or pallets
39	GT	Technical Equipment	Lack and/or breakdown; lack of operating staff; includes GPU, air start, pushback tug, de-icing

Technical and Aircraft Equipment			
41	TD	Technical Defects	Aircraft defect including items covered by MEL
42	TM	Scheduled Maintenance	Late release from maintenance
43	TN	Non-Scheduled Maintenance	Special checks and/or additional works beyond normal maintenance schedule
44	TS	Spares and Maintenance	Lack of spares, lack of and/or breakdown of specialist equipment required for defect rectification
45	TA	AOG Spares	Awaiting AOG spare(s) to be carried to another station
46	TC	Aircraft Change	For technical reasons, e.g., a prolonged technical delay
47	TL	Standby Aircraft	Standby aircraft unavailable for technical reasons

Damage to Aircraft			
51	DF	Damage During Flight Operations	Bird or lightning strike, turbulence, heavy or overweight landing, collisions during taxiing
52	DG	Damage During Ground Operations	Collisions (other than taxiing), loading/offloading damage, towing, contamination, extreme weather conditions

EDP / Automated Equipment Failure			
55	ED	Departure Control	Failure of automated systems, including check-in; load control systems producing mass and balance
56	EC	Cargo Preparation Documentation	Failure of documentation and/or load control systems covering cargo
57	EF	Flight Plans	Failure of automated flight plans systems

Flight Operations and Crewing			
61	FP	Flight Plan	Late completion of or change to flight plan
62	FF	Operational Requirement	Late alteration to fuel or payload
63	FT	Late Crew Boarding or Departure Procedures	Late flight deck, or entire crew, other than standby; late completion of flight deck crew checks
64	FS	Flight Deck Crew Shortage	Sickness, awaiting standby, flight time limitations, valid visa, health documents, etc.
65	FR	Flight Deck Crew Special Request	Request not within operational requirements
66	FL	Late Cabin Crew Boarding or Departure Procedures	Late Cabin crew other than standby; late completion of cabin crew checks
67	FC	Cabin Crew Shortage	Sickness, awaiting standby, flight time limitations, valid visa, health documents, etc.
68	FA	Cabin Crew Error or Special Request	Request not within operational requirements
69	FB	Captain Request for Security Check	Extraordinary requests outside mandatory requirements

Weather			
71	WO	Departure Station	Below operating limits
72	WT	Destination Station	Below operating limits
73	WR	En-Route or Alternate	Below operating limits
75	WI	De-Icing or Aircraft	Removal of ice and/or snow; excludes equipment – lack of a breakdown
76	WS	Removal of Snow, Ice , Water, and Sand from Airport	Runway, taxiway conditions
77	WG	Ground Handling Impaired by Adverse Weather Conditions	High winds, heavy rain, blizzards, monsoons, etc.

Air Traffic Flow Management Restrictions			
81	AT	ATFM due to ATC En-Route Demand/Capacity	Standard demand / capacity problems
82	AX	ATFM due to ATC Staff / Equipment En-Route	Reduced capacity caused by industrial action or staff shortage, equipment failure, military exercise or extraordinary demand due to capacity reduction in neighbouring area
83	AE	ATFM due to Restriction at Destination Airport	Airport and/or runway closed due to obstruction, industrial action, staff shortage, political unrest, noise abatement, night curfew, special flights
84	AW	ATFM due to Weather at Destinations	

Airport and Government Authorities			
85	AS	Mandatory Security	Passengers, baggage, crew, etc.
86	AG	Immigration, Customs, Health	Passengers, crew
87	AF	Airport Facilities	Parking stands, ramp congestion, lighting. Buildings, gate limitations, etc.
88	AD	Restrictions at Destinations Airport	Airport and/or runway closed due to obstruction industrial action, staff shortage, political unrest, noise abatement, night curfew, special flights
89	AM	Restrictions at Airport of Departure	Including air traffic services, start-up and pushback, airport and/or runway closed due to obstruction or weather (restriction due to weather in case of ATFM only) industrial action, staff shortage, political unrest, noise abatement, night curfew, special flight

Reactionary			
91	RL	Load Connection	Awaiting load from another flight
92	RT	Through Check-In Error	Passenger or baggage check-in at originating station
93	RA	Aircraft Rotation	Late arrival of aircraft from another flight or previous sector
94	RS	Cabin Crew Rotation	Awaiting cabin crew from another flight
95	RC	Crew Rotation	Awaiting flight deck, or entire crew, from another flight
96	RO	Operations Control	Re-routing, diversion, consolidation, aircraft change for reasons other than technical

Miscellaneous			
97	MI	Industrial Action within own Airline	
98	MO	Industrial Action outside own Airline	Industrial actions (except Air Traffic Control Services)
99	MX	Miscellaneous	No suitable code; explain reasons(s) in plain text

Table A.1 – IATA Delay Codes (no official use - accuracy cannot be guaranteed)

Appendix B

Maintenance Delay Categorization Groups

Reason Group MDCG	2nd Order reason	Chargeable?	Description
A/C Mechanical Fault	Adjusted	YES	Adjusted engine idle/trim, doors sensors, transmitters. Rigged engines, flight controls, doors, windows
	Cleaned	YES	Clean: cannon plugs, connectors, sensors, floors/carpeting
	electrical cycle	NO	Electrical cycled, reset, powered up down, RTS test, BITE test: C/B's, relays, switches
	electrical rerack	YES	Electrical rerack, reseated, swapped, reinstalled, indicators, computers, black boxes
	hydro/mech reset	YES	Hydro/Mech reset or manually cycle: actuators, valves, land gear and flt controls, stairs, cabin/cardo doors
	install missing parts	YES	Installed missing parts/placarded
	incomplete information	YES	no corrective action specified or provided
	Lubricated	YES	Lubricated: cables, linkages
	no defect	YES	No defect, with no reference to speific ATA system or component.Test within limits
	re-programmed	YES	Re-programmed, update, reloaded, realign IRS/compass, cleared and reset memory : software
	repaired item	YES	Repaired, stop drilled, sealed/reselaed, freed, weeded, blended: cannon plugs, wires, perma swedge
	replaced LRU	YES	Replaced rotable components (ATA code)
	replaced non-LRU	YES	Replaced light bulbs, light caps, lines, hoses
	repositioned	YES	Repositioned or realigned: lines, hoses, clamps, panels, wires, seals
	Serviced	NO	Fluids, air, water, oxigen, nitrogen, charge batteries, unbalanced fuel transfer
	Tightened	YES	Tightened, retorwued, secured: bolts, lines, nuts, rivets, springs
	tires (cut/debris)	NO	Tires: cut or imbeded with debris
Ground Activities	a/c damage	NO	A/c damage during ground activities
	engine air start equipment	NO	Problems with the engine air start equiment, APU
	ground support equipment	NO	Faults with GSE ou caused by GSE
	human factors	NO	Training/skills, wrong procedures/installation
	loading (baggage, catering)	NO	Faults with ACARS, loading unavailable or late
	servicing (toilet, water, fuel)	NO	Refuel, toilet waste
Down Line	down line short due delays and cancellations	NO	Delay Due to other delays or cacelations
FOD	bird strike	NO	Damage cause by bird strike
	Debris	NO	Damage cause by debris
	Tools	NO	Tools inside engine or other systems

Maintenance	a/c damage	NO	A/c damage by maintenance procedures
	approval required	YES	Approval required for technical objection (TOA/NTO) - contact Boeing
	deferred maintenance (HIL/MEL/placarded)		Corrective action which is deferred/placarded/MEL/HIL
	human factors	NO	Training/skills, wrong procedures/installation
	late out of maintenance	NO	Late out of scheduled maintenance checks
	no wrong procedures	NO	Correct maintenance procedures
	planning (personnel or maintenance)	NO	Wrong or miss planning
	personnel not available	NO	Not enough personnel to perform actions of maintenance
	precautionary maintenance	NO	No corrective maintenance performed: installing/continuing placard (deferring) items; hyfraulic or fuel leaks within limits; Manual closing or cycling passenger/crew/crago door
Non-Technical	air traffic control	NO	Delays due to ATC
	communications (human factor)	NO	Wrong interpretation
	documentation	NO	Paperwork, manuals
	Facilities	NO	No facilities available
	flight crew	NO	Flight crew delays, flight crew request
	flight operations	NO	Switch a/c decisions
	MEL extension required	NO	Required an extension of MEL to dispatch an a/c
	MEL interpretation	NO	Miss interpretation of MEL
	Weather	NO	Delays due to weather conditions
Parts	cannibalization		Spare part removed from another a/c
	inadequate parts		Parts not adequate
	NIL stock		Parts not available in stock
	parts location unknown		Location of the parts needed is unknown
	tools (not available/ US)		Tools not available or unserviceable
Incomplete Record	No Information/ Unknown Action		Incomplete information about the event

Table B.1 – Description of the Maintenance Delay Categorization Groups

Appendix C

Example of Martinair Data

DATE	A/C	FLIGHT	STATION	DELAY TIME	ATA	ATA SEQ	ACTION CODE	CHARG (1) NON CHARG (2)	MDCG	Reason
30-Apr-09	MCT	MP73	SPL	0:55	28	22	10	1	A/C MECHANICAL FAULT	ADJUSTED
30-Apr-09	MCW		SPL	3:30	0	0	16	2	MAINTENANCE	HUMAN FACTOR
28-Apr-09	MCT	MP70	MIA	0:30	27	10	10	1	A/C MECHANICAL FAULT	ELECTRICAL CYCLED
27-Apr-09	MCY		SPL	20:30	71	0	16	1	A/C MECHANICAL FAULT	ADJUSTED
25-Apr-09	MCR		SPL	4:00	49	17	16	2	A/C MECHANICAL FAULT	REPLACED LRU
25-Apr-09	MCR	MP73	SPL	2:00	36	23	14	1	A/C MECHANICAL FAULT	REPLACED LRU
25-Apr-09	MCS		GYE	4:45	36	22	16	1	A/C MECHANICAL FAULT	REPLACED LRU
25-Apr-09	MCS	MP81	SPL	8:45	49	17	14	1	A/C MECHANICAL FAULT	REPLACED LRU
25-Apr-09	MCU	MP85	SPL	5:08	78	30	10	2	A/C MECHANICAL FAULT	REPLACED LRU
24-Apr-09	MCS	MP74	GYE	0:41	36	22	10	1	A/C MECHANICAL FAULT	REPLACED LRU
24-Apr-09	MCY	MP81	SPL	7:00	29	0	10	1	A/C MECHANICAL FAULT	REPAIRED
22-Apr-09	MCR	MP81	SPL	3:05	5	20	14	2	PARTS	NIL STOCK
22-Apr-09	MCU	MP63	SPL	3:56	5	20	14	2	MAINTENANCE	APPROVAL REQUIRED
20-Apr-09	MCW		SPL	56:15	53	0	16	1	A/C MECHANICAL FAULT	ADJUSTED
15-Apr-09	MCY	MP85	SPL	11:31	21	8	10	2	PARTS	CANNIBALIZATION
12-Apr-09	MCS	MP83	SPL	0:29	29	30	10	1	A/C MECHANICAL FAULT	REPLACED LRU
12-Apr-09	MCU	MP77	SPL	4:31	27	60	14	2	A/C MECHANICAL FAULT	ADJUSTED
10-Apr-09	MCT	MP82	NBO	0:12	24	0	10	2	MAINTENANCE	DEFERRED/PLACARDED/MEL/HIL
08-Apr-09	MCT		SPL	28:00	32	31	16	1	A/C MECHANICAL FAULT	REPLACED NON-LRU
07-Apr-09	MCU	MP83	NBO	0:15	24	0	10	1	A/C MECHANICAL FAULT	ELECTRICAL CYCLED
06-Apr-09	MCW	MP69	SPL	0:38	52	31	10	2	GROUND ACTIVITIES	A/C DAMAGE
06-Apr-09	MCY		SPL	2:45	32	51	16	2	A/C MECHANICAL FAULT	REPLACED LRU

DATE	A/C	FLIGHT	STATION	DELAY TIME	ATA	ATA SEQ	ACTION CODE[11]	CHARG (1) NON CHARG (2)	MDCG	Reason
05-Apr-09	MCR	MP63	SPL	0:52	56	11	14	2	A/C MECHANICAL FAULT	REPLACED LRU
05-Apr-09	MCW	MP71	SPL	11:22	56	11	10	2	A/C MECHANICAL FAULT	REPLACED LRU
04-Apr-09	MCP	MP81	SPL	1:27	32	41	10	2	FOD	TOOLS
04-Apr-09	MCT		KTR	4:30	49	0	16	1	A/C MECHANICAL FAULT	ELECTRICAL CYCLED
04-Apr-09	MCT		NBO	1:45	73	21	16	1	A/C MECHANICAL FAULT	REPLACED LRU
04-Apr-09	MCT	MP82	BEN	1:03	73	22	10	1	A/C MECHANICAL FAULT	REPLACED LRU
04-Apr-09	MCU	MP62	SCL	1:18	72	31	10	2	MAINTENANCE	A/C DAMAGE
03-Apr-09	MCT	MP81	SPL	0:15	0	0	10	2	MAINTENANCE	DEFERRED/PLACARDED/ MEL/HIL
03-Apr-09	MCY		VCP	53:31	34	11	16	1	A/C MECHANICAL FAULT	REPLACED LRU
02-Apr-09	MCP	MP62	GYE	3:12	25	11	10	1	A/C MECHANICAL FAULT	CLEANED
02-Apr-09	MCR		SPL	2:00	32	46	16	2	MAINTENANCE	LATE OUT OF MAINTENANCE
01-Apr-09	MCY	MP76	UIO	0:19	34	11	10	1	A/C MECHANICAL FAULT	CLEANED

Table B.1 – Example of Martinair's Delay Data for MD11[12].

[11] Action Code distinguish between a delay (code 10 - delay), swapping aircrafts (code 14 – aircraft substitute) and unscheduled ground time (code 16 – aircraft unavailable)
[12] Owing to space limitations, it is not presented one column with a brief description of the event.

Date	A/C	ATA	Type	Date	A/C	ATA	Type
30-Mar-09	MCG	25-50	M	17-Mar-09	MCG	25-20	P
30-Mar-09	MCG	32-45	M	17-Mar-09	MCG	25-00	P
29-Mar-09	MCG	25-00	P	17-Mar-09	MCG	25-20	P
29-Mar-09	MCG	33-00	P	17-Mar-09	MCG	25-20	P
29-Mar-09	MCG	25-30	P	17-Mar-09	MCG	25-30	P
29-Mar-09	MCG	23-30	P	17-Mar-09	MCG	25-30	P
29-Mar-09	MCG	23-32		17-Mar-09	MCG	25-00	
29-Mar-09	MCG	32-00		17-Mar-09	MCG	38-00	P
28-Mar-09	MCG	25-25	P	17-Mar-09	MCG	25-35	P
28-Mar-09	MCG	05-20		17-Mar-09	MCG	25-00	P
28-Mar-09	MCG	52-50	P	16-Mar-09	MCG	38-30	P
27-Mar-09	MCG	73-22		16-Mar-09	MCG	38-30	M
27-Mar-09	MCG	25-00	P	16-Mar-09	MCG	25-28	P
27-Mar-09	MCG	33-44		15-Mar-09	MCG	25-98	P
26-Mar-09	MCG	25-20	P	15-Mar-09	MCG	25-00	P
24-Mar-09	MCG	79-31	M	15-Mar-09	MCG	23-32	P
24-Mar-09	MCG	33-10	P	15-Mar-09	MCG	25-60	P
23-Mar-09	MCG	25-40	P	15-Mar-09	MCG	25-25	P
23-Mar-09	MCG	73-00	P	14-Mar-09	MCG	12-14	M
23-Mar-09	MCG	79-31	P	14-Mar-09	MCG	38-30	P
23-Mar-09	MCG	33-21		14-Mar-09	MCG	24-50	M
23-Mar-09	MCG	33-21		14-Mar-09	MCG	24-50	M
23-Mar-09	MCG	23-30		14-Mar-09	MCG	05-20	M
23-Mar-09	MCG	25-25		14-Mar-09	MCG	29-11	P
23-Mar-09	MCG	25-25	P	13-Mar-09	MCG	25-25	P
23-Mar-09	MCG	00-00		13-Mar-09	MCG	32-00	M
23-Mar-09	MCG	73-00		13-Mar-09	MCG	32-40	M
21-Mar-09	MCG	23-40	M	13-Mar-09	MCG	32-40	M
21-Mar-09	MCG	33-00		13-Mar-09	MCG	32-41	M
21-Mar-09	MCG	25-25	P	12-Mar-09	MCG	25-25	P
21-Mar-09	MCG	05-20	P	12-Mar-09	MCG	25-32	
21-Mar-09	MCG	23-00	P	12-Mar-09	MCG	23-32	P
21-Mar-09	MCG	52-00	P	12-Mar-09	MCG	38-00	P
20-Mar-09	MCG	25-40	P	12-Mar-09	MCG	33-20	P
20-Mar-09	MCG	25-30	P	12-Mar-09	MCG	33-10	
20-Mar-09	MCG	35-10	P	11-Mar-09	MCG	25-00	P
19-Mar-09	MCG	25-60		11-Mar-09	MCG	25-00	P
19-Mar-09	MCG	32-41		11-Mar-09	MCG	23-32	M
19-Mar-09	MCG	25-60	P	11-Mar-09	MCG	25-00	P
19-Mar-09	MCG	25-00	P	09-Mar-09	MCG	00-00	
18-Mar-09	MCG	25-25	P	09-Mar-09	MCG	25-00	P
18-Mar-09	MCG	33-00	P	09-Mar-09	MCG	38-30	P
18-Mar-09	MCG	33-11		09-Mar-09	MCG	25-00	P
18-Mar-09	MCG	33-11		09-Mar-09	MCG	00-00	
18-Mar-09	MCG	23-00	P	09-Mar-09	MCG	33-00	P
18-Mar-09	MCG	23-00	P	08-Mar-09	MCG	23-51	M
18-Mar-09	MCG	25-40	P	08-Mar-09	MCG	25-00	P
18-Mar-09	MCG	25-25		08-Mar-09	MCG	05-20	

Date	A/C	ATA	Type	Date	A/C	ATA	Type
07-Mar-09	MCG	36-10	P	02-Mar-09	MCG	33-23	
07-Mar-09	MCG	25-00	M	02-Mar-09	MCG	25-20	
06-Mar-09	MCG	33-00	P	01-Mar-09	MCG	33-11	P
04-Mar-09	MCG	23-00		01-Mar-09	MCG	34-57	P
04-Mar-09	MCG	34-00	P	01-Mar-09	MCG	05-00	P
03-Mar-09	MCG	34-00	P	01-Mar-09	MCG	25-00	P
03-Mar-09	MCG	12-15	M	01-Mar-09	MCG	25-00	
03-Mar-09	MCG	05-20		01-Mar-09	MCG	35-20	P
03-Mar-09	MCG	25-00	M	01-Mar-09	MCG	23-32	P
02-Mar-09	MCG	25-00	M	01-Mar-09	MCG	23-32	P
02-Mar-09	MCG	25-32	M	01-Mar-09	MCG	23-32	P
02-Mar-09	MCG	23-32	P	01-Mar-09	MCG	25-00	P
02-Mar-09	MCG	25-20		01-Mar-09	MCG	25-40	P
02-Mar-09	MCG	33-00	P	01-Mar-09	MCG	33-10	

P – Pilot complaint *M – Maintenance complaint*

Table B.2 – Example of Martinair's Complaints Data for the aircraft MCG of B767 fleet[13].

[13] Owing to space limitations, it is not presented one column with a description of the complaint

Date	Shift	Actual Manpower per shift	Average Manpower	Date	Shift	Actual Manpower per shift	Average Manpower
01/02/2009	N	18	22	**15/02/2009**	N	16	21
	D	33			D	29	
	E	16			E	18	
02/02/2009	N	21	40	**16/02/2009**	N	12	34
	D	59			D	53	
	E	39			E	37	
03/02/2009	N	22	27	**17/02/2009**	N	17	28
	D	36			D	37	
	E	24			E	29	
04/02/2009	N	19	29	**18/02/2009**	N	26	36
	D	40			D	46	
	E	29			E	36	
05/02/2009	N	20	25	**19/02/2009**	N	27	31
	D	30			D	32	
	E	25			E	35	
06/02/2009	N	21	24	**20/02/2009**	N	27	31
	D	29			D	34	
	E	21			E	31	
07/02/2009	N	15	24	**21/02/2009**	N	26	26
	D	34			D	35	
	E	22			E	18	
08/02/2009	N	16	23	**22/02/2009**	N	14	17
	D	32			D	24	
	E	21			E	12	
09/02/2009	N	18	33	**23/02/2009**	N	14	32
	D	47			D	54	
	E	35			E	29	
10/02/2009	N	22	26	**24/02/2009**	N	21	30
	D	30			D	42	
	E	27			E	28	
11/02/2009	N	22	32	**25/02/2009**	N	28	35
	D	39			D	49	
	E	34			E	29	
12/02/2009	N	23	26	**26/02/2009**	N	25	27
	D	26			D	32	
	E	28			E	25	
13/02/2009	N	23	26	**27/02/2009**	N	26	31
	D	26			D	34	
	E	28			E	32	
14/02/2009	N	17	23	**13/02/2009**	N	23	26
	D	29			D	26	
	E	22			E	28	

N – Night shift; D – Day shift; E – Evening shift

Table B.3 – Example of Martinair's Manpower Data for every day of one month.

Date	A/C	Hours	Cycles	TAH	TAC
31-Jan-09	MCP	14:58	2	67242:20	13843
30-Jan-09	MCP	16:41	3	67227:22	13841
29-Jan-09	MCP	08:08	2	67210:41	13838
28-Jan-09	MCP	13:58	3	67202:33	13836
27-Jan-09	MCP			67188:35	13833
26-Jan-09	MCP	07:07	1	67188:35	13833
25-Jan-09	MCP	08:52	1	67181:28	13832
24-Jan-09	MCP			67172:36	13831
23-Jan-09	MCP	10:55	2	67172:36	13831
22-Jan-09	MCP	12:41	3	67161:41	13829
21-Jan-09	MCP	17:09	2	67149:00	13826
20-Jan-09	MCP	25:47:00	4	67131:51	13824
19-Jan-09	MCP	09:15	1	67106:04	13820
18-Jan-09	MCP	17:05	3	67096:49	13819
17-Jan-09	MCP	15:35	4	67079:44	13816
16-Jan-09	MCP	15:20	3	67064:09	13812
15-Jan-09	MCP	07:06	1	67048:49	13809
14-Jan-09	MCP	21:18	4	67041:43	13808
13-Jan-09	MCP	12:18	2	67020:25	13804
12-Jan-09	MCP	12:08	2	67008:07	13802
11-Jan-09	MCP	21:12	3	66995:59	13800
10-Jan-09	MCP	22:21	4	66974:47	13797
09-Jan-09	MCP	10:56	2	66952:26	13793
08-Jan-09	MCP	12:57	3	66941:30	13791
07-Jan-09	MCP	17:39	2	66928:33	13788
06-Jan-09	MCP	15:26	3	66910:54	13786
05-Jan-09	MCP	08:44	1	66895:28	13783
04-Jan-09	MCP	18:04	3	66886:44	13782
03-Jan-09	MCP	16:52	4	66868:40	13779
02-Jan-09	MCP	15:42	3	66851:48	13775
01-Jan-09	MCP	09:12	1	66836:06	13772

TAH – Total a/c hours; TAC – Total a/c cycles

Table B.4 – Example of Martinair's Aircraft Utilization Data for the aircraft MCP of MD11 fleet.

Perf- Date	A/C	Checktype	Int. Check (Also performed)	TAH	TAC	Interval [h]	Due at.	Perf. at
19-Dec-05	MCR	AC	AC10	51153	10819	700	51205	51153
01-Mar-06	MCR	AC	AC11 (C10,DC02)	51766	10949	700	51853	51766
17-Apr-06	MCR	AC	AC12	52399	11091	700	52466	52399
05-Jun-06	MCR	AC	AC01	52986	11224	700	53099	52986
17-Jul-06	MCR	AC	AC02	53561	11347	700	53686	53561
28-Aug-06	MCR	AC	AC03	54132	11464	700	54261	54132
16-Oct-06	MCR	AC	AC04	54816	11602	700	54832	54816
04-Dec-06	MCR	AC	AC05 (FRE1003A,FRE2101A,FRE2102A,FRE2103A,FRE2302C,FRE3411)	55495	11739	700	55516	55495
22-Jan-07	MCR	AC	AC06	56041	11848	700	56195	56041
12-Mar-07	MCR	AC	AC07 (FRE-600HRS)	56627	11970	700	56741	56627
30-Apr-07	MCR	AC	AC08 (FRE-400HRS,FRE-600HRS,FRE-WEEKLY,FRE7103A)	57253	12101	700	57327	57253
18-Jun-07	MCR	AC	AC09 (FRE-400HRS,FRE-600HRS,FRE-WEEKLY)	57870	12221	700	57953	57870
11-Aug-07	MCR	AC	AC10 (FRE-WEEKLY,C11,CC06)	58595	12366	700	58640	58595
01-Oct-07	MCR	AC	AC11 (FRE-400HRS,FRE-600HRS,FRE-WEEKLY)	59230	12496	700	59270	59230
19-Nov-07	MCR	AC	AC12 (FRE-400HRS,FRE-600HRS,FRE-WEEKLY)	59874	12634	700	59930	59874
07-Jan-08	MCR	AC	AC01 (FRE-400HRS,FRE-600HRS,FRE-WEEKLY)	60509	12762	700	60574	60509
24-Feb-08	MCR	AC	AC02 (FRE-400HRS,FRE-600HRS,FRE-WEEKLY)	61169	12894	700	61209	61169
14-Apr-08	MCR	A	A03 (AI03,FRE-400HRS,FRE-WEEKLY)	61812	13031	700	61869	61812
26-May-08	MCR	A	A04 (AI04,FRE-400HRS,FRE-WEEKLY)	62389	13153	700	62512	62389
14-Jul-08	MCR	A	A05 (AI05,FRE-400HRS,FRE-WEEKLY)	63013	13288	700	63089	63013
02-Sep-08	MCR	A	A06 (AI06,FRE-WEEKLY)	63436	13378	700	63713	63436
20-Oct-08	MCR	A	A07 (AI07,FRE-400HRS,FRE-WEEKLY)	64110	13515	700	64136	64110
08-Dec-08	MCR	A	A08 (AI08,FRE-WEEKLY)	64724	13640	700	64810	64724
20-Jan-09	MCR	A	A09 (AI09,C12,CI12,FRE30MT,FRE36MT)	65147	13728	700	65424	65147
23-Feb-09	MCR	A	A10 (AI10,FRE-400HRS,FRE-600HRS,FRE-WEEKLY)	65607	13821	700	65847	65607
14-Apr-09	MCR	A	A11 (AI11,ARC-90,FRE-WEEKLY)	66244	13946	700	66307	66244
25-May-09	MCR	A	A12 (AI12,ARC-70-20,FRE-WEEKLY,TEMP3)	66755	14051	700	66944	66755

TAH – Total a/c hours; TAC – Total a/c cycles

Table B.5 – Example of Martinair's Maintenace Checks Data for the aircraft MCR of MD11 fleet.

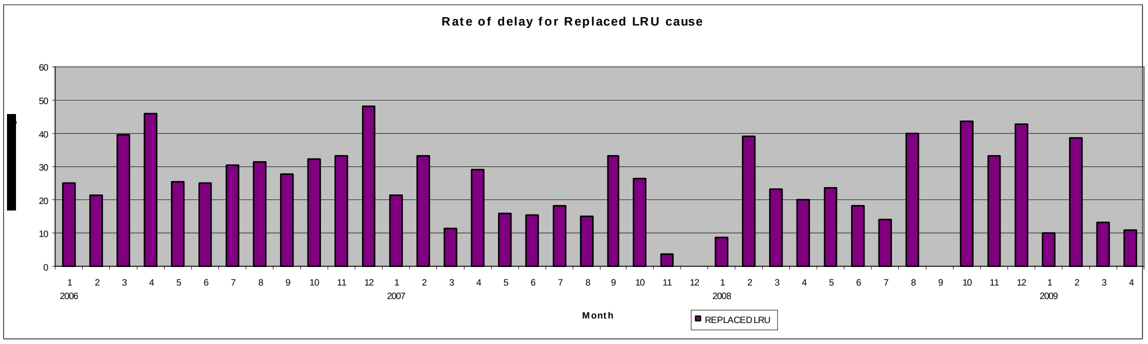
Appendix D

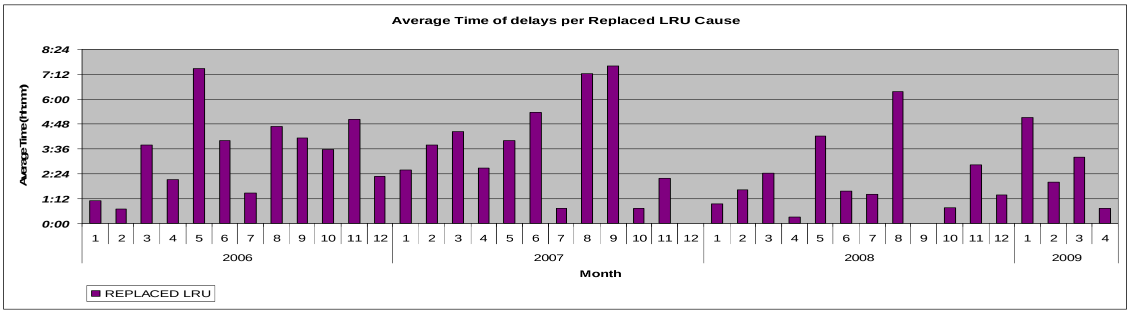
Some 2nd Order reasons Delays and UGTs Graphs

BOEING B767

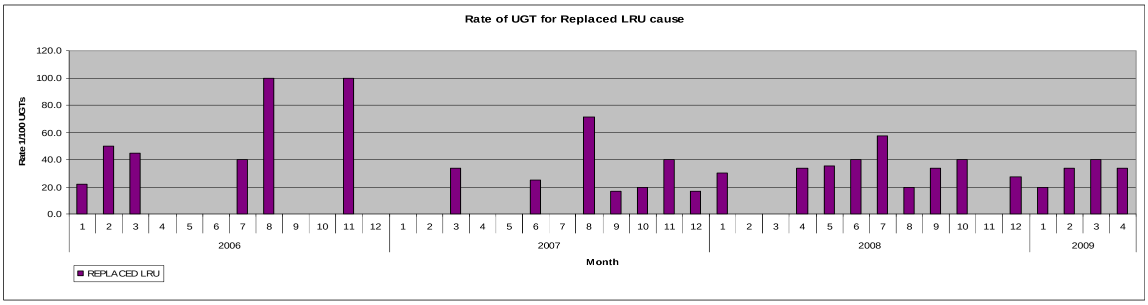
A/C Mechanical Fault – REPLACED LRU

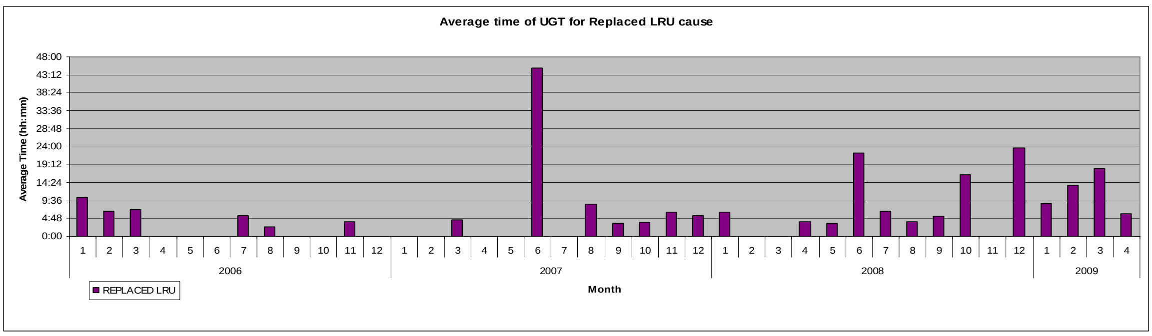
Delays





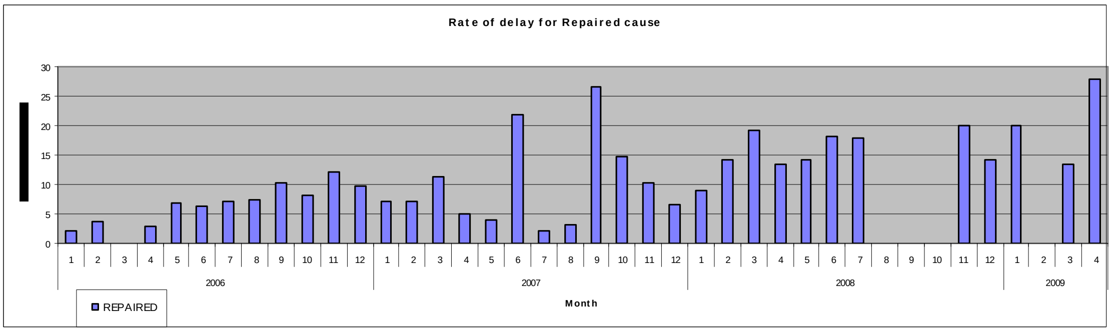
UGTs

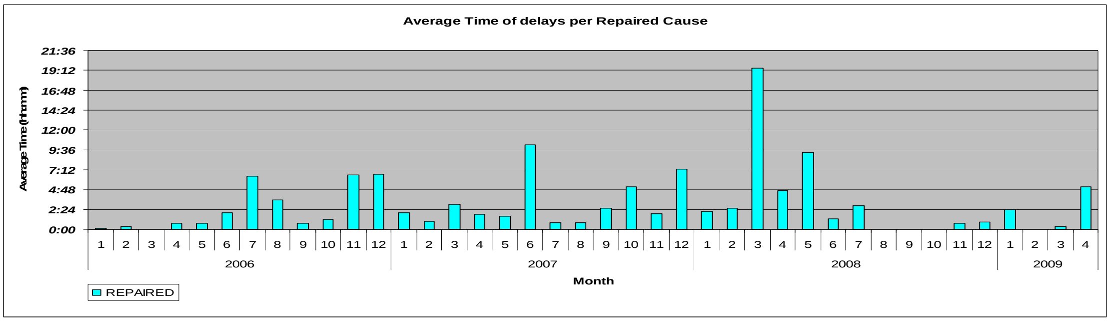




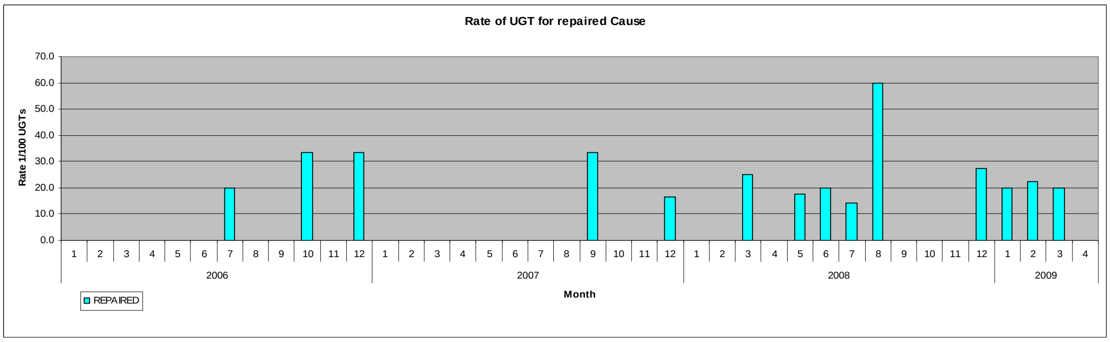
A/C Mechanical Fault - REPAIRED

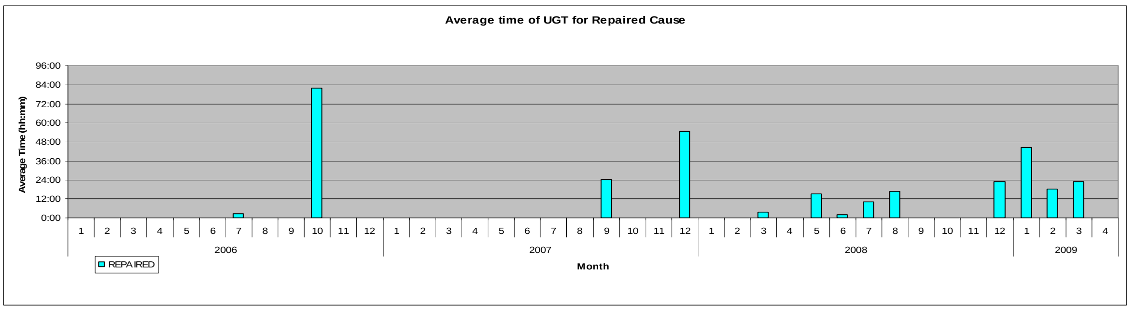
Delays





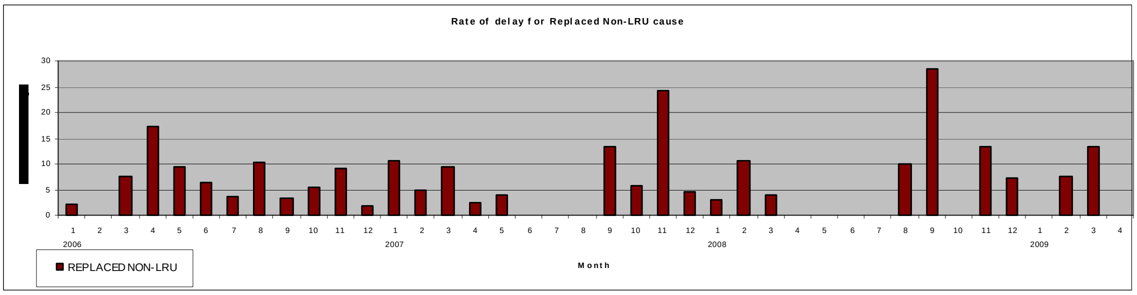
UGTs

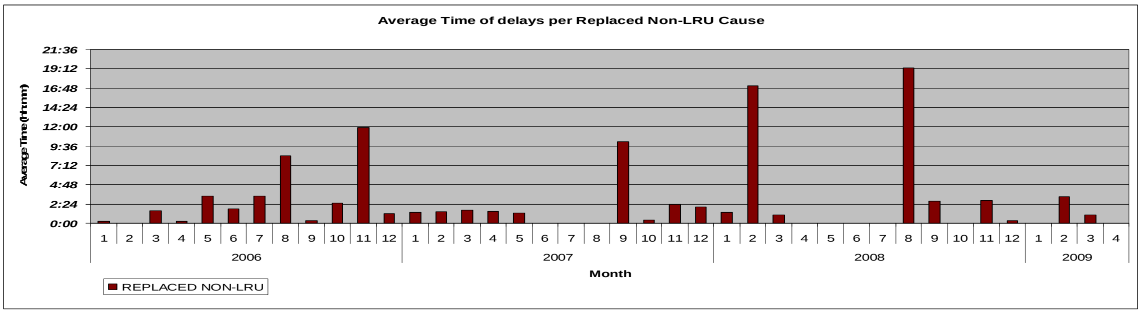




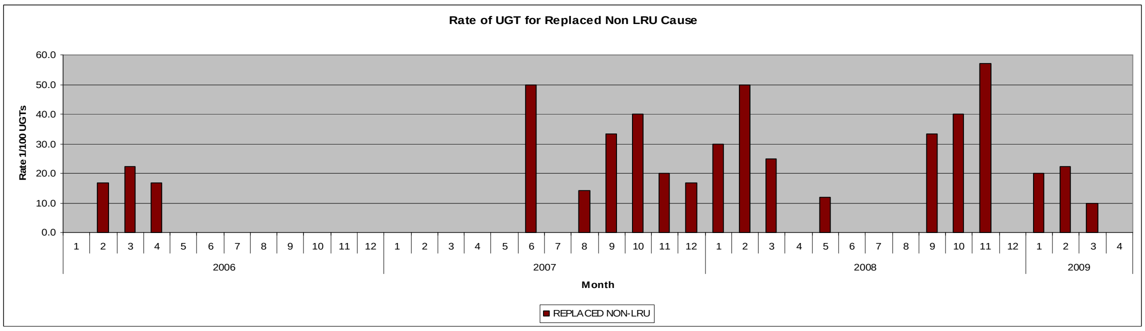
A/C Mechanical Fault – REPLACED NON-LRU

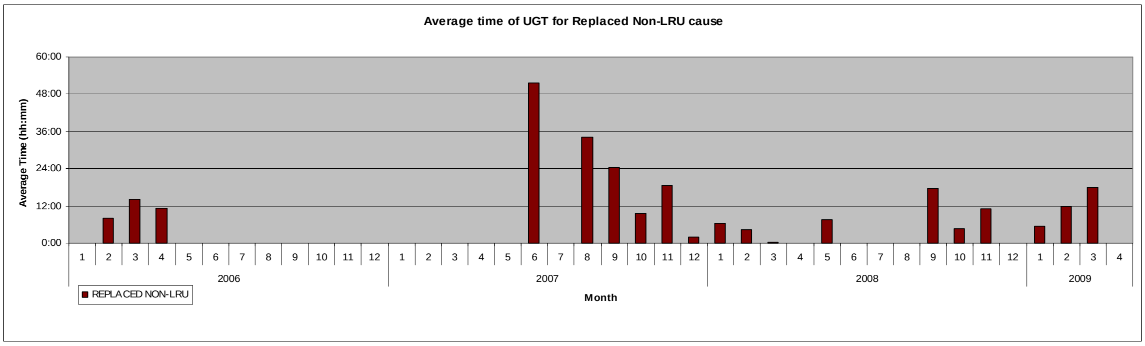
Delays





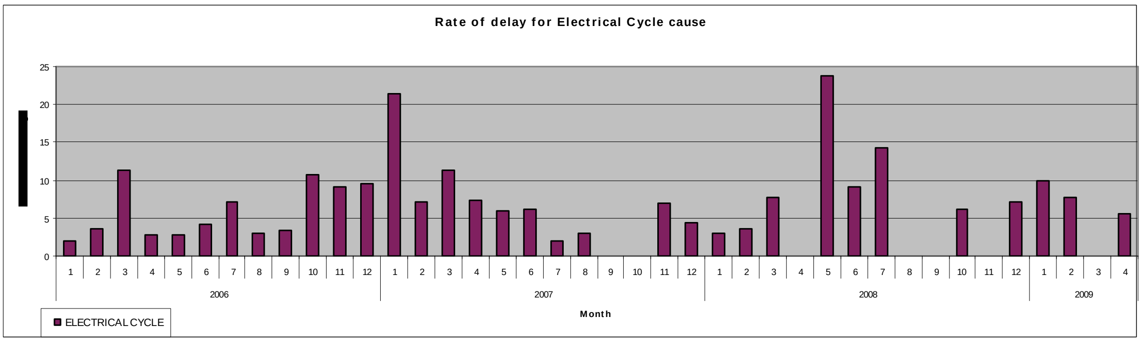
UGTs

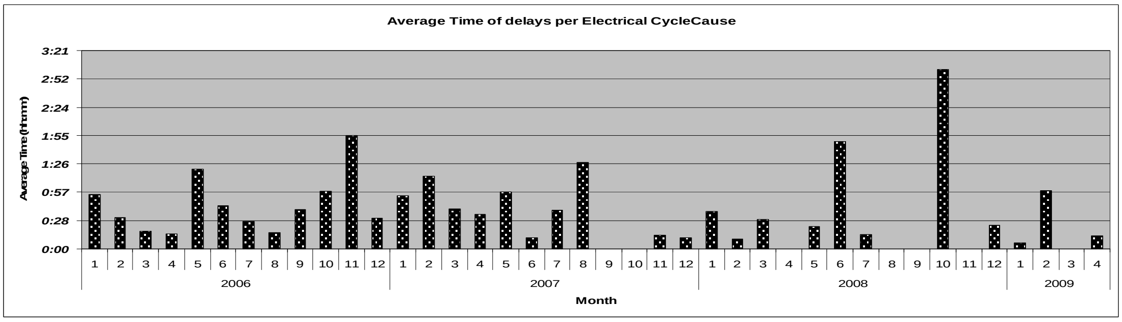




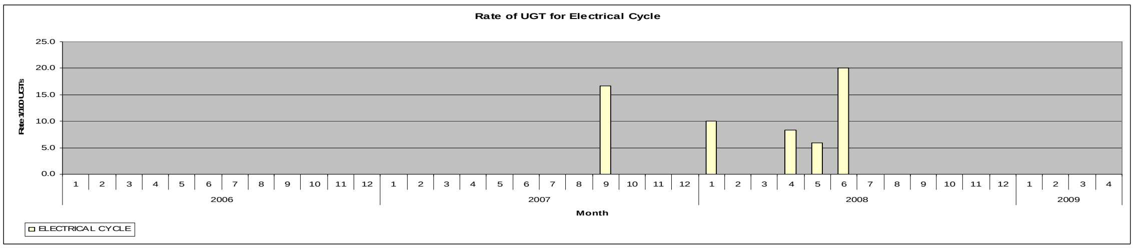
A/C Mechanical Fault – ELECTRICAL CYCLE

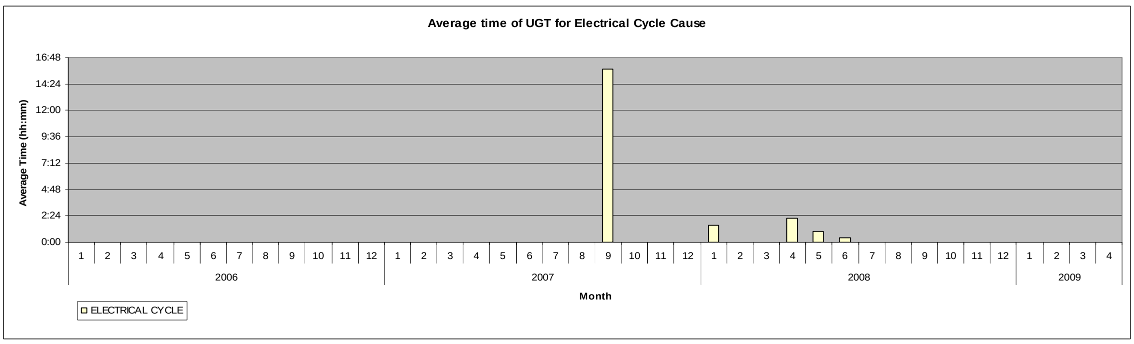
Delays





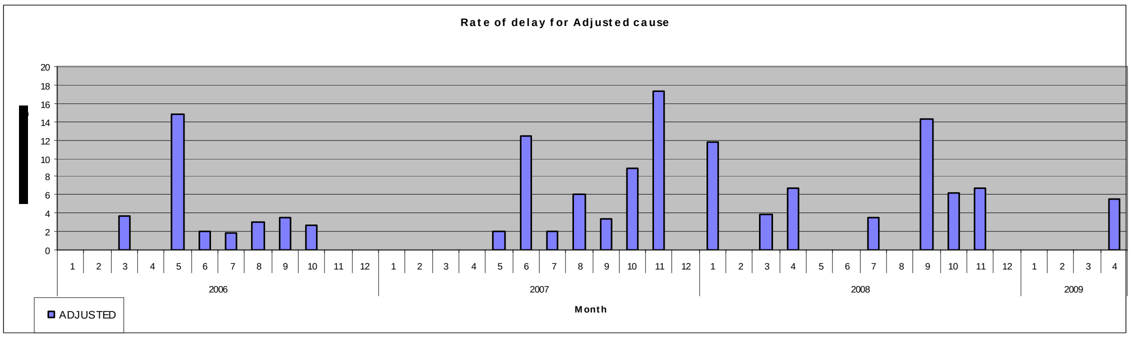
UGTs

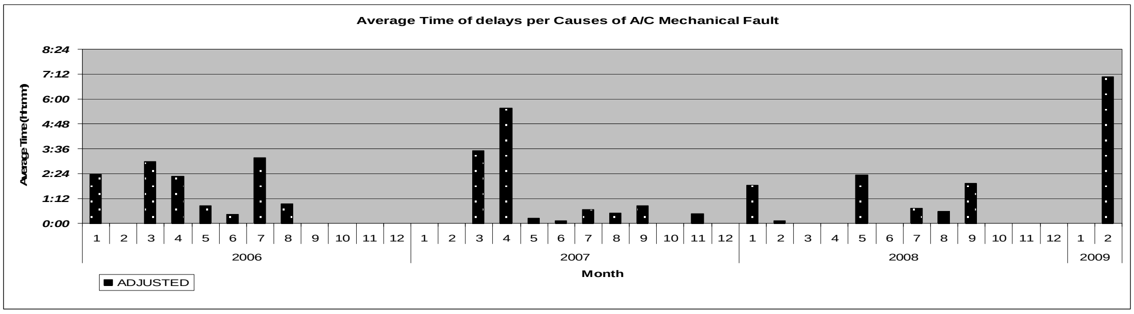




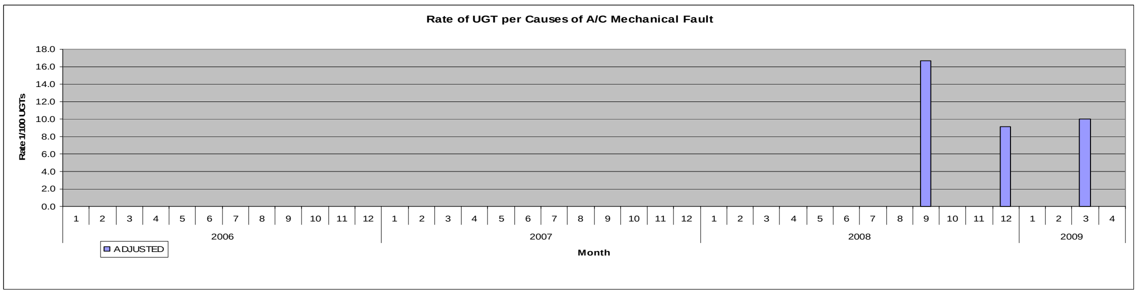
A/C Mechanical Fault – ADJUSTED

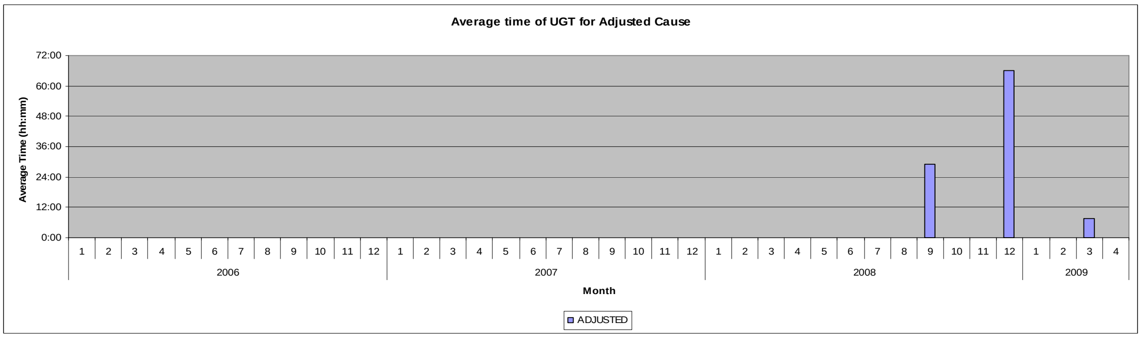
Delays





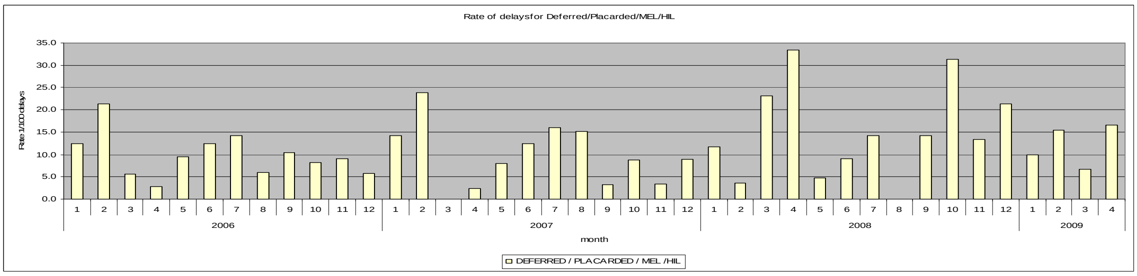
UGTs

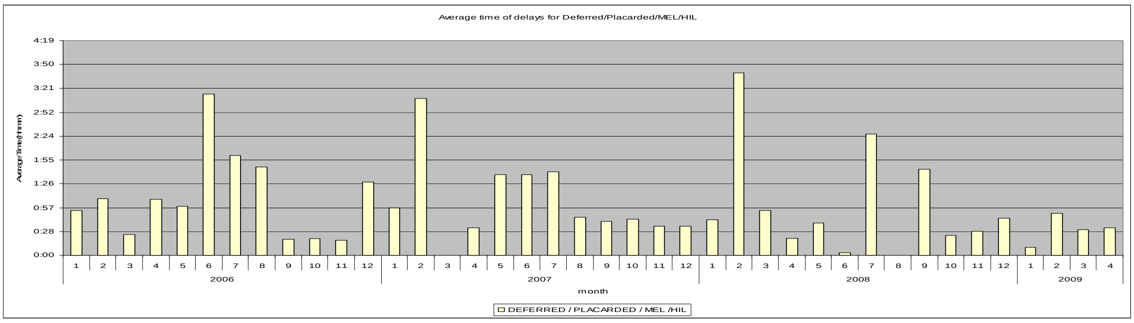




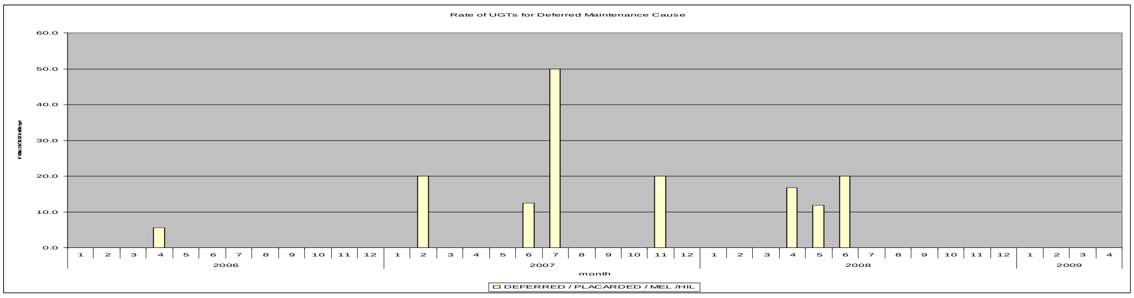
Maintenance – DEFERRED/PLACARD/MEL/HIL

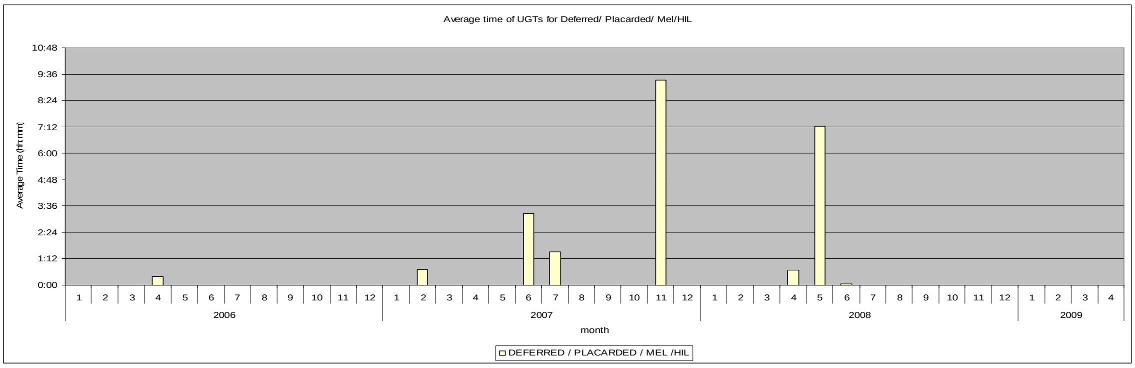
Delays





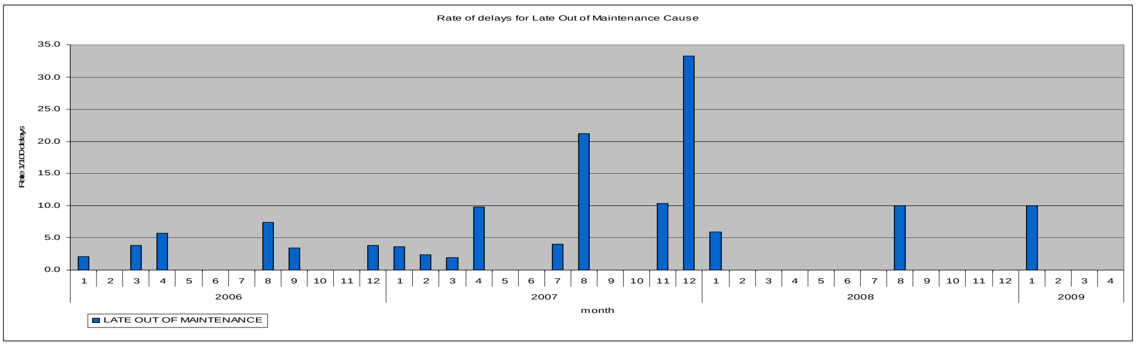
UGTs

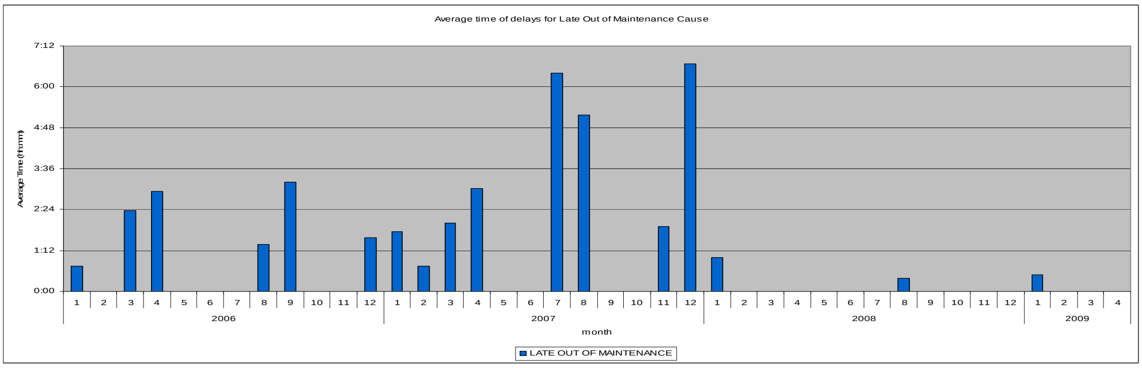




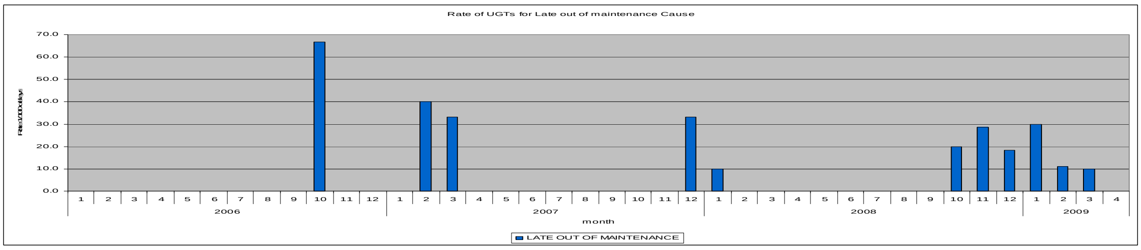
Maintenance – LATE OUT OF MAINTENANCE

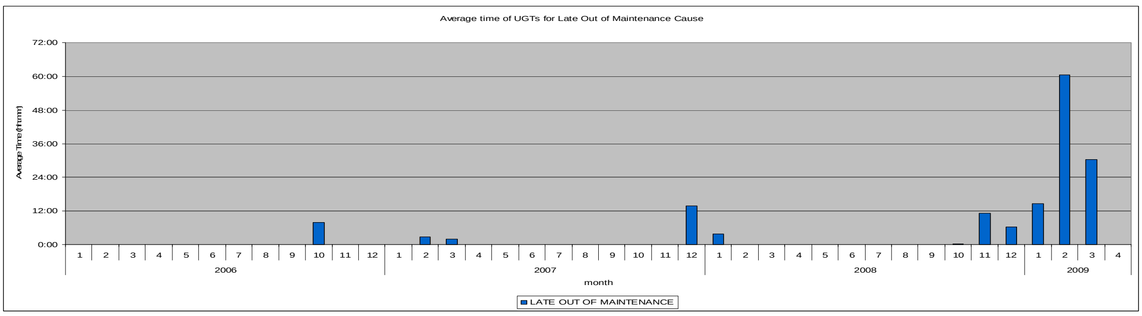
Delays





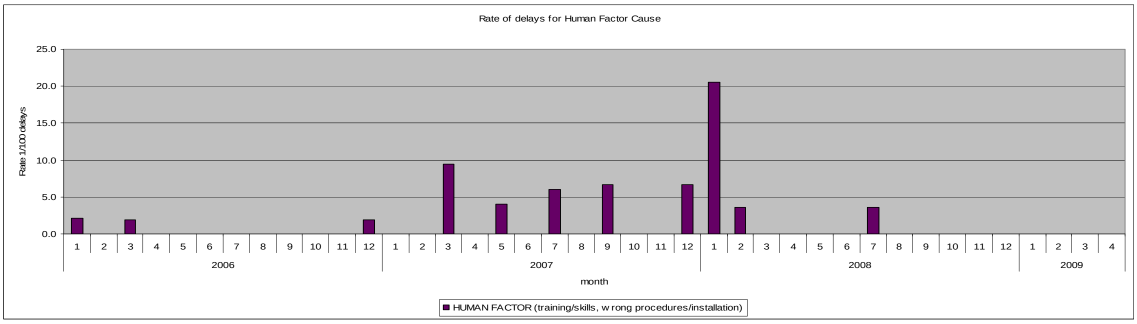
UGTs

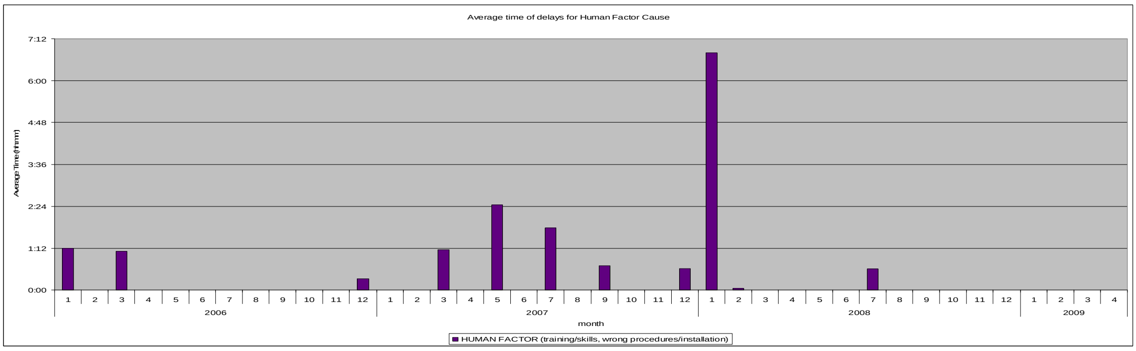




Maintenance – HUMAN FACTORS

Delays



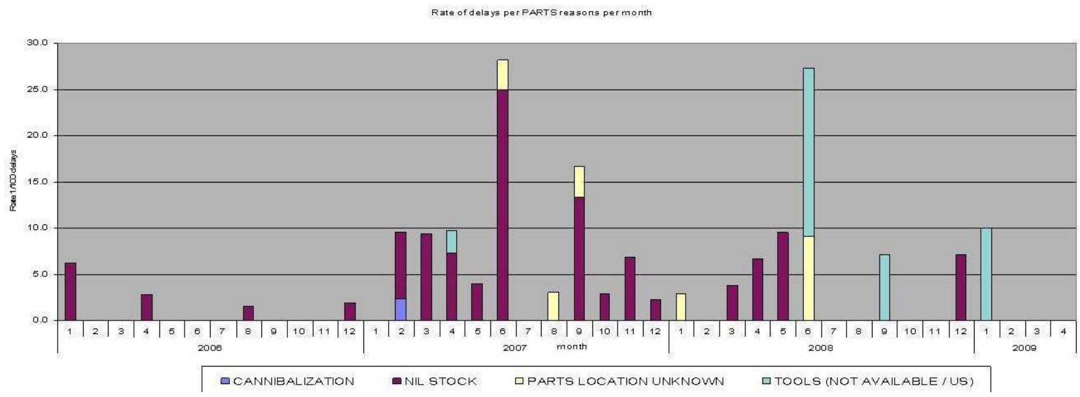


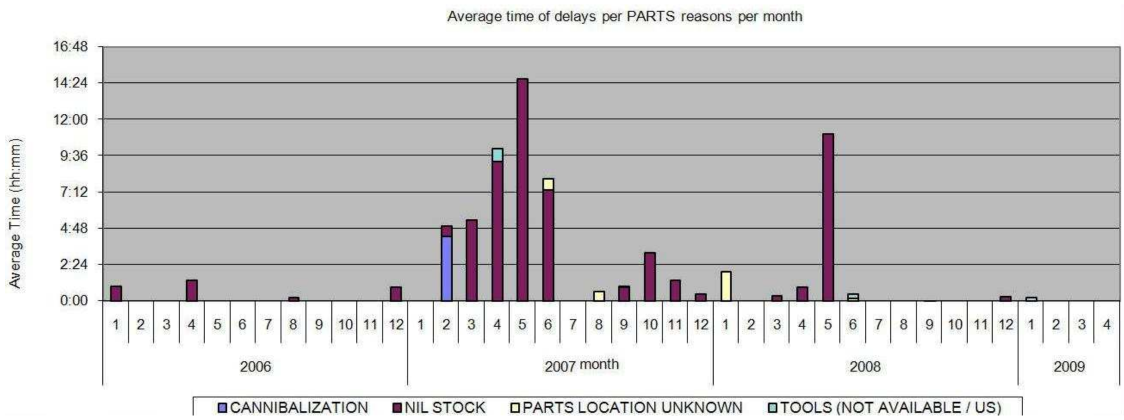
UGTs

The number of UGTs was not sufficient to be plotted.

Parts

Delays

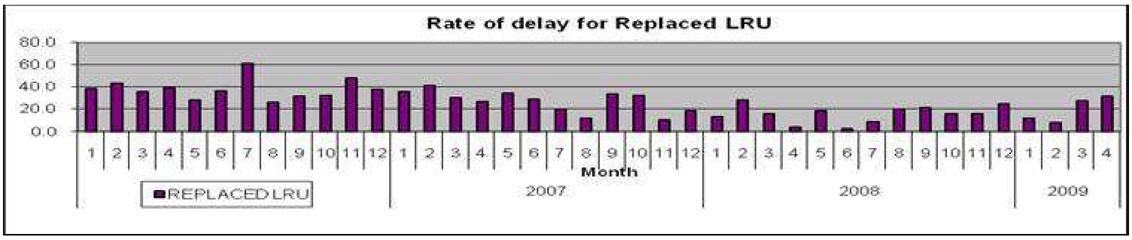


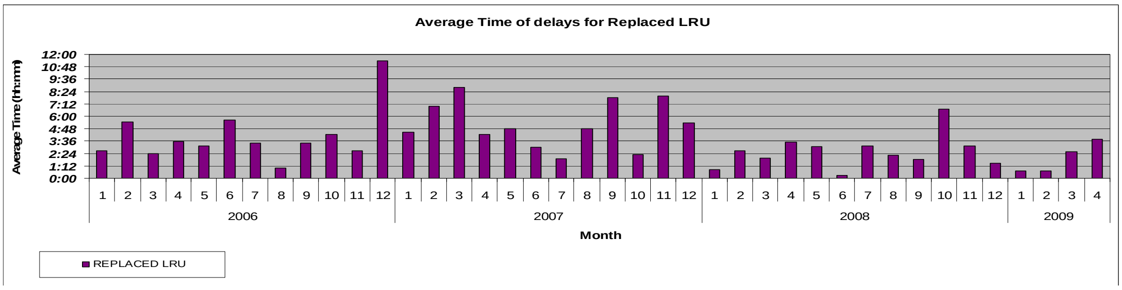


MCDONNELL DOUGLAS MD11

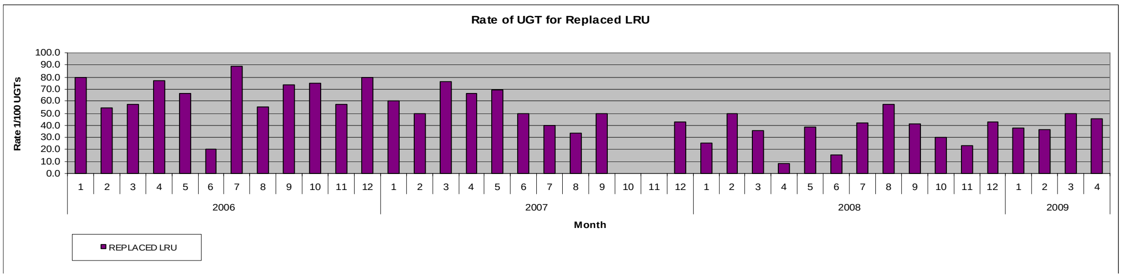
A/C Mechanical Fault – REPLACED LRU

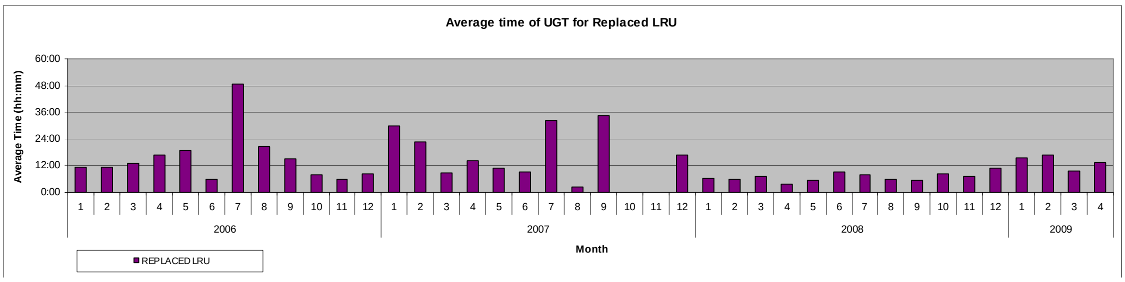
Delays





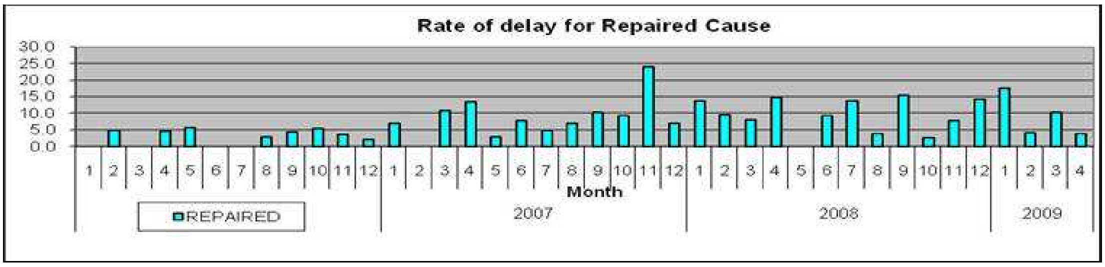
UGTs

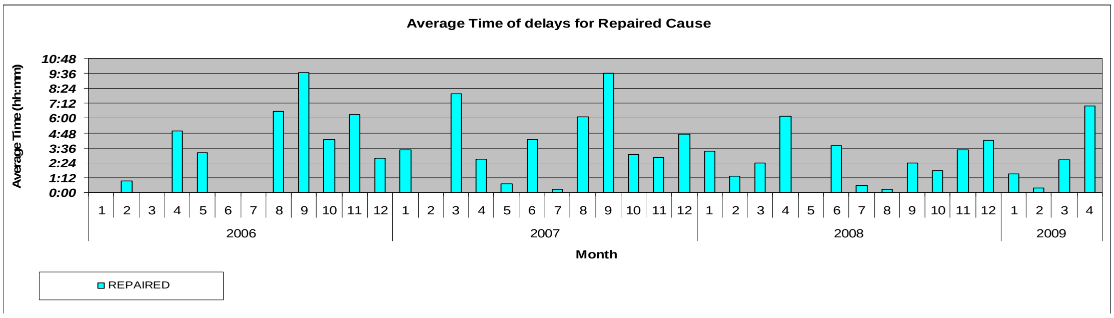




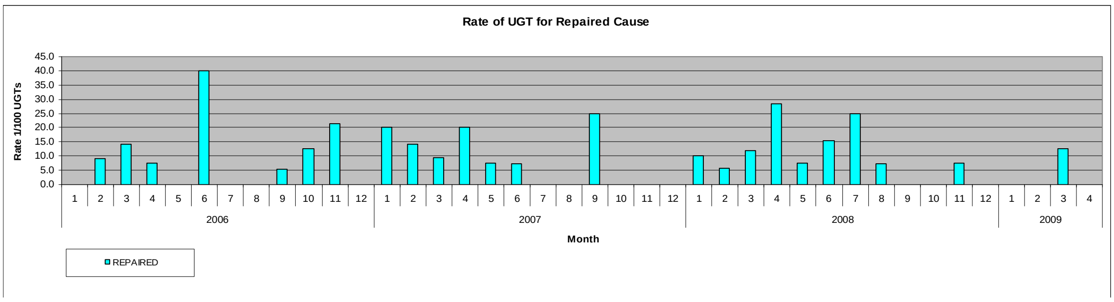
A/C Mechanical Fault – REPAIRED

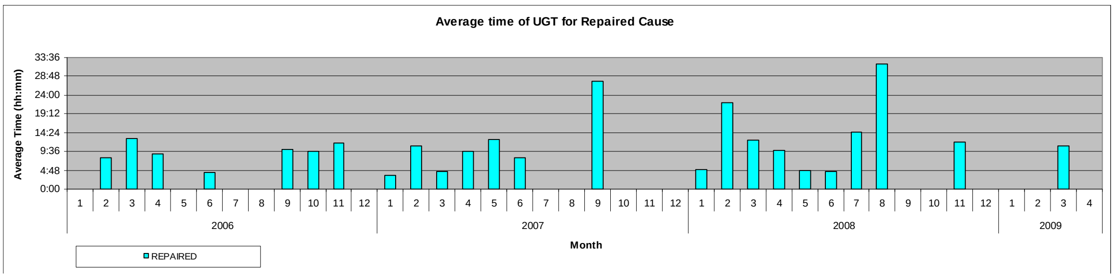
Delays





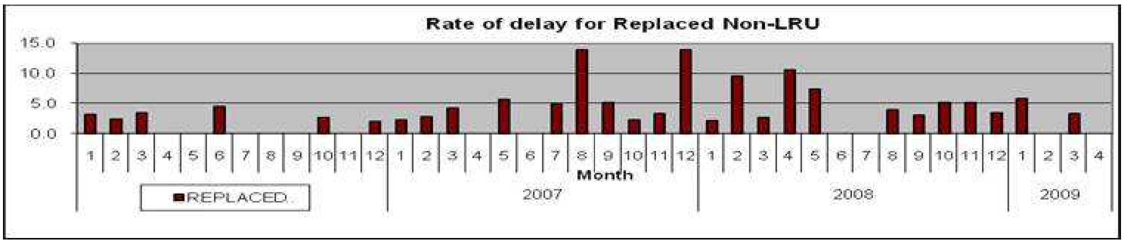
UGTS

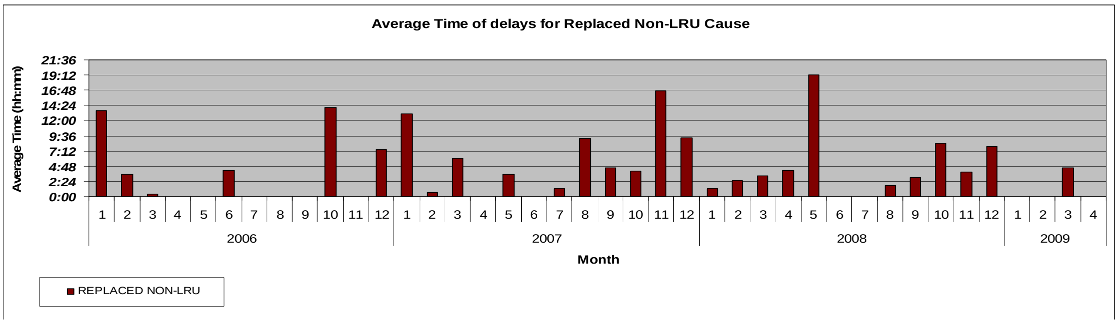




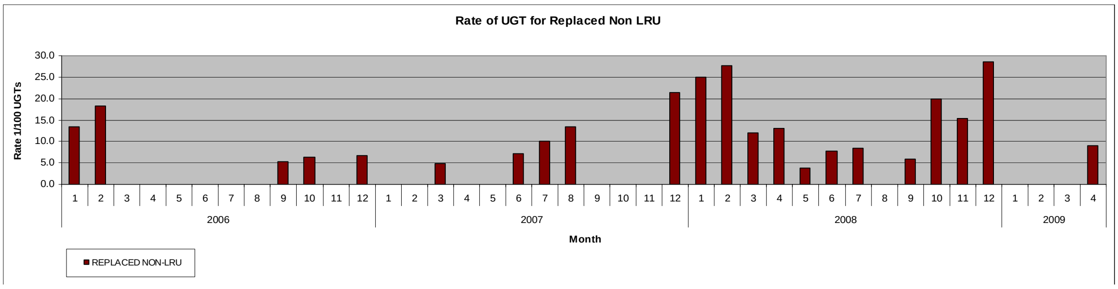
A/C Mechanical Fault – REPLACED NON-LRU

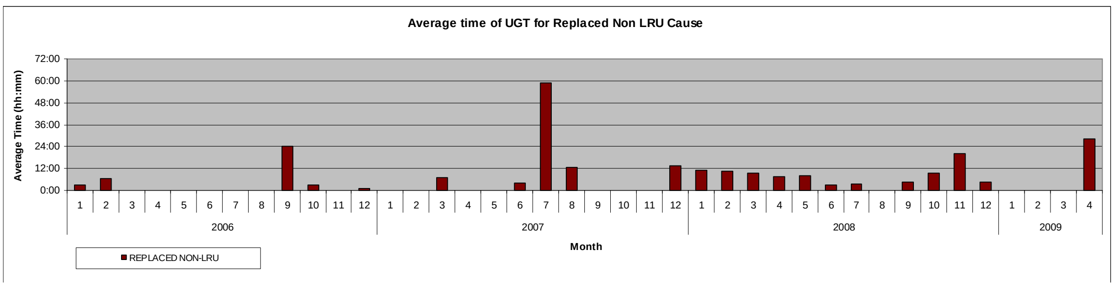
Delays





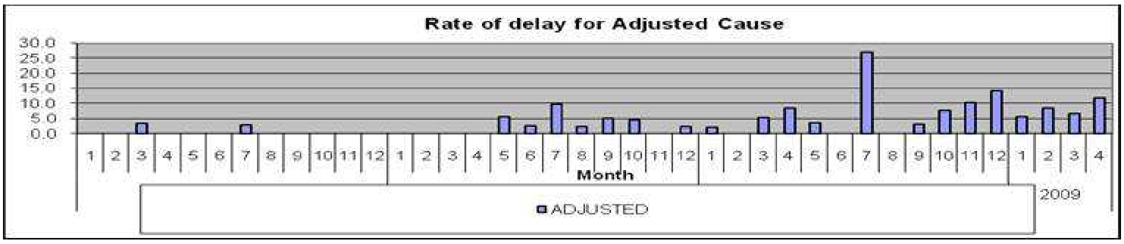
UGTS

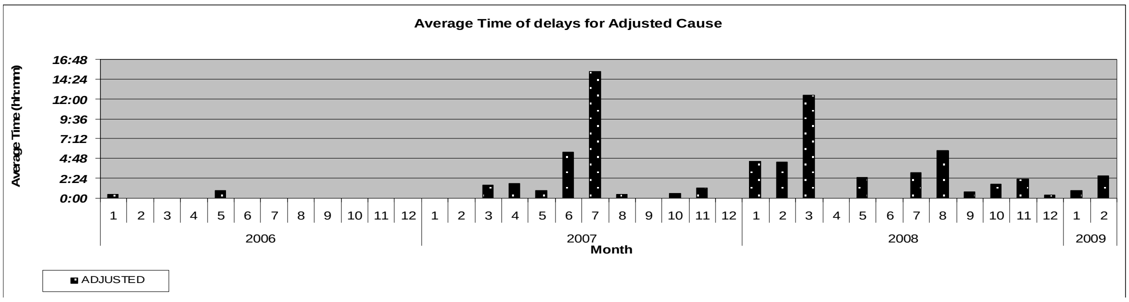




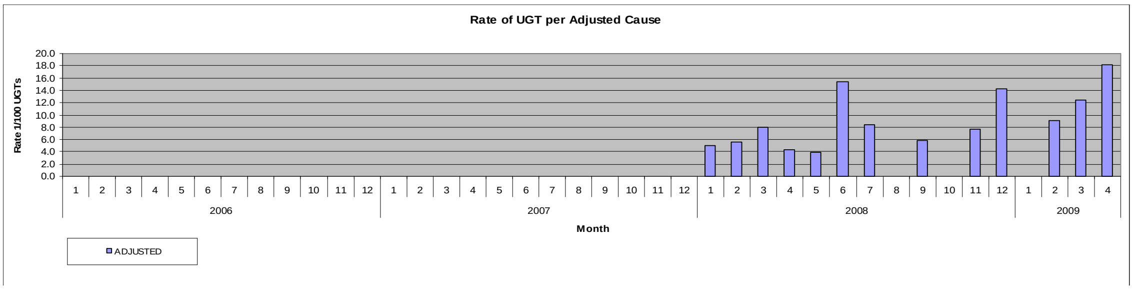
A/C Mechanical Fault – ADJUSTED

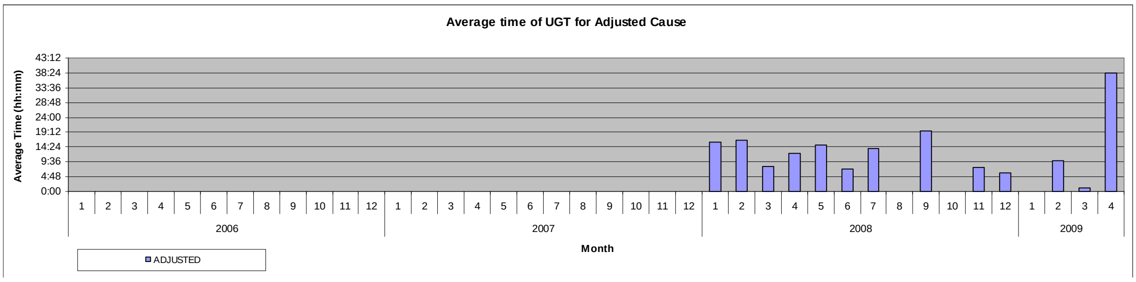
Delays





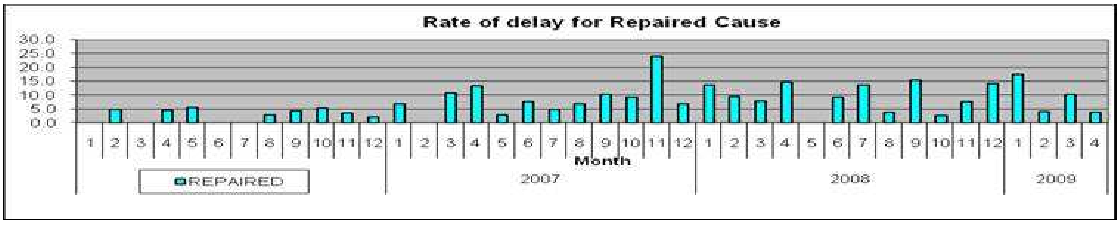
UGTs





A/C Mechanical Fault – ELECTRICAL CYCLE

Delays



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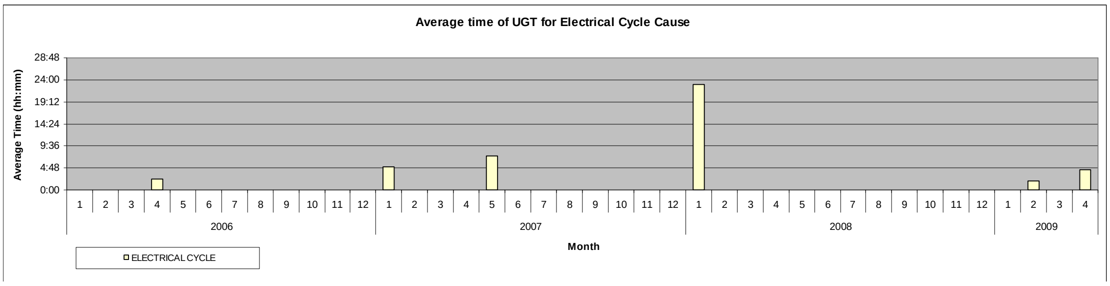
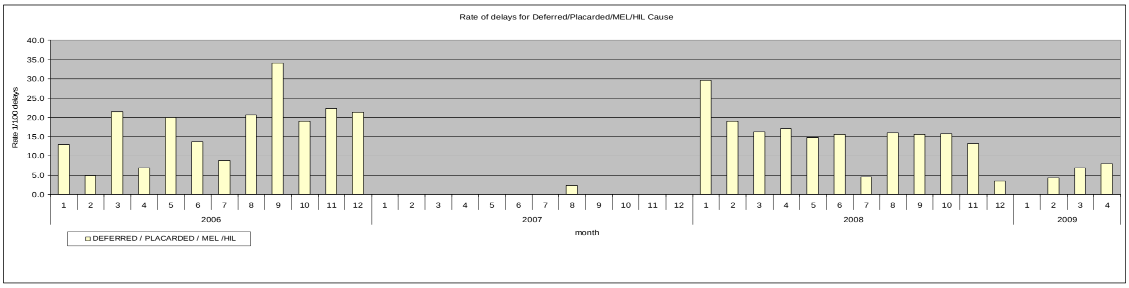
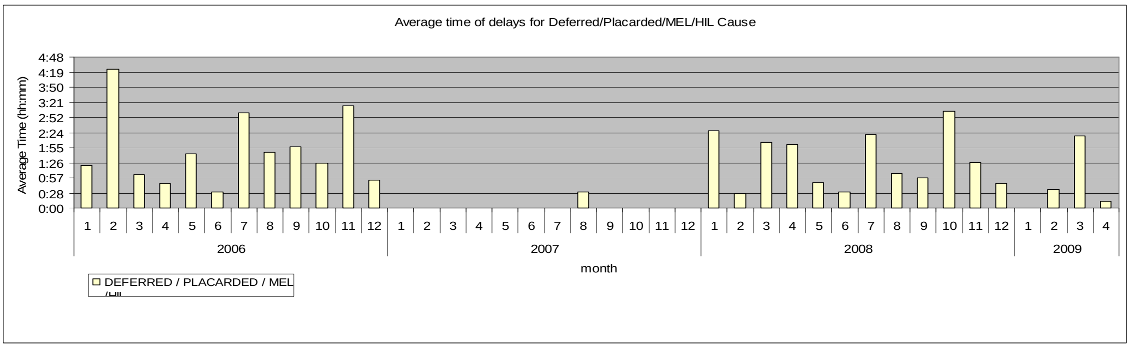


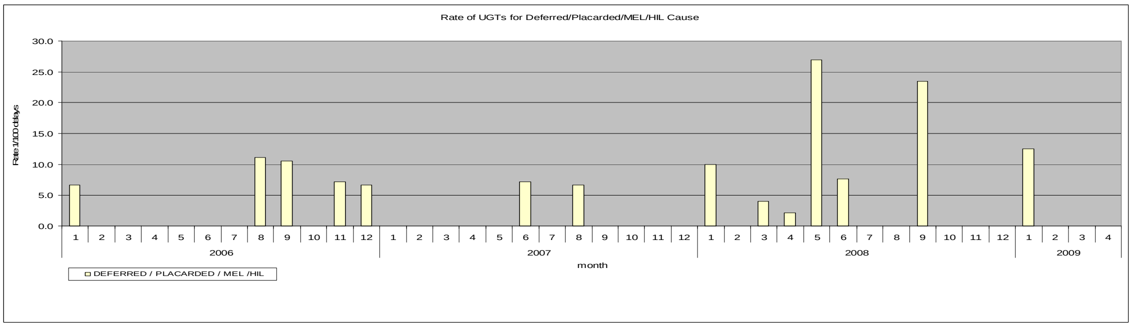
Maintenance – DEFERRED/PLACARD/MEL/HIL

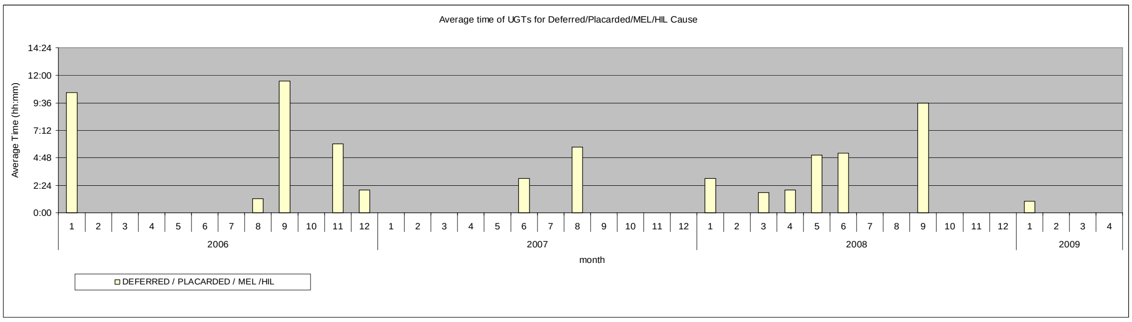
Delay





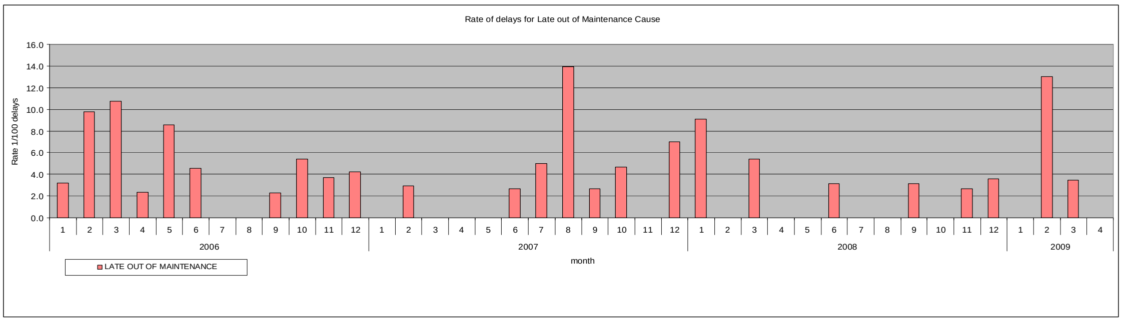
UGTs

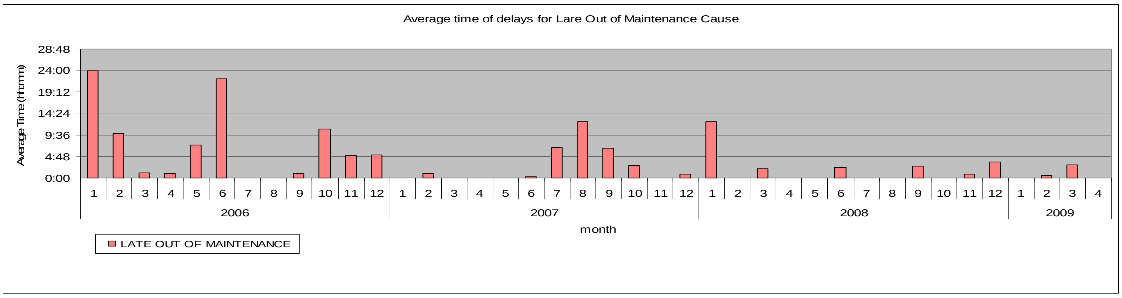




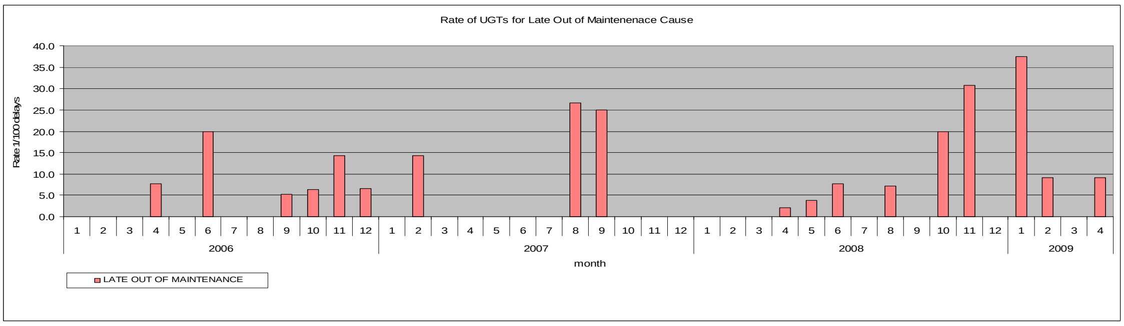
Maintenance – LATE OUT OF MAINTENANCE

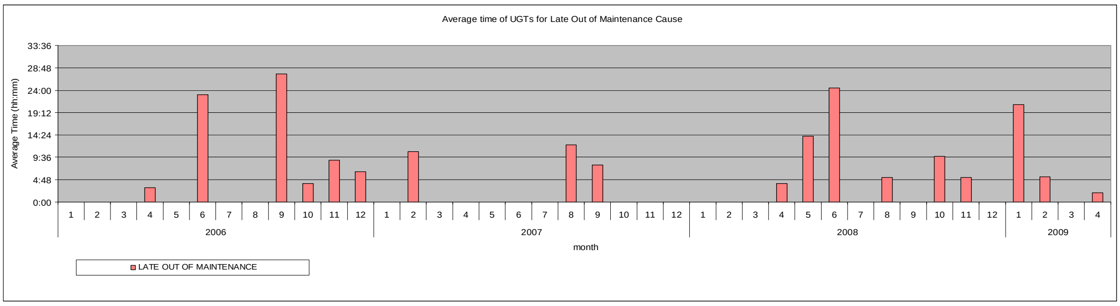
Delays





UGTs





Parts

Delays