ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

OPPORTUNITIES OF COST REDUCTION AND RISKS OF BUDGET OVERRUN IN MAINTENANCE SPENDING OF AN AIRLINE IN THE CURRENT MARKET CONDITIONS

Ph.D. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

GÜNCEL PAZAR KOŞULLARINDA BİR HAVAYOLUNUN BAKIM HARCAMALARINDA BÜTÇE AŞIM RİSKLERİ VE MALİYET AZALTMA FIRSATLARI

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To my dearest family,

FOREWORD

"If you want to be a Millionaire, start with a billion dollars and launch a new airline." Virgin Airlines' founder Sir Richard Charles Nicholas BRANSON's quote is well known to address the challenges of successfully running an airline. In the early years of aviation, passenger transportation was a luxurious phenomenon and it was hardly reached by the middle class. Airlines were subsidized companies and there were literally no independent carriers serving commercial transportation market.

First privatizations and entrepreneurship arose with the help of inclusive economic initiatives and this helped commercial airplanes becoming accessible by the middle class. And, as the world population grew in number and by their travel needs, we are now talking about a trillion dollar worth of civil aviation market served by airlines who have to stand on their own feet, except very few government backed flag carriers. The growth of carriers in numbers boosted airplane production, innovation and growth in number of airplane manufacturer companies and sites. Airplanes and their power plants are even used as a popular commodity in the leasing markets, thanks to the coherent network of global finance system. The civil aviation market is now a substantial ecosystem of aircraft and equipment manufacturers, airline entities, civil aviation authorities, air and ground crew and their associations, investors, insurers, lessors, maintenance organizations, part providers, logistics providers, fuel providers, ground handling companies and more.

Once a good aviation expert asked me a question. What does airline's produce? Tickets? Flights? Transportation? The correct answer was seats. That is what airlines produce and their size is measured by available seat kilometers (ASK's), which leads to another fundamental metric Revenue Passenger Kilometers (RPK's). These are the key metrics to weigh an airline. Not airplane count, number of bases or number of destinations. This brings the second question into minds. What does maintenance repair and overhaul (MRO) organizations produce? Labor? Maintenance? C checks? Correct answer to the second question is flight hours. Flight hours is what MRO's give to the airlines (on their airplanes) for them to produce ASK's, fill those seats with load factors and earn money according to yields (RPK's). None of the rest of the aviation ecosystem members has such a direct and controllable relationship as MRO's have with the airline. Because the MRO gives the tool of flight to the airline to earn money. Without underestimating the key role of every other "aviator" in the food chain, maintenance function has always been the second in the row in this big picture.

The maintenance cost of airline, weather it is performed in-house, outsourced or managed with a combination of both, is only the third largest cost element after operations and fuel. Some studies and research may indicate maintenance being the fourth after aircraft ownership cost. It is in fact a fluent classification, which changes every year, at different location, every different business climate and geopolitical change. Nevertheless, it is not a bold statement to say maintenance spending is 10 to 15 percent of an airline's overall costs.

Fuel, being the foremost leading airline cost, is handled with top priority to reduce its spending. Airplanes and engines that are more efficient, financial risk sharing tools to cure fuel price volatility (hedging), digital solutions to optimize fuel spent during phases of flight and even some genius new algorithms accurately estimating fuel need to reduce cost of fuels as a substantial weight element of the airplane. These are all popping up in time, consuming a good amount of scholar and industrial time and somehow heading to success. However, the gain is easily vulnerable to a wind of political change in the Gulf, a war risk at an oil exporter country or even a new maritime environmental regulation to drain the capacities of world refineries and escalating jet fuel price to unexpected highs. Cost of fuel is being worked very hard on, but it is still mostly uncontrollable for an airline.

Cost of aircraft ownership depends on the aircraft availability as well as the ease of financing. Airlines that are capable to access the finance with lower costs are by nature cost efficient in terms of aircraft ownership. However, even those financial markets are subject to volatility. Needless to mention the fluctuation of airplane asset values in decade long periods. Changing from where it is looked at, it is another mostly uncontrollable cost element for an airline.

Maintenance cost is different though. It has more room to play, as the sources are numerous in the first place. Seasonality is a great contributor. Even it has great connection with the world's trending asset acquisition method, the leasing and its maintenance obligations.

The aim of the dissertation is to explore the scientifically unexplored chapters of airline maintenance costs and unexpected contributors affecting them. First, the reason why maintenance has to be done is recorded. Next, maintenance costs are classified. Known cost models are introduced and a new one has been proposed. Then the concept of grounding cost is proposed as a noteworthy cost contributor, maybe even greater than the maintenance itself. Maintenance and grounding cost models are integrated for the first time. The last chapter is reserved to a critical contributor of maintenance costs, the aircraft leasing.

I hope the reader and the researcher will benefit out of this study at both battlefronts: The academy and the industry. In addition, I will be greatly fulfilled if this study could contribute to both fronts just a little bit.

September 2019

Remzi SALTOĞLU
M.Sc. Aeronautical Engineer

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ABBREVIATIONS

ABH	: Available Block Hour
AC	: Advisory Circulars
ACMG	: Airline Cost Management Group
ACMI	: Aircraft, Complete crew, Maintenance and Insurance
AD	: Airworthiness Directives
ALS	: Airworthiness Limitations Section
APU	: Auxiliary Power Unit
ASK	: Available Seat Kilometers
BHDOC	: Block Hour Direct Operating Cost
BtB	: Back to Birth
CPFF	: Cost plus fixed fee
CPIF	: Cost plus incentive fee
CPPF	: Cost plus percentage fee
CRS	: Certificate of Release to Service
DBH	: Designed Block Hour
EASA	: European Aviation Safety Agency
EFH	: Engine Flight Hour
EO	: Engineering Order
FAA	: Federal Aviation Administration
FC	: Flight Cycles
FFP	: Firm fixed price
FH	: Flight Hours
FPIF	: Fixed price incentive fee
HMV	: Heavy Maintenance Visit
IATA	: International Air Transport Association
ICAO	: International Civil Aviation Organization
IFE	: In-Flight Entertainment
LLP	: Life Limited Part
LOC	: Standby Letter of Credit
LOI	: Letter of Intent

LRU	: Line Replaceable Unit
MCTF	: Maintenance Cost Task Force
MPD	: Maintenance Planning Data, Document
MRB	: Maintenance Review Board
MRO	: Maintenance, Repair and Overhaul
MSG	: Maintenance Steering Group
MTBF	: Mean Time Between Failure
MTOW	: Maximum Take-off Weight
MR	: Maintenance Reserve
OEM	: Original Equipment Manufacturer
PBH	: Power by the Hour
RA	: Return Adjustment
RPK	: Revenue Passenger Kilometers
TAT	: Turn Around Time
W&B	: Wheel and Brake

SYMBOLS

ACP	: Aircraft capacity
ALC	: Aircraft lease cost during downtime
AOC	: Aircraft ownership cost
c	: Index for chartered flight
CIL	: Cosmetic items labor
CIM	: Cosmetic items material
CMV	: Current market value
DLC	: Daily lease cost
DT	: Downtime number of days
DTC	: Downtime cost
EOL	: Engineering order labor
EOM	: Engineering order material
LBR	: Labor rate
LF	: Load factor
MEF	: MRO efficiency factor
MLC	: MRO labor capacity
MLR	: Monthly lease rate
MOC	: Monthly ownership cost
MSR	: Monthly sub charter rate
MST	: Maintenance stop time
MTC	: Maintenance cost
MTL	: MPD tasks labor
MTM	: MPD tasks material
n	: Index for no-subcharter option
NDM	: Number of days in one month
NFL	: Non-routine labor factor
NFM	: Non-routine material factor
NPP	: Net profit per passenger
NRL	: Non-routine labor
NRM	: Non-routine material

OPCc	: Total opportunity cost for ACMI operator
OPCs	: Total opportunity cost for scheduled operator
OPF	: Opportunity cost per flight
OWC	: Ownership cost during downtime
OWD	: Daily ownership cost
OWT	: Ownership cost per trip
s	: Index for scheduled flight / subcharter option
SAC	: Sub charter cost during downtime
SAD	: Daily sub charter cost
STC	: Special tool cost
TAT	: Turn-around time
TRC	: Transportation Cost

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OPPORTUNITIES OF COST REDUCTION AND RISKS OF BUDGET OVERRUN IN MAINTENANCE SPENDING OF AN AIRLINE IN THE CURRENT MARKET CONDITIONS

SUMMARY

Aviation industry became commercial when the first passengers were admitted to flights against a certain fee to be paid. However, the real commercialization has happened once the commercial aviation companies and the entire aviation industry have gone through some set of changes towards liberalization, the deregulation. Once the airlines transformed from being non-profit centered luxurious transport service providers to regular and reachable transportation companies, alternatives came into play, the pressure of competition increased and ultimately margins reduced. The world's air transport volume in terms of passengers and cargo steadily increases, along with the growing world economy. The number of commercial aircraft and airlines are growing with comparable or higher pace.

Commercial airlines as economically viable companies aim to produce seats flown from point A to B, known as Available Seat Kilometers (ASK). Once those seats are filled with paying passengers, their mainstream revenue comes to earth, Revenue Passenger Kilometers (RPK) RPK is a product of ASK and ticket price and load factor. Ancillary revenues are produced from in-flight services and so forth. However, the main revenue of an airline is ticket sold for their scheduled and unscheduled commercial flights. There it comes to the picture, the aircraft maintenance. The equipment (aircraft) needed to generate ASK's has to provide the highest level of safety and reliability through maintenance for the flights to take place. However, the same "maintenance" is a cost driver which is a little above 10% of the overall cost elements of the airlines.

This 10% cost out of the overall budget of an airline may seem insignificant when compared to other segments in the entire pie chart. In descending order; fuel and oil, aircraft ownership and flight crew cost are higher cost elements, therefore any analyst's attention will be on these items when elaborating financial viability of an airline, along with its market (RPK) strength. The percentage of 10 of maintenance cost is just the visible and measurable performance indicator though. When the very well known, but never accounted grounding cost term is incorporated to such calculations, the whole chart would drastically change in the favor of maintenance segment getting bigger.

Grounding cost is significant, but not the only hidden and variable cost driver associated with maintenance. The statistical figures out of past performances of airlines might not change greatly, however a particular airline's decision making for maintenance and relevant contractual terms will affect its profitability and beyond, survivability. Reviewing every segment of maintenance cost drivers, we are able to see such cost reduction opportunities with great magnitudes.

To capture economic aspects of aircraft maintenance systematically, it is essential to use the following categories: Airframe, component and engine maintenance. While the Maintenance Steering Groups (MSG) of each particular commercial aircraft sets the maintenance requirements of each component, system and structure at the design phase, this effort's effect on maintenance cost is present but not the ultimate. The aircraft owner's decision on the source of maintenance provision is far more effective and controllable.

As an example, when looking at component maintenance in particular, a power by the hour (PBH) contract for the maintenance of a set of line replaceable units (LRU's) might bring an airline some 40% reduction in (component maintenance) cost. This opportunity comes into picture long time after the first reliability studies of the MSG. Same airline might not have the same cost reduction opportunity with a different fleet mix, fleet count, average age, geographical location and logistic network.

Airframe maintenance segment includes base maintenance checks that are accomplished in the hangar environment. Line maintenance checks, which are performed as a part of daily operations, are also cost drivers with lesser room to bring out cost reduction opportunities. Base checks however, are accomplished by pulling the aircraft from operations. Within the context of this dissertation, base maintenance events are also the drivers of a hidden cost of grounding. Some simple analysis shows that the grounding cost of base maintenance is somehow greater than the cost of maintenance itself. Therefore, turn around time (TAT) of the base checks shall be considered as a quantitative factor for maintenance decision.

If it were a standard cost, the grounding, it would be much easier for the maintenance source decision-making process. However, it is not. The business model of the airline and the seasonality factor makes things complicated. A model for grounding cost calculation has introduced in this study. Seasonality affects both the conventional maintenance costs and the grounding costs. Therefore, an integrated cost model for base maintenance is proposed as a further academic and industrial reference. What not included in such cost calculations is a decision making process for in-house or outsourced maintenance. A generic make or buy comparison would work at every instance when an airline intends to start maintenance organizations for any of the maintenance segments discussed. The general assumptions of this study use the idea of third party maintenance that the low cost airlines are utilizing. The legacy airlines with extensive maintenance capabilities were founded during non-viable/regulated era of the airline industry anyways.

Airlines owning or financing their fleets can manage their maintenance costs with their own decision making process autonomously. The leased aircraft fleet is growing though and some half of all commercial airline fleet are on lease now. This fact can be interpreted in many ways. Airlines are lacking own financial resources and having difficulty accessing to available financial credit. World's financial institutions are seeing aircraft as a profitable commodity. New generation aircraft are coming into production more often and the pressure of average fleet age is increasing. Global and regional crises forcing airlines to sell and lease back their fleets to enhance balance sheets, and many more. Whatever the chain of reasons are there, a typical airline is leasing their aircraft. The leasing contracts contain great risks for airlines in terms of extreme maintenance costs that they have to undertake.

From the lessor's perspective, maintenance related terms are set and explained to ensure that the residual value of the aircraft is preserved at the end of the lease period.

However it can also be interpreted as a way of generating additional revenues, if not an over safe system set out to mitigate costs definitely not in the favor of the airline. From this standpoint, the airline shall comprehend maintenance cost drivers arising from leasing contracts very well and shall be able to pinpoint risks for better decision-making and budget assembly.

Aircraft leasing has been studied as a life cycle itself and the maintenance cost sensitive aspects of each phase of this cycle have been evaluated. The term maintenance reserve, as the ancillary fee paid to the lessor is most of times comprehended as a sort of deposit to be claimed back by the airline. In real life however, there are huge costs buried within maintenance reserve mechanisms. Beyond maintenance reserve concept, an alternate way of ensuring the residual value of the airplane at the lease end is present. Return adjustment (RA) is a method, which can be demonstrated by airlines with large fleets and good financial reputation. Case studies demonstrate some 30% cost reduction, comparing maintenance reserve and return adjustment methods for lease lifecycle's contractual maintenance costs.

This study aims to look at real life maintenance costs those arise during operation of aircraft. In the era of liberal economies, harsh competition and highly vulnerable airline industry, every penny counts for the survival. Maintenance decision makers play a role beyond what is presumed and they are the key contributors to the profit opportunities and risks of financial turmoil.

GÜNCEL PAZAR KOŞULLARINDA BİR HAVAYOLUNUN BAKIM HARCAMALARINDA BÜTÇE AŞIM RİSKLERİ VE MALİYET AZALTMA FIRSATLARI

ÖZET

Havacılık sektörü, ilk yolcular belirli bir ücret karşılığında uçuşlara kabul edilmeye başlandığında ticari oldu. Bununla birlikte, gerçek ticarileşme, ticari havacılık şirketleri ve tüm havacılık endüstrisi serbestleştiğinde, serbestleştirmeye yönelik bazı değişikliklerden geçtiğinde oluştu. Havayolları kar merkezli olmayan lüks taşımacılık hizmeti sağlayıcılarından düzenli ve ulaşılabilir taşımacılık şirketlerine dönüştüğünde alternatifler ortaya çıktı, rekabet baskısı arttı ve sonuçta marjlar düştü. Dünya hava taşımacılığı hacmi, yolcu ve kargo bakımından, büyüyen dünya ekonomisi ile birlikte giderek artmakta. Ticari uçak ve havayollarının sayısı da bu artışla karşılaştırılabilir veya daha yüksek bir hızla artmaktadır.

Ekonomik olarak sürdürülebilir şirketler olarak ticari havayolları, Mevcut Koltuk Kilometre (ASK) olarak bilinen, A noktasından B noktasına uçan koltuklar üretmeyi amaçlar. Bu koltuklar ücretli yolcularla dolduğunda, ana gelirleri dünyaya gelir, Gelir Yolcu Kilometreleri (RPK). RPK, bir ASK ürünüdür ve bilet fiyatı ve yük faktörü ile şekillenir. Yardımcı gelirler, uçuş hizmetlerinden ve benzeri ürünlerden elde edilir. Ancak bir havayolu şirketinin ana geliri, tarifeli ve tarifesiz ticari uçuşları için satılan biletlerdir. İşte burada uçak bakımı resime girmektedir. ASK'ları üretmek için gerekli olan ekipman (uçak), bakımlarla en üst düzeyde emniyet ve güvenilirlik sağlamak zorundadır. Ancak aynı "bakım", havayollarının toplam maliyet unsurlarının %10'unun biraz üzerinde olan bir maliyet kalemidir.

Bir havayolu şirketinin genel bütçesinin bu %10'u, tüm bütçesindeki diğer kalemlere kıyasla önemsiz görünebilir. Bakıldığında akaryakıt, uçak mülkiyeti ve uçuş ekibi maliyeti daha yüksek maliyet unsurlarıdır. Bu nedenle pazardaki (RPK) gücünün yanı sıra bir havayolu şirketinin finansal verimliliğini geliştirirken herhangi bir analistin dikkati bu unsurlarda olacaktır. Yüzde 10 bakım maliyetinin sadece görünen ve ölçülebilir kısmıdır. Çok iyi bilinen, ancak hiç hesaba katılmamış yerde kalma maliyeti terimi bu tür hesaplamalara dahil edildiğinde, tüm grafik büyük ölçüde bakım segmenti lehine değişebilecektir.

Yerde kalma maliyeti önemlidir, ancak bakımla ilgili tek gizli ve değişken maliyet faktörü değildir. Havayollarının geçmiş performanslarından elde edilen istatistiksel ortalamalar çok fazla değişmeyebilir. Diğer yandan belirli bir havayolu şirketinin bakım ve ilgili sözleşmelere ilişkin kararları, karlılığını ve daha ötesinde hayatta kalma kabiliyetini etkileyecektir. Bakım maliyet segmentlerini inceleyerek, bunlarla ilgili maliyet azaltma fırsatlarını büyük oranda görebilmekteyiz.

Uçak bakımının ekonomik yönlerini sistematik olarak incelemek için, aşağıdaki kategorilerin kullanılması önemlidir: Gövde, komponent ve motor bakımı. Her bir ticari uçağın Bakım Yönlendirme Grubu (MSG), her bir bileşenin, sistemin ve yapının tasarım aşamasında bakım gereksinimlerini belirlerken, bu çabanın bakım maliyeti

üzerindeki etkisi mevcuttur ancak nihai değildir. Uçak sahibinin bakım sağlayıcısı konusundaki kararı çok daha etkili ve kontrol edilebilirdir.

Örnek olarak, özellikle komponent bakımına bakarken, hatta değiştirilebilir ünitelerin (LRU'ların) bakımı için uçuş saati başına kontrat (PBH) sözleşmesi, bir havayolu şirketinin (komponent bakımı) maliyetinde %40 azalma sağlayabilir. Bu fırsat, MSG'nin ilk güvenilirlik çalışmalarından uzun süre sonra ortaya çıkmaktadır. Aynı havayolu, farklı bir filo yapısı, uçak sayısı, ortalama yaş, coğrafi konum ve lojistik ağı ile aynı maliyet azaltma fırsatlarına sahip olmayabilir.

Gövde bakım segmenti, hangar ortamında gerçekleştirilen temel bakım kontrollerini içerir. Günlük operasyonların bir parçası olarak yapılan hat bakım kontrolleri, aynı zamanda maliyet azaltma fırsatlarını ortaya çıkarmak için daha az imkan tanıyan maliyet faktörüdür. Ancak üs bakımları (C bakımları), uçağı operasyondan çekerek gerçekleştirilir. Bu tez kapsamında C bakımları aynı zamanda gizli bir yerde kalma maliyetinini ortaya çıkaran unsur olarak ele alınmıştır. Bazı basit analizler, C bakımının yerde kalma maliyetinin, bakım maliyetinden bir şekilde daha büyük olduğunu göstermektedir. Bu nedenle, C bakım süreleri (TAT), bakım kararı için nicel bir faktör olarak kabul edilecektir.

Yerde kalma sabit bir maliyet olsaydı bakım planlama ve karar verme süreci çok daha kolay olurdu. Ancak, gerçek hayatta bu öyle değil. Havayolunun iş modeli ve mevsimsellik faktörü işleri karmaşıklaştırmakta. Bu çalışmada yerde kalma maliyet hesaplaması için bir model tanıtılmıştır. Mevsimsellik hem geleneksel bakım maliyetlerini hem de yerde kalma maliyetlerini etkiler. Bu nedenle, planlı üs bakımı için entegre bir maliyet modeli, ilerideki akademik ve endüstriyel çalışmalara referans olarak önerilmiştir. Bu tür maliyet hesaplamalarına dahil olmayan şey, bakımı kurum içi veya kurum dışında yapmak için karar verme sürecidir. Genel bir dahilde yapma veya taşere etme karşılaştırması, bir havayolu için tartışılan bakım segmentlerinden herhangi biri için kaynak bulmak istediğinde her durumda işe yarar. Bu çalışmanın genel varsayımları, düşük maliyetli havayollarının kullandığı bakımları organizasyon dışında yaptırma kararını temel almaktadır. Zaten geniş kapsamlı bakım yeteneklerine sahip olan eski havayolları, havayolu endüstrisinin regüle edilmemiş dönemlerinde kurulmuştur.

Filolarına sahip olan ya da uçaklarını dışarıdan finanse eden havayolları bakım maliyetlerini kendi karar süreçleriyle özerk bir şekilde yönetebilirler. Yine de kiralık uçak filosu giderek büyüyor ve tüm ticari havayolu filolarının yarısı kiralık uçaklardan meydana gelmiş durumda. Bu gerçek birçok farklı şekilde yorumlanabilir. Havayolları finansal kaynaklarından yoksundur ve finansal kredilere erişmekte güçlük çekmektedir. Dünyadaki finansal kurumlar uçağı karlı bir emtia olarak görüyor. Yeni nesil uçaklar daha sık üretime giriyor ve rekabetin getirdiği ortalama filo yaşı baskısı artıyor. Küresel ve bölgesel krizler havayollarını bilançolarını geliştirmek için filolarını satmaya ve kiralık olarak geri almaya zorlamakta. Sebepler zinciri ne olursa olsun, tipik bir havayolu uçaklarını kiralıyor. Kiralama sözleşmeleri, havayolları için üstlenmeleri gereken aşırı bakım maliyetleri bakımından büyük riskler içermekte.

Kiraya verenin bakış açısına göre, uçağın parasal değerinin kiralama süresi sonunda korunmasını sağlamak için bakımla ilgili koşullar belirlenir ve açıklanır. Bununla birlikte, havayolunun lehine olmayan ve maliyetleri azaltmak için kurulan aşırı güvenli bir sistem değilse, kiralayanın ek gelir elde etmesinin bir yolu olarak da yorumlanabilir. Bu bakımdan havayolu, kiralama sözleşmelerini ve kaynaklanan bakım maliyeti etkenlerini çok iyi kavramalıdır. Daha iyi karar alma ve bütçe uyumu için riskleri tam olarak belirlemelidir.

Uçak kiralama işlemi bir hayat döngüsü olarak ele alınmış ve bu döngünün her bir aşamasının bakım maliyetine etki eden yönleri değerlendirilmiştir. Bakım rezervi terimi, kiralayana ödenen ek bir kira ücret olarak çoğu zaman havayolunun geri alacağı bir tür mevduat olarak anlaşılır. Ancak gerçek hayatta, bakım rezervi mekanizmalarına dahil olan çok büyük maliyetler bulunmaktadır. Bakım rezervi kavramının ötesinde, kiralama sonunda uçağın parasal değerini korumanın alternatif bir yolu mevcuttur. İade düzeltmesi (RA), büyük filoları ve iyi bir finansal itibarı olan havayolları tarafından uygulanabilecek bir yöntemdir. Örnek çalışmalar, aynı kira süresince sözleşmeye bağlı bakım maliyetleri için bakım rezervini ve iade ayarlama yöntemlerini karşılaştırılmış, %30'a varan maliyet avantajı görülmüştür.

Bu çalışma, uçağın operasyonu sırasında ortaya çıkan gerçek hayat bakım maliyetlerini incelemeyi amaçlamaktadır. Liberal ekonomiler, sert rekabet ve son derece savunmasız havayolu endüstrisi dönemlerinde, hayatta kalmak için her kuruş önemlidir. Bakımın karar vericileri, öngörülenin ötesinde bir rol oynar ve kar fırsatlarına ve finansal risklere hayati katkı yapar.

1. INTRODUCTION

Commercialization of the air transportation goes back more than 100 years. But since US government deregulated aviation industry in 1978, this industry has substantially changed. Air News Times (2011) stated that since 1978, there has been 189 times that U.S. airlines have sought for bankruptcy protection until 2009, in which American Airlines being the 189th. U.S. airlines have lost \$54.5 billion and have been unsuccessful in making money in the last ten years.

There were more than 10 major airlines in who merged into four, between 2004 and 2015. The reduction in demand, low efficiency of the airplanes and their inability to ensure profitable business cases caused this historical consolidation. The ones who survived took great lessons from this fall-out and established efficient and flexible business plans. The airline business is now profitable, but those profits are too slim to accept more airlines in the market without a big risk to go bankrupt.

Europe on the other hand, contains a variety of different airlines, even more than one big carriers in some countries. However, the high turnover, low profit business cases lead to airline folding wings. Recent insolvencies of Alitalia, Air Berlin, and Monarch are red flags of an unhealthy foundation of airline business cases in Europe too.

Air News Times (2011) asserted that the reasons for this are passengers accustomed to low fares, costly labor costs, and unpredictable fuel prices. However, expensive aircraft, commencements of disease and worries against terrorism have forced the airlines to the cracking point. First, asset costs. Second, fuel is airline's largest expense and its price is uncontrollable. Third, costly labor costs because of pilots, mechanics and other labor market conditions. Furthermore, there are government rules and labor union mandates, which reduce the total working hours. Fourth, recessions, in which airlines lose passengers when businesses went bankrupt and vacationers lose their jobs. Fifth, uncontrollable outbreaks of diseases such as SARS, snowstorms, volcanic ash clouds, earthquakes and terrorism can affect flight planes and frighten the passengers.

In addition to these, airlines have to be concerned about the competition. If one airline reduce ticket prices, other airlines usually do the same. They even give away their profits significantly, because airlines know that passengers might choose a ticket, which is few dollars cheaper.

When we look at the challenges above, we see most of them are uncontrollable by the airlines or at least, there are trade-offs between the solutions for each. Every year, airplane and engine manufacturers are coming up with more efficient, less consuming airplanes and engines. On the white paper, this promises cutting costs of fuel and maintenance. However, the same efficient equipment costs higher and the savings that are promised are ousted far more with the financing costs arisen.

According to IATA (2015) as given in Figure 1.1, the leading costs of an airline are Fuel and Oil, Aircraft Ownership, Cabin and Flight Deck Crew and Maintenance. Costs of specialty jobs on an airline such as pilots and mechanics do not fluctuate dramatically, but saving opportunities are limited. Depending on the region, the cost of pilots and other airline employees are stable in both directions. The unions and the competitor pressure eliminate the chances of suppressing the salary costs.

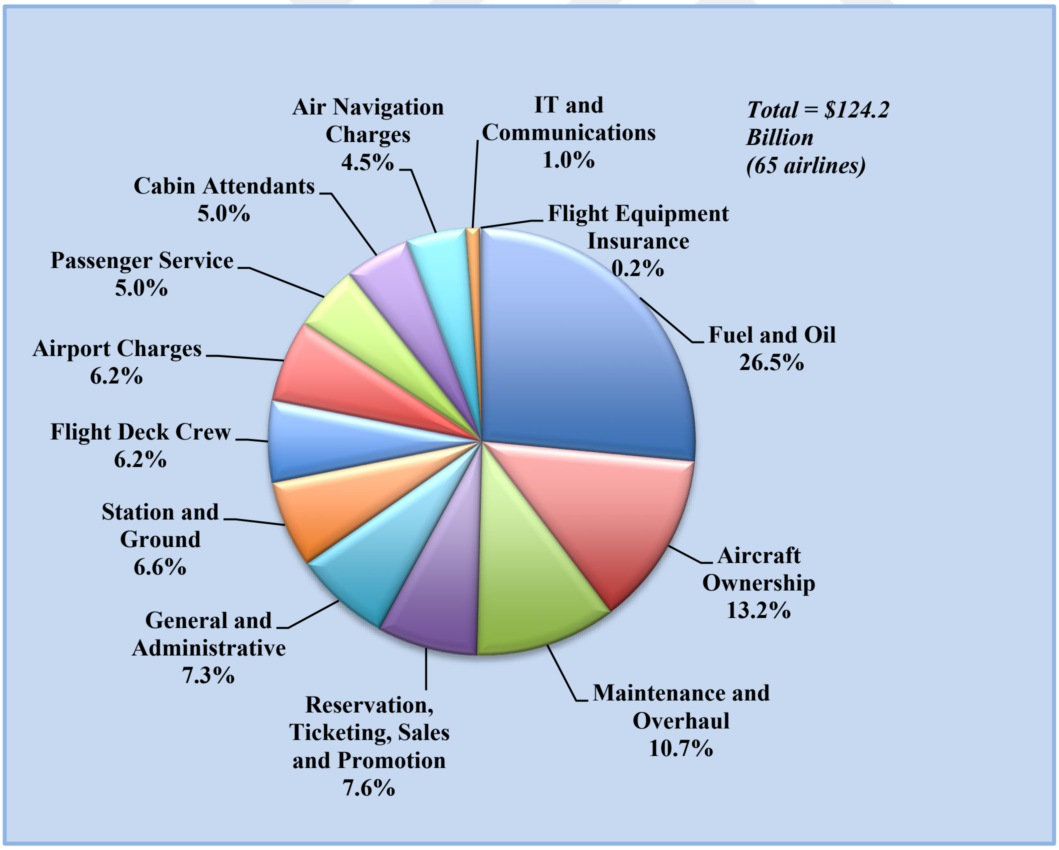


Figure 1.1 : IATA Airline Cost Management Group 2015 statistics.

Leaving all the other cost drivers to different disciplines to discuss, maintenance is a far more controllable aspect of airline spending and when combined with the asset (airplanes) management opportunities, it could be a significant area of cost reduction (and survival margin) for an airline operator.

1.1 Purpose of Dissertation

This study aims to introduce a holistic approach for aircraft maintenance cost reduction efforts (Table 1.1). Aircraft manufacturers of the aviation industry show obvious efforts to reduce life cycle costs. Maintenance being the most controllable cost driver, sizeable amount of progress is observed to make the airplanes less demanding for periodic maintenance against a high demand for overall reliability. As it will be discussed in the later chapters of the dissertation, the terms safety and reliability are the nucleus of maintenance 'design criteria' of the commercial aircraft. However, the focus of aircraft manufacturers is mainly on the improvement opportunities at design level. Once the design is complete, further improvements are exercised as well. Nevertheless, such efforts will be at a greater cost and lesser impact.

Manufacturers aim reducing number of periodic maintenance tasks, extending task intervals, improving on-wing duration of engines and increasing life times of components. OEM's also try to reduce the resources (mostly labor requirement) to perform maintenance. However, almost all the attempts of measuring (and reducing) maintenance resources are limited to single maintenance tasks or task groups. This dissertation therefore aims to add a new dimension to maintenance cost studies by moving up from tasks to checks, exploring real life cases and looking at actual dollar values spent by the airlines.

It is very naïve to say that the cost of maintenance can be depicted from the labor column of a Maintenance Planning Document (MPD) of an aircraft. There are several contributing factors, hidden costs and cost variations in the life cycle cost for an airline in the real life. The study will explain but not use the maintenance cost elements from the MPD labor hours and materials base point. On the contrary, it will discuss the real life examples and try to surface practical and controllable face of aircraft maintenance cost management.

The dissertation also aims to discuss phenomenon such as grounding cost and aircraft end of lease costs, which are seldom analyzed. There are two well-known and important outcomes of maintaining an aircraft. These are reliability and availability.

However, it is quite challenging to identify some objective criteria to quantify the cost of grounding. Here in this study, few different approaches have been suggested to put the grounding cost as a driver of the maintenance source selection process.

Table 1.1 : What is introduced in this dissertation?

State-of-Art	Dissertation
Maintenance cost is a relatively small portion of overall airline costs. Its effect is insignificant.	Showed that maintenance costs are more controllable than other airline costs and comprise great risks of budget overrun.
Statistics suggest that, out of all 4 segments of maintenance costs (engine, component, line and base), base maintenance seems to be the element with lowest cost.	Explained that direct cost of base maintenance is relatively low, but its impact is the highest due to its direct effect to aircraft availability.
The industry accepts downtime cost "natural" and do not take into account for scheduled maintenance planning.	Proved that downtime cost is significant and shall be calculated with an industry-wide standard formula. Such formula is presented.
Direct maintenance costs are the only drivers of maintenance source selections.	Demonstrated that downtime cost is a bigger contributor to overall costs. Therefore suggested downtime as an integral part of source selection process.
Maintenance tasks are considered to demand a standard maintenance labor and that labor is fulfilled with standard efficiency.	Showed that a maintenance cost model can converge to reality when it includes labor efficiency factor as a variable.
Current maintenance models work on a standard ratio between routine task labor and non-routine labor. Same applies to material cost estimations.	Explained the variation of non-routine labor and material factor between operators, airplane types and ages, operation regions and type of the maintenance tasks.
Maintenance cost studies pronounce number of tasks, manhours required per task and intervals of tasks or task groups.	Suggested and used real dollar value as the outcome of maintenance cost models.
Sensitivity to seasonality is neglected at maintenance cost models and formulas.	Explained that geographical location, type of operation and seasonality is a significant driver of cost variances.
As the seasonality and downtime costs are avoided in maintenance cost models, cost of maintenance does not contribute to maintenance schedule decisions.	Generated an integrated maintenance and downtime cost function to be used for decision making, where seasonality is taken into account.
Type of lease and leasing contract discussions do not look at the maintenance cost, although it comprises the biggest risk.	Depicted the entire aircraft leasing lifecycle from maintenance cost standpoint, to mitigate cost risks.
Maintenance reserves in aircraft leasing agreements are accepted as an uncontrollable phenomena. They do not have effect on maintenance costs.	Discussed various types and methodologies of maintenance reserves. Showed that reserve types and terms effect maintenance costs.
Leased aircraft selections are generally made according to leasing fees.	Explained the best practice of leased aircraft selection, comprising the comparison of lifecycle maintenance costs.
Maintenance cost reduction efforts focus in interval extension and resource efficiency improvement in general.	Synthesized a holistic approach to tackle overlooked cost risks and opportunities, which oversees downtime, aviation contracts, supply/demand interaction and seasonality.

Finally yet importantly, the concept of aircraft leasing and its implications to the overall maintenance costs are discussed. An airline spending on maintenance is not independent from the agreement with aircraft owner and the terms within. Studying real life maintenance costs, but avoiding aircraft leasing agreements and maintenance reserves contradicts the general aim of this study and any study to identify improvement opportunities in cost of maintenance. Therefore, a comprehensive chapter discusses the impact of leasing to real-life maintenance costs.

These subjects, which are academically less considered, have more influence in real economic life of an airline. The goal is to introduce new terminology to the readers' and researchers' and initiate new thinking and study applicable to the ultimate effort of airline profitability.

1.2 Hypothesis

Mostly aircraft OEM originated data for defining maintenance costs are not sufficient to accurately estimate and control life cycle cost of an aircraft. The real life application of maintenance has far more practical elements, which are under the control of airline operators in various levels. These 'tools', when systematically used, has greater impact than those defined in the design phase of and aircraft. With the fact that a great deal of regional, commercial and macro-economic factors are bundled within such tools, airlines still have a great deal of control over reducing their maintenance costs, chance to achieve a better financial competitiveness and autonomy of surviving in their highly competitive business environment.

Maintenance is a design criterion. However, the maintenance life-cycle cost of an aircraft is shaped greatly the moment it is introduced to the airline fleet through a purchase or leasing contract. Regardless of future maintenance decisions and actions, a contract clause may cause a substantial deal of variation of costs in the lifecycle. Therefore, the aircraft leasing contracts and their maintenance related terms shall be carefully analyzed to pinpoint the risks and opportunities of costs in the highly competitive and low margined airline economics.

1.3 Methodology

This thesis is an effort of fundamental research about a topic, which has not been systematically handled in academic domain. Aircraft are high-tech machines that are flying thanks to explorations and studies in aeronautical science. Air transportation industry is a sizeable industry with great effects on world's economic growth. Aircraft becoming widely used as a tradable asset and a popular commodity relates the topic to the science of economy. However, the research of maintenance costs of aircraft and airlines is predominantly an aeronautical engineering study, because of its technical content.

The hypothesis of the study came to life, based on substantial years of observations in aviation maintenance field. The need for this exploration has appeared during several cases of facing overwhelming differences between planned and accomplished, promised and fulfilled, aimed and achieved.

To lay a foundation to the research, the theory of maintenance and theoretical maintenance concepts were elaborated. Aiming to reach an aircraft maintenance cost model that can be applied in real life, literature was investigated. Some models out of aviation literature was presented and their results were compared. None of those models contained the grounding cost element in their calculations. Therefore grounding cost was studied and implemented to the newly introduced cost model. Another important factor of maintenance cost, the leasing contracts, were evaluated. The aim of carrying real life problems of aircraft maintenance costs to the academic ground was achieved by elaborating pitfalls of leasing contracts in terms of lifecycle maintenance costs.

1.4 Literature Review

Despite the fact that downtime cost is expensive, yet at the time of authoring of this dissertation, there are not many sources found related to this. Kumar, Crocker, Knezevic and El-Haram (2000) asserted that downtime should be considered only for unscheduled maintenance. There is no downtime related to scheduled and preventive maintenance. They defined the downtime cost related to unscheduled maintenance as cost of revenue loss (p. 199). However Dinesh Kumar et al., as cited in Saranga (2004) opposes this opinion and stated that whenever a system stops to operate, whether it is scheduled or unscheduled, the cost of loss revenue (CLR) is an unexceptional and an unavoidable cost (pp. 70-71).

In the same journal article, Saranga (2004) also asserted that indirect downtime cost should be added if the unscheduled grounding happened. It differs according to the situation. For example, the cost of transporting passengers to their destinations using other airlines, or the cost of providing accommodation to passenger if no immediate flight exists. They are classified as CC (cost of compensation). Furthermore, if the unscheduled grounding occurred repeatedly, passenger opportunity cost will appear (p. 71). Eurocontrol's Business Case Team (2013) asserted that the loss of possible revenue, which is illustrated by the passenger opportunity cost, includes the passenger value of time (p. 14). Saranga (2004) formulated the cost of revenue loss due to downtime both for scheduled and unscheduled maintenance (p. 71). His formulations are given later in this study. However, the model proposed by Saranga (2004) for the scheduled downtime includes only the cost of revenue loss. It does not include the lease or ownership cost of the aircraft or even the possibility of the operator to subcharter another aircraft to continue its operation.

Another model is proposed by Bazargan (2014), who presented a mathematical model for aircraft dispatching strategy in order to have a minimum total maintenance cost and an increase in aircraft availability. The study was carried out concerning the Cessna 172 aircraft used for flight training in Embry-Riddle Aeronautical University (ERAU), United States. It presents the possibility of having minimum direct maintenance cost and minimum maintenance schedule. However, since the aircraft are not used commercially, only direct maintenance cost was taken into account in the analysis. Nevertheless, the mathematical model used in the article has the desired characteristics with the model, which is going to be proposed in this study. The mathematical model proposed by Bazargan (2014) is shown in the appendix.

The study carried out by Aircraft Commerce (2006, 2010, 2011) used interview technique to gather maintenance cost data from service providers and airline executives. According to their study, one segment of maintenance such as base, component or engine was evaluated for a certain aircraft type. All direct maintenance cost elements are gathered to calculate an aircraft type's maintenance cost over its life cycle per flight hour or cycle. By applying such a method, Aircraft Commerce become a unique source of information for maintenance costs analysis for various aircraft types and maintenance segments. The drawback of such a method is that, a limited group of both service providers and airline operators could be reached to collect the data. The reliability of the information cannot be confirmed, as the data shown represents commercially sensitive information.

On the other hand, Aircraft Commerce (2006, 2010, and 2011) is using the similar methodology to model specific aircraft, engine and component maintenance cost for several years. Trusting that the information that they represent are unbiased, tolerating a certain level of deviation due to its interview based modelling, their referred studies are a good sources to compare airplane types and other models and statistics in terms of maintenance costs.

In this study, IATA resources have been widely referred to for various reasons. Primarily, as a non-profit organization, the reference information is expected to be unbiased and accurate. IATA's ACMG studies rely upon streamlined data provided by member airlines. ACMG Report (2014) is only one of ACMG's publicly available sources of information and it was widely referred in this study. The information contained are systematically collected from IATA ACMG member airlines. This method is similar to Aircraft Commerce methodology. However, personal interviews and service provider contribution do not take place IATA ACMG's methodology.

There is a significant flaw with ACMG's data set though. IATA ACMG Report (2014) compares all cost statistics of A320 (Figure 1.2) and B737 (Figure 1.3) including maintenance. The airlines feeding the information might be operating both aircraft type and only one of them. Their network footprint might be significantly different. However, such a difference does not explain the variation of cost data provided by different airlines on the same aircraft type.

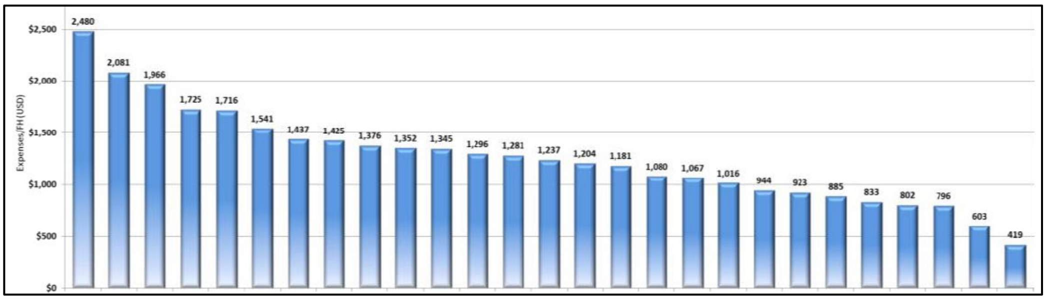


Figure 1.2 : A320 MRO Expenses per FH – IATA ACMG (2014).

The two graphs from the same source are quite striking about IATA ACMG's methodology. Compared to A320, B737's having less maintenance cost is a known phenomenon, which can be reached from other references as well. Here the noteworthy information is the variance of the data obtained from different airlines. The variance in both graphs can lead to two different facts. ACMG's member airlines are providing statistical data in incomparable domains. This is a red flag against the reliability of their information in general.

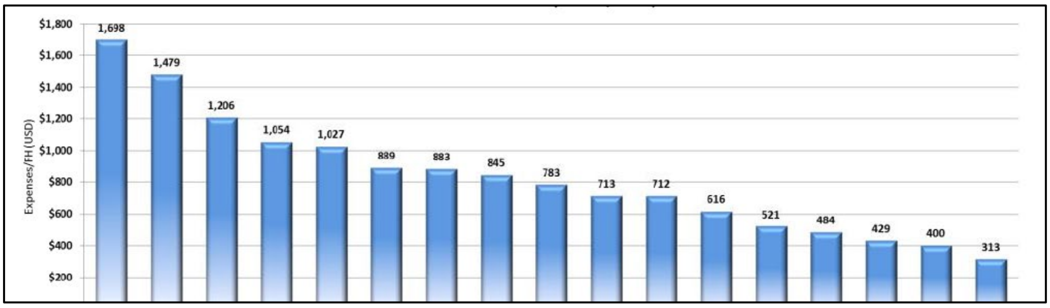


Figure 1.3 : B737 MRO Expenses per FH – IATA ACMG (2014).

On the other hand, such variance in their maintenance expenses might be based on correct data. Then the purpose of this study is very much justified with this fact. The A airline spending X amount for the maintenance and B airlines maintenance spending on the same type of airplane which is Y should not be several times more than X.

Another valuable source of information is IATA MCTF reports. Maintenance Control Task Force is a dedicated team of experts, getting into the detail of maintenance costs, IATA MCTF (2014) results were compared with Aircraft Commerce cost models. Total maintenance cost per flight hour were at comparable ranges, while the breakdown of the cost varied. This has been noted as a valuable discussion point.

Marx, Mavris and Schrage (1995) proposes a deviation of 10 to 25% over the wing (maintenance) costs. They suggest that such variation is insignificant and will not affect the overall life cycle cost. IATA studies contradict with this proposition, at least in the commercial aviation domain.

Papakostas, Papachatzakis, Xanthakis, Mourtzis and Chryssolouris (2008) focuses on the cost model of line maintenance activities between the flights. Solving an operation research problem, they have selected decision-making criteria as cost, remaining useful life (RUL), operational risk and flight delay. The cost of delay terminology is used, but from an unscheduled maintenance standpoint.

Sriram and Haghani (2001) initiates a study from a wider planning perspective. They tackle the problem faced by an airline needing to construct a 7-day planning schedule with maintenance constraints for a heterogeneous fleet of aircraft. The paper presents a formulation for planning, which uses cost as a function.

Cost modelling integrated with grounding costs are widely seen in operations research area. Arguello, Bard and Yu (2008) exercises a greedy randomized adaptive search procedure to solve the irregular operations problem of an aircraft. Irregularities and their affect in flight schedules is a popular research topic. However, it leaves the direct maintenance cost problem untouched.

Buyers (2015) highlights the opportunities of reducing costs and turn-around times and increasing efficiencies. They bring the term "labor efficiency factor" into discussion. LEF will be used in the integral part of this study. Buyers' reference is noteworthy as it underlines the significance of source selection for the maintenance cost reduction efforts.

McFadden and Worrels (2012) opens up a new discussion point by suggesting the dramatic change in global aircraft maintenance outsourcing after de-regulation of airlines in 1978. Growth estimations in MRO outsourcing and its market, varying labor rates across geographies and types of maintenance outsourcing models are some of the topics discussed in this study.

IATA (2017) which is the Guidance Material and Best Practices for Aircraft Leases provides information about many aspects related to aircraft leases with a focus on the technical perspective. The content is very useful to pinpoint the aircraft leasing process and its affects from the maintenance cost perspective. IATA formed a joint group of experts and identified the aircraft leasing lifecycle. This information is crucial to set the foundation of maintenance reserve concepts.

2. AIRCRAFT MAINTENANCE PROGRAM PHILOSOPHY

2.1 Definition of Aircraft Maintenance

All machines, even the simplest one, need to undergo maintenance program after some defined hours of work. Imagining an aircraft, it consists of many parts and components, which form big complex structure. For that reason, there is no doubt that an aircraft also requires maintenance programs to be carried out after a specified operation period. According to British Standards 4778, as cited in Kumar et al. (2000), the definition of maintenance is "the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function."

From the definition given above, Kumar et al. (2000) described maintenance as all the activities, which guarantee the systems to operate as required. The aims of maintenance are to guarantee that the state of the systems is according to the approved requirements, guarantee that the system is suitable and safe, lower the outcome of failures, keep the value of the system, keep the high level of safety and reliability of the system and keep the system accessible to maintain production (p. 170). In addition to Kumar et al. (2000), Gupta, Bazargan and McGrath (2003) stated that to provide aircraft that are safe, airworthy and punctual, are the main objectives of maintenance program for aircraft (p. 387). Bazargan (2014) also asserted that the objectives of maintenance to yield safe and airworthy aircraft make it as the foundation of successful aircraft management (p. 11). Hurst (1995) stated that attaining the highest availability is the main objective of aircraft maintenance programs (p. 31-2). In view of this information, it is clear that maintenance programs have a very important role on the continuing of aviation industry. They help operators to reach important objectives such as, safety, airworthiness and high availability. Authorities require the operators to maintain their aircraft because it deals with the safety of many people. Furthermore, proper maintenance will yield good aircraft punctuality, high operating hours and thus better revenues for aircraft operators.

2.2 Maintenance Program Application

Ackert (2010) stated that an aircraft is created to transport people with specific standards and requirements of reliability and comfortability. To fulfill this objective, its airframe, components, engines and systems are scheduled for maintenance as contained in the maintenance program. In the beginning of aviation industry, pilots and mechanics built the maintenance program. They developed simple maintenance program according to their experiences. However, in the fifties as large jets started to enter the market, aircraft manufacturer began to become the source of maintenance program as people care more for reliable and safer aircraft. It was the origin of primary maintenance process, which is called Hard-Time (HT). In this type of process, to reach the highest level of safety and reliability, aircraft is disassembled, overhauled and reassembled at regular intervals. However, in 1960 representatives from airlines and FAA found that this type of maintenance process is not effective. Then the second primary maintenance process, which is called On-Condition (OC), is introduced. In this type of process, in order to decide whether a part can continue to operator or not, that part is checked against defined physical standards at specific intervals. To remove the part before failure happened during operation is the objective of this type of maintenance process.

The Aircraft maintenance programs can be performed either by the aircraft operator itself or by the Maintenance, Repair, and Overhaul (MRO) companies. In both cases, they need to follow the specified procedures released by the aircraft, engine and component manufacturers. Kinnison as cited in Eurocontrol (2008) asserted that Maintenance Planning Document (MPD) of Airbus or Maintenance Planning Data (MPD) of Boeing are examples of documents released by aircraft manufacturers for maintenance program preparation. These documents contain usually what, how and when the minimum mandatory maintenance tasks need to be carried out (p. 2). Using these documents, operators and MRO companies can plan the maintenance programs accordingly. Because aircraft is a complex structure formed by many parts and components, its maintenance program is categorized into several types of maintenance. Kumar et al. (2000) classified those tasks into corrective maintenance task, preventive maintenance task and conditional maintenance task (p. 174).

Kumar et al. (2000) defined preventive maintenance task as maintenance activity, which is done to lower the chance of the system having a failure or to make the best use of the operational advantage. The preventive maintenance tasks are usually carried out at specific intervals according to flight hours, distance flown or number of landings. They consist of replacements and overhaul (p. 176). The time needed for the completion of preventive maintenance tasks is given in Figure 2.1.

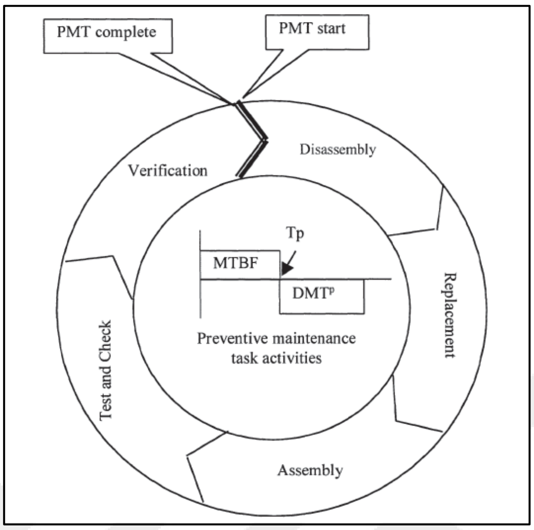


Figure 2.1 : Activities of a typical preventive maintenance task, adapted from Kumar et al. (2000).

Corrective maintenance task is described as unscheduled or unplanned maintenance task. It is defined as unscheduled maintenance because it consists of a set of actions that are carried out to repair the system after it experienced failure (p.175). The activities of common corrective maintenance task are shown in Figure 2.2.

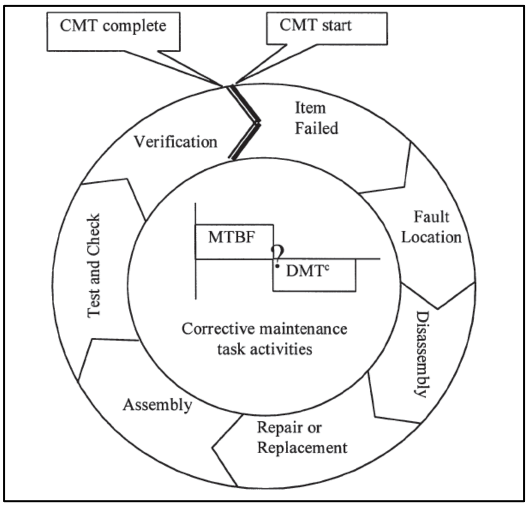


Figure 2.2 : Activities of a typical corrective maintenance task, adapted from Kumar et al. (2000).

Conditional or predictive maintenance task realizes that change in the performance condition of a system may appear before failure happened. Actions are taken if growing failure has been detected. The common activities of conditional maintenance is shown in the Figure 2.3.

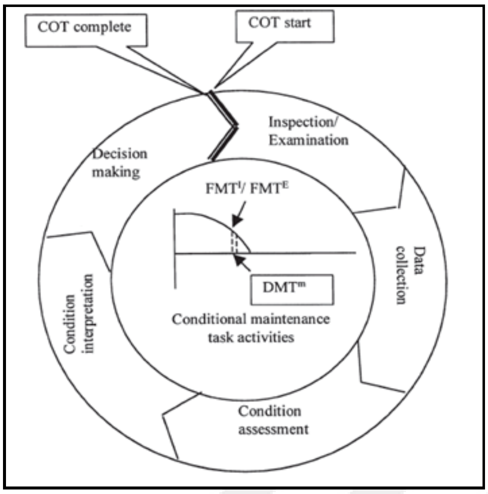


Figure 2.3 : Activities of a typical conditional maintenance task, adapted from Kumar et al. (2000).

Kumar et al. (2000) stated that both corrective and preventive maintenance tasks are commonly used by maintenance organizations in the past. Nevertheless, in recent years, the importance of safety precautions appears and makes the conditional or predictive maintenance much more preferred. Using corrective maintenance, maintenance managers may maximize the use of a component until it fails. However, sometimes component failures may happen and harm other parts of the systems in inappropriate time (p. 178).

2.2.1 Maintenance program history

Intergraph (n.d) stated that in aviation industry, a decision logic process that is used to set the activities that are needed to have aircraft system operates accordingly is called MSG (Maintenance Steering Group). To develop maintenance programs, which certify that equipment is maintained at maximum safety and reliability at the most minimum cost possible, is the main purpose of MSG decision logic. MSG-1, the "Maintenance Evaluation and Program Development Document" was established in 1968 and was designed for Boeing 747-100. Ackert (2010) stated that in MSG-1, to build the aircraft's scheduled maintenance tasks, both hard time and on condition process are included. Intergraph (n.d) discussed that MSG-2; the "Airline/Manufacturer Maintenance Program Planning Document" was developed by airline in 1970. Its principles were parts-driven, bottom-up and process-oriented. The term Boeing 747 was discarded so that it can be used on other aircraft. Ackert (2010) described that Condition-Monitoring (CM) as the third primary maintenance process was also brought to front at the same time. In this kind of process, the mechanical performance is observed and examined without any checks or inspections scheduled at specific intervals. There is an acceptable range in which the data trend need to follow. The unit is taken out when the data trend goes across the unacceptable limit.

The most recent evolution of MSG is MSG-3, the "Operator/Manufacturer Scheduled Maintenance Development Document" that was developed in 1979. The philosophy of MSG-3 is a system-driven, top-down and task-oriented. Boeing 757 and 767 were the first aircraft that use MSG-3 decision logic. Delmas (2013) from Airbus showed the evolution of MSG in Figure 2.4.

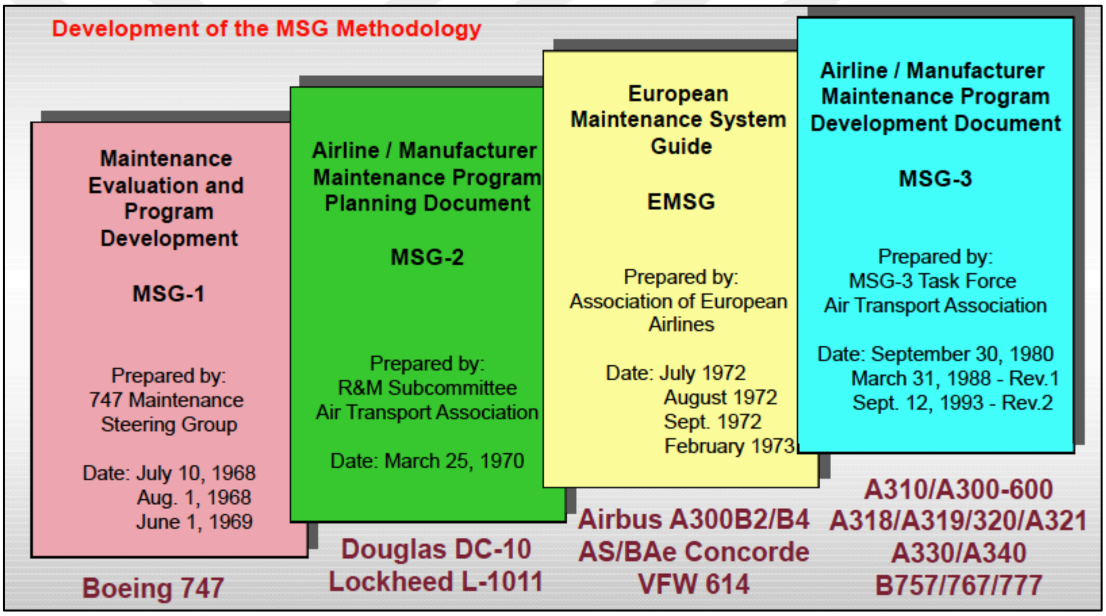


Figure 2.4 : Development of MSG methodology, adapted from Delmas (2013).

2.2.2 MSG3 concept introduction

Ackert (2010) stated that in 1979 Air Transport Association (ATA) task force found some limitations in MSG-2 decision logic. MSG-2 did not distinguish which maintenance is done for safety reason and which maintenance is done for economic reason. Since there are many components that need to be independently checked, it was very complicated to control the program. As the complexity of an aircraft increased, the program could not cope with it effectively.

Intergraph (n.d) described that the MSG-3 decision logic helped the aircraft operators in reducing the maintenance cost without affecting the reliability level. Concentrating on potential failures and planning the proactive and preventive maintenance task correctly played important roles on improving the reliability. One example of commercial aviation success of MSG-3 was proven by DC-9 of Northwest Airlines, which reached the 98.5% reliability level. The evolution of the maintenance flow days and man-hours were tabulated as shown in Figure 2.5. Ahmadi, Söderholm and Kumar (2010) asserted that the purpose of MSG-3 methodology as in Figure 2.6.

Interval Check	**Pre-MSG-3 (Traditional Program)**		**Post-MSG-3 Analysis**		**Man-hour Savings**
Months	Flow Days	Man Hours	Flow Days	Man Hours	Percent
18	16	12,000	7	5,250	56
36	40	30,000	30	25,000	25
108	50	37,500	40	30,000	20

Figure 2.5 : Northwest Airlines MSG-3 analysis of the DC-9, adapted from Intergraph (n.d).

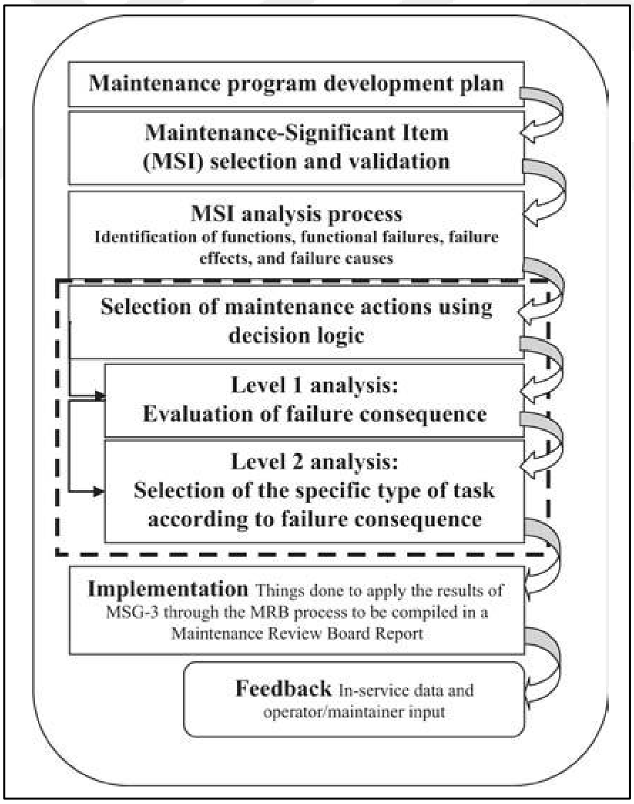


Figure 2.6 : Maintenance task analysis process using MSG-3 decision logic, adapted from Ahmadi, Söderholm and Kumar (2010).

MSG-3 (2007) is to encourage the development of aircraft initial scheduled maintenance tasks and intervals, which will satisfy the authorities, operators and the manufactures during Maintenance Review Board (MRB) process. MSG-3 consists of four sections, systems and power plant, which include components and Auxiliary Power Unit (APU), aircraft structure, zonal inspection and lightening/high intensity radiation field. The analysis steps of MSG-3 are:

1. Maintenance Significant Item (MSI) selection.
2. MSI analysis process, which includes identification of functions, functional failures, failure effects and failure causes.
3. Maintenance actions are selected using decision logic, which includes level 1 analysis (evaluation of the failure consequence) and level 2 analysis (selection of specific task corresponding to the failure consequence).

The maintenance task analysis process using MSG-3 decision logic is shown in Figure 2.6.

2.2.3 Maintenance program development

Ahmadi, Söderholm and Kumar (2010) stated that Type Certification (TC) process and Maintenance Review Board (MRB) process are two different processes from which the aircraft initial maintenance requirements come from. The Type Certification process aims to generate maintenance requirements, which certify that the defined safety standards are obeyed by the aircraft design. All the resulting requirements are put together into Airworthiness Limitation Section (ALS). ALS consists of Safe Life Airworthiness Limitation Items (Life Limited Parts document), Damage Tolerant Airworthiness Limitation Items (ALI documentation for structure), the Certification Maintenance Requirements (CMR) document systems, the Ageing Systems Maintenance (ASM) document and the Fuel Airworthiness Limitations (FAL) document. All the documents that are stored in ALS are approved separately.

On the other hand, in Maintenance Review Board process, the initial maintenance requirements for new aircraft or on-wing power plants are built together by industry, manufacturers, authorities, vendors and operators. The requirements that come from MRB process are compiled together in a Maintenance Review Board Report (MRBR). The MRBR drafts and gives an idea about the initial minimum scheduled maintenance or inspection requirements for a specific aircraft type's airframe, engines and systems. This draft will be used by the operators to develop their own continuous airworthiness maintenance program, which need to be approved by the civil aviation authorities.

Transport Canada as cited in Ahmadi, Söderholm and Kumar (2010) showed in Figure 2.7, the connection between TC process, MBR process and the establishment of operator's approved maintenance program.

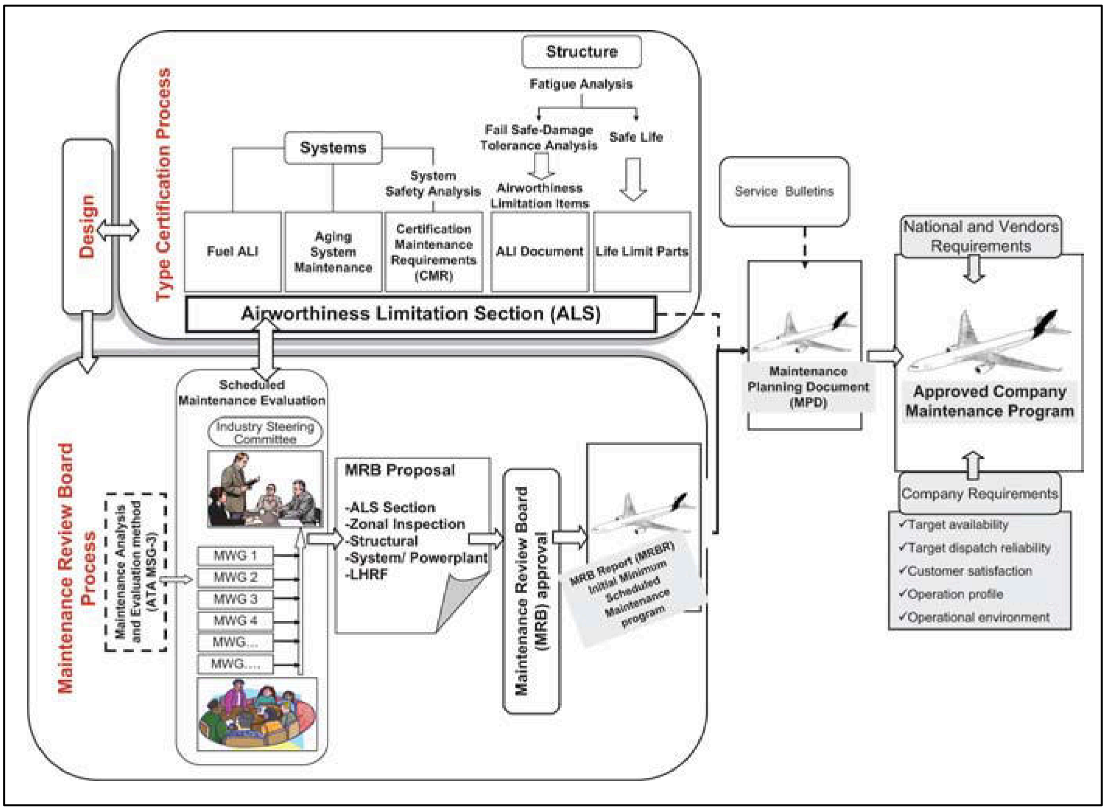


Figure 2.7 : Aircraft maintenance program development, adapted from Ahmadi, Söderholm and Kumar (2010).

The aircraft initial scheduled maintenance program issued in MRBR is recently developed using MSG-3 methodology, which has been discussed in the previous section.

Delmas (2013) from Airbus discussed that most of the repetitive maintenance tasks required by various documents are available in the MPD. To give the necessary maintenance planning information so that operators can build their own scheduled maintenance program is the main purpose of MPD. In accordance with AMC M.A.302 (ED 2008/013/R of 12/12/2008): "An owner or operator's maintenance program should normally base upon the maintenance review board (MRB) report where applicable, the maintenance planning document (MPD), the relevant chapters of the maintenance manual or any other maintenance data containing information on scheduling. Furthermore, an owner or operator's maintenance program should also take into account any maintenance data containing information on scheduling for components."

Delmas (2013) stated further that repetitive, scheduled, routine and on aircraft level maintenance tasks, which are already mandated by miscellaneous source documents, are covered in MPD. Besides collecting all the maintenance requirements, MPD also put additional information such as zone, access, preparation and man-hours. There are four sections and one appendix contained in MPD. The first section is General Introduction which contains MPD general policy, MPD scope and purpose, normal utilization for a given aircraft type, revision policy, overall program description, inspection interval policy, abbreviations, effectivity cross reference list, service bulletin list, etc. The second section is System, APU and Power Plant which contains all the scheduled maintenance tasks concerning the aircraft systems and components, APU and powerplants. The third section is Structure, which contains the initial scheduled maintenance tasks and intervals of aircraft structure. The fourth section is Zonal, which gives information regarding the General Visual Inspection (GVI) requirements for each aircraft zone. However, MPD does not cover on component level, troubleshooting/defect correction, unscheduled maintenance, one time inspection or any additional maintenance requirements.

2.2.4 Operator maintenance program

Despite the fact that the scheduled maintenance tasks of general aircraft type are all covered in MPD, usually a fleet of an operator does not need to deal with all the tasks due to different design standards. That is why in this case MPD customization is needed. The information that is required to customize MPD is aircraft type, engine type, mod status, cabin layout, weight variant, APU type, SB status and emergency equipment list. During MPD customization, operators may add some tasks due to miscellaneous reasons such as national requirements, airline policy, aircraft operations (such as ETOPS), aircraft configuration (cabin layout, entertainment), vendor recommendations and previous experience on other aircraft types. The customized MPD is defined as Operator's Maintenance Program (OMP). Robelin (2010) from EASA illustrates the origins of all the tasks contained in OMP, which is approved by the National Aviation Authority (NAA). This process is shown in Figure 2.8.

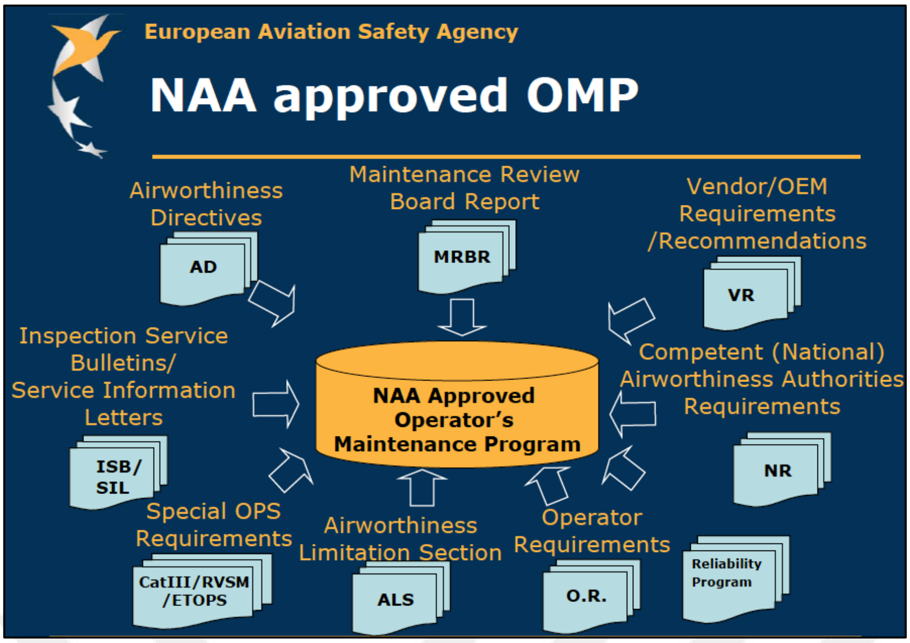


Figure 2.8 : NAA approved OMP, adapted from Robelin (2010).

2.2.5 Maintenance program optimization (equalized vs block)

Eurocontrol (2008) stated that aircraft maintenance tasks are classified with increasing complexity from the simplest ones to the most difficult ones into line/transit, A, B, C and D maintenance. Even though currently maintenance programs are planned according to the Maintenance Steering Group (MSG) 3 task-oriented principle, the letter check classification is still referred in the aviation industry. However, in practice, MRO companies will have different ways in determining which tasks to be carried out and how many crews are needed according to the aircraft types (pp. 2-3). Figure 2.9 shows the typical maintenance checks' classification with increasing in complexity released by Eurocontrol in 2008.

Check	Location	Description	Duration [(a)]
'Line' / 'transit'	At gate	Daily (before first flight or at each stop when in transit). Visual inspection; fluid levels; tyres and brakes; emergency equipment	≈1 hour
'A'	At gate	Routine light maintenance; engine inspection	≈10 hours (whole shift) / overnight
'B'	At gate	If carried out, similar to 'A' check but with different tasks (may occur between consecutive 'A' checks)	≈10 hours to ≈1 day
'C'	Hangar	Structural inspection of airframe, opening access panels; routine and non-routine maintenance; run-in tests	≈3 days to ≈1 week
'D'	Hangar	Major structural inspection of airframe after paint removal; engines, landing gear and flaps removed; instruments, electronic and electrical equipment removed; interior fittings (seats and panels) removed; hydraulic and pneumatic components removed	≈1 month

(a) Duration will depend on whether defects are found that require remedy

Figure 2.9 : Typical maintenance check, adapted from Eurocontrol (2008).

As indicated above in the figure, it can be seen that there is an increase not only in the duration but also in the tasks' difficulty as the type of maintenance goes from line check to the letter checks. Furthermore, besides the maintenance tasks that are already defined in the procedures, there may be extra tasks released by the authorities that need to be performed by the operators. Eurocontrol (2008) stated that, the civil aviation authorities for example Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) might release supplementary or amended tasks through Advisory Circulars (AC) and Airworthiness Directives (AD) (pp. 2-3). Sometimes, depending on their urgencies, the operators will perform these extra tasks overnight or at the same time with the scheduled maintenance checks.

Delmas (2013) stated that in developing aircraft maintenance schedule, factors such as fleet size, fleet age, aircraft utilization, aircraft ground time, airline policies and manpower skills and availability shall be taken into account. There are several different concepts in packaging aircraft maintenance program. There are block concept, equalized concept and on demand concept. In block concept, the maintenance tasks are classified according to their intervals and they are executed before their due dates arrive. Due to classification in accordance with tasks' intervals, the maintenance workload and ground time from one event to another differ remarkably. In equalized concept, the maintenance ground times are defined first and then the tasks are classified in order to fit with them. Therefore, in this concept, the maintenance workload and ground time are steady. In on demand concept, the maintenance intervals are defined first and the tasks are not classified according to them. Next due is managed task by task. In this concept, the selected work package defines the manpower load and maintenance ground time. Figures 2.10, Figure 2.11 and Figure 2.12 illustrated how the three concepts differ from each other.

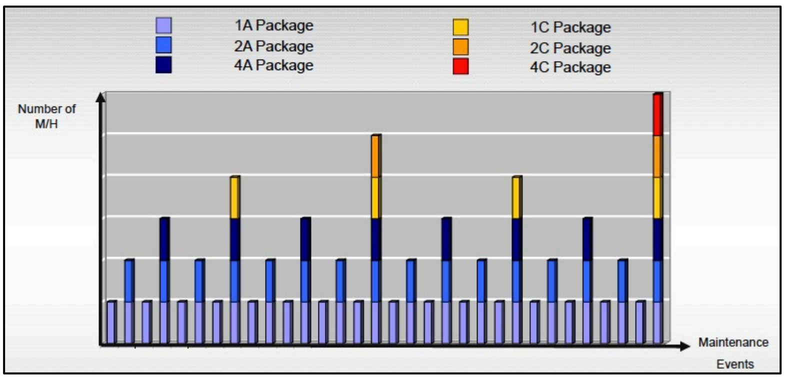


Figure 2.10 : Block concept, adapted from Delmas (2013).

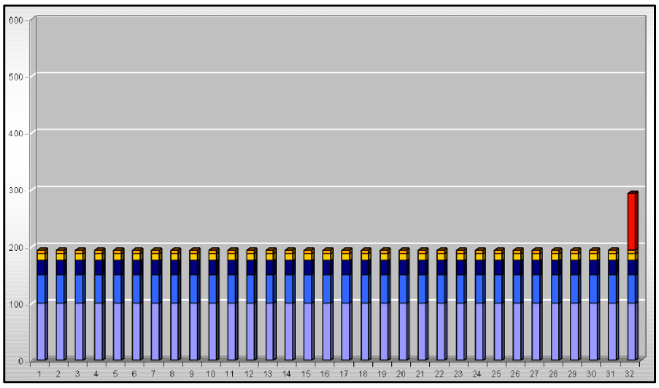


Figure 2.11 : Equalized concept, adapted from Delmas (2013).

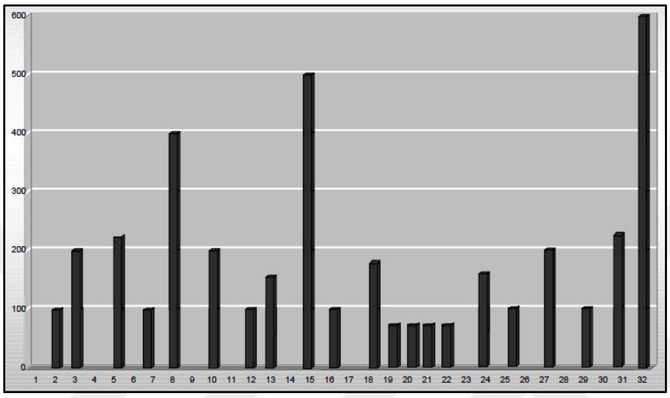


Figure 2.12 : On-demand concept, adapted from Delmas (2013).

3. TYPES OF MAINTENANCE

3.1 Classification Types

Various classifications exist to define aircraft maintenance. Within the context of this study, we will look at those through the maintenance provider perspective. In other words, we select a top to down approach to introduce maintenance elements or segments to better fit into the maintenance services market in real life. This approach will lead to the following list of maintenance types:

- Airframe maintenance
    - Line maintenance
    - Base maintenance
- Component maintenance
    - Heavy components
    - LRU components
- Engine maintenance

This itemized list of maintenance types is essential to study maintenance market, in the light of pricing structure and cost modelling according to such market conditions in real life.

3.1.1 Airframe maintenance

"Airframe maintenance" is the general term used to define scheduled and unscheduled (defect rectification) maintenance actions performed on the aircraft itself. These scheduled maintenance events are performed either on the ramp (line maintenance), at an operation base or in a hangar environment. The maintenance events, which require hangar environment, are also called base maintenance. In the following section, the focus will be on the base maintenance, as the line maintenance is generally performed by the airline itself and the cost structure is based on labor overhead. There are many examples where the line maintenance is also outsourced as well. However, from the cost standpoint, the line maintenance contracts are very straightforward and away from the scope of the dissertation.

Ackert (2012) stated that airframe heavy structural inspections are usually performed each 6-12 years, which rely on the aircraft type. In general, to perform these checks, the aircraft stops to operate for a number of weeks. For each aircraft configuration, MPD records the entire recommended scheduled maintenance task. The scheduled maintenance tasks are classified further into three programs, which are systems & powerplant, zonal inspections and structural inspections. During the system and powerplant inspection, functional and operational checks are performed on airplane systems such as flight controls, pneumatics, electrical power, etc. Zonal inspection program consists of visual checks of electrical wiring, hydraulic tubing, water/waste plumbing, pneumatic ducting, components, fittings, brackets, etc. The objective of this inspection is to evaluate the general condition of connections of all systems and structures located in every zone. Structural inspection program consists of visual check of corrosion, stress corrosion, minor damage and fatigue cracking. For zonal and structural inspections, the exterior paint and the large parts of outer paneling are removed. These are done to expose the airframe, supporting structure and wings throughout the inspections (p. 6). Figure 3.1 shows airframe heavy structural inspection costs, intervals and reserve rates for several aircraft types with full workscope (systems, structures and zonal and material) assumptions.

Aircraft	Check	Phase	Interval	Costs - 2010 $	Rates ($ / Mo)
A320-200	4C / 6Y SI	First-Run	72 Months	$750K - $850K	$10.400 - $11.800
A320-200	8C / 12Y SI	First-Run	144 Months	$850K - $900K	$5,500 - $5,900
A330-300	4C / 6Y SI	First-Run	72 Months	$1.4M - $1.6M	$19,500 - $22,200
A330-300	8C / 12 Y SI	First-Run	144 Months	$1.5M - $1.7M	$10,400 - $11,800
B737-800	C6-C8 Equivalent	First-Run	120 / 144 Mo	$1.3M - $1.5M	$9,000 - $12,500
B747-400	C4 / D-Check	Ageing	72 Months	$4.0M - $4.5M	$55,500 - $62,500
B757-200	S4C	Ageing	72 Months	$1.5M - $1.7M	$22,200 - $23,600
B767-300ER	S4C	Ageing	72 Months	$2.0M - $2.3M	$27,800 - $31,900
B777-300ER	C4 / SI	First-Run	96 Months	$2.5M - $2.8M	$26,000 - $29,100
E190	C4 / SI	First-Run	96 Months	$475K - $575K	$4,900 - $5,900
CRJ-700	HSI	First-Run	96 Months	$425K - $525K	$4,400 - $5,400

Figure 3.1 : Airframe heavy structural inspection costs, intervals and reserve rates, adapted from Ackert (2012).

3.1.2 Engine maintenance

Ackert (2012) stated that engine maintenance involves either separation of pairs of major mating engine flanges or removal/substitution of a disk, hub or spool. Two main elements constitute the engine maintenance. They are Performance Restoration and

Life Limited Part Replacements. The purpose of Performance Restoration task is to reestablish the performance of the engines and keep the engine's direct maintenance cost or cost per flying hour at minimum. Throughout Performance Restoration, the core module is disassembled and airfoils such as rotors and stators are inspected and if necessary repaired or substituted. In Life Limited Part Replacements, some parts that have specific operating life limit should be replaced. These parts are the rotating compressor and turbine hubs, shafts or disks within the engine (p.11). Figure 3.2 shows engine performance restoration costs, intervals and reserve rates for various engine types.

Engine	Thrust	Phase	FL	Time On-Wing (FC)	Costs 2010 $	Rate ($ / FH)
CFM56-5B6/P	23.500	First-Run	1.7	16.000 -17.000	$2.0M - $2.2M	$72- $80
CFM56-5B4/P	27,000	First-Run	2.0	11,500 -12,500	$2.0M - $2.2M	$86 - $96
CFM56-5B3/P	33,000	First-Run	2.0	7,500 – 8,500	$1.8M - $2.2M	$124 - $134
CFM56-7B24/P	24,000	First-Run	1.7	17,000 – 18,000	$2.0M - $2.3M	$70- $78
CFM56-7B26/P	26,300	First-Run	2.0	12,500 – 13,500	$1.8M - $2.2M	$78- $88
CFM56-7B27/P	27,300	First-Run	2.0	10,000 – 12,000	$2.0M - $2.2M	$86 - $96
V2524-A5	24,000	First-Run	1.7	15,000 – 16,000	$1.8M - $2.2M	$72 - $82
V2527-A5	27,000	First-Run	2.0	15,000-11,500	$1.8M - $2.2M	$95 - $105
V2533-A5	33,000	First-Run	2.0	6,500 – 7,500	$1.8M - $2.2M	$135 - $145
Trent 772	71,200	First-Run	6.0	3,500 – 4,000	$3.6M - $4.2M	$185 - $195
PW4068	68,000	First-Run	6.0	3,000 – 3,500	$3.2M - $3.6M	$180 -$190
PW4070	70,000	First-Run	6.0	2,750 – 3,250	$3.5M - $4.0M	$195 - $205
CF6-80E1A4	70,000	First-Run	6.0	3,000 – 3,500	$3.0M - $3.4M	$165 - $175
GE90-115B	115,00	First-Run	8.0	2,250 – 2,750	$4.4M - $4.8M	$250 - $260

Figure 3.2 : Engine performance restoration costs, intervals and reserve rates, adapted from Ackert (2012).

3.1.3 Component maintenance

Definition of an aircraft component falls under the general term "aircraft part" in various sources. A component however, is repaired and overhauled "off-wing" the aircraft. This definition is relevant to this study, as the removed component for maintenance brings aspects of impact to the overall maintenance cost with its implications to the aircraft grounding. There are two types of components present, rotable and repairable. Our focus will be on the rotables, on which there is a serial number present. The economic value and complexity of such components, rotables, pulls them under our scope.

Aircraft commerce (2011) stated that component maintenance involves hard timed, condition-monitored and life limited parts components that throughout base maintenances are scheduled to be removed and inspected. In the scope of this study, the reason for removal concept of a component will be mentioned, hard rime, on-condition or condition monitoring, but will not be examined from the reason of removal standpoint. Rather the economic implications of component maintenance will be evaluated.

Components with redundancy are referred to as condition-monitored and include items such as the servos that move flight control surfaces. Since there are two servos with the same function, one can fail without jeopardizing safety.

Components that are inspected or tested regularly to detect deterioration or failure are referred to as on-condition. For, example, the thickness of a brake disc pack is crucial to its ability to provide sufficient braking power. The thickness is monitored by calipers or a thickness indication pin, and the brake is removed for repair when the thickness is still more than a minimum specified limit.

Hard-time components are those that are repaired or discarded at regular intervals, and are included as part of the items in maintenance checks. Examples of hard-time components are safety-related items, such as life jackets and gas bottles that inflate emergency evacuation slides.

The adoption of a maintenance steering group (MSG) 3 system has changed the concept of the maintenance for many rotable and repairable components. They are now ‘on-condition’ or ‘condition monitored’, rather than hard-timed, which has altered the predictability of component maintenance and made its management more complex. It is now therefore harder to estimate their related maintenance and repair costs.

While the definition of components and their categories seem irrelevant to their maintenance costs, it is however important to know such classification to analyze the real life maintenance applications through MRO contracts. From this standpoint, two terms have to be introduced, LRU and heavy component.

Many on-condition and condition monitored components are accessible and can be removed and replaced in a short period during line-and-ramp checks after failing at random during operation. These are line replaceable units (LRUs). LRUs are also items that are more critical to the continued operation of the aircraft in the event of failure, such as avionics. Stocks of these are kept at the main operating base and at some outstations across a carrier’s route network. Airlines can own a complete inventory of LRUs themselves, or be supplied by a third-party supplier, in which case airlines are usually provided with a leased homebase stock of the items that are the most critical and have the highest failure rate. They then pay a pool access fee to the provider to supply the airline with any required component within an agreed period. The supplier also repairs and manages the stock of parts for the airline customer. The type of contract is known of power by the hour, PBH agreement.

Heavy component is a term to describe some set of components, which includes wheels and brakes; landing gear; thrust reversers; and the auxiliary power unit (APU). Although wheels and brakes can be removed relatively easily, these items are grouped separately because they are not condition monitored, several hours' downtime are usually required to remove and replace them, and they are not inspected or tested during base checks. Wheels and brakes, thrust reversers, and the APU are on condition components. The landing gear is a hard-time component.

Heavy component definition is important, as they are not covered in the scope of a typical total component support PBH agreement mentioned earlier, as seen in the table below. Individual PBH agreements can be offered by providers on heavy components, but not as a part of a full component repair scheme. This classification is crucial and will be used often in this study, as one great scale to estimate and compare maintenance cost of an aircraft. Aircraft component classification according to PBH Agreements is given in Table 3.1.

An airline's conventional component maintenance cost is composed of two elements: Repairs and exchanges. To ensure aircraft availability as the highest possible, components that require maintenance are replaced from the component stock and core units are sent for repair. The aim is to dispatch the aircraft as soon as possible. The possible scenarios for component maintenance are given in Table 3.2.

As the fleets grow, airlines tend to enter into pool agreements with component services providers, especially for LRU components. Pool agreements bring airlines a better control and forecast of component maintenance costs and some reduction in such cost. An airline with more than 10 A320 family aircraft in operation has demonstrated a make and buy study for component pool agreement and achieved some 40 percent reduction in overall component related maintenance costs, as seen in Appendix A.

Table 3.1 : A typical list of excluded components from a PBH agreement.

ATA Chapter	Description	Exclusions
21	Air conditioning	
22	Auto flight	
23	Communications	In-flight entertainment system / equipment, boom sets, megaphones, handsets, monitors, directors, reproducers
24	Electrical power	Main batteries, emergency power supplies
25	Equipment and furnishings	All except cockpit seats, emergency locator transmitter
26	Fire protection	
27	Flight controls	Flight control surfaces
28	Fuel	
29	Hydraulics	
30	Ice and rain protection	
31	Indicating / recording systems	
32	Landing gear	Wheels, tires, brakes, landing gear assemblies, landing gear overhaul parts (i.e. shock absorber), nose and main gear doors.
33	Lights	All filaments, florescent tubes and batteries (not including control equipment)
34	Navigation	
36	Pneumatics	
38	Water / waste	Sinks, basins and toilet units
49	APU	Bare APU
52	Doors	Door assemblies (not including actuators, motors, dampers and snubbers)
53	Fuselage	
54	Pylons	
55	Stabilizers	
56	Windows	All except cockpit windows
71-80	Engine / power plant	Bare engine, cowls, thrust reverser, nacelle items, aft nozzle nozzle and plug, fan blades, engine overhaul parts
21-80	All chapters	Components which are not considered LRU's (rods, harnesses, ducts, trays, tracks, brackets, doors, tanks, cranks, struts, latches, locks, swivel, hinges)
21-80	All chapters	Components that are considered as subassemblies to pool components. Components that are considered as next higher assemblies to pool components.
21-80	All chapters	All life limited parts
21-80	All chapters	Expendables

Table 3.2 : Typical component maintenance solutions used in the market.

Cause of removal / Type of action	Scheduled	Unscheduled	AOG
Buy the part	Not applicable	Sometimes needed if part is not accessible within an accessed pool	Not unlikely, if exchange option not available
Use the stock	Not necessary if replacement planned during heavy check	Stock is vital, otherwise the status will become AOG	Primarily checked, but if not found in stock, other methods tried
Have it repaired	If there is no replacement unit, can cause grounding	Mostly no time for repair lead time	Repair is not an option.
Exchange	Might be necessary if part is not available	If exchange is available, it can be used.	If exchange is available, it can be used
Pool access	A solution for all scheduled, unscheduled and AOG cases		

3.2 PBH as a Contract Type

Component maintenance depicted as one of the maintenance segments, PBH term is pronounced as its popular contract type. Power by the Hour agreements are often referred to contracts with fee charging mechanisms based on flight hours and flight cycles accumulated. A certain scope of work is selected and undertaken by the service provider during a predetermined period, which spans multiple years, if not decades.

At early years of a PBH contract, the service provider undertakes less amount of work as the younger airplanes, systems and components demonstrate higher reliability. High reliability means less failure and maintenance requirement. From another perspective, it is reasonable to expect less costly PBH agreements for younger airplanes. Maintenance service providers account the probability of higher maintenance need in older airplanes and adjust the PBH fees accordingly. Few PBH contracts exercise a constant fee per every flight hour or cycle accumulated. The economic impact of selection between a stable rate and adjusted rate implicate a great impact to the life cycle cost of component maintenance.

The failure rates and reliability of aircraft components will vary. Modifications could be utilized to improve their reliabilities. However, an airline's real maintenance cost will be mainly shaped by the maintenance contract type (Figure 3.3) and even the contractual clauses negotiated between the airline and the service provider.

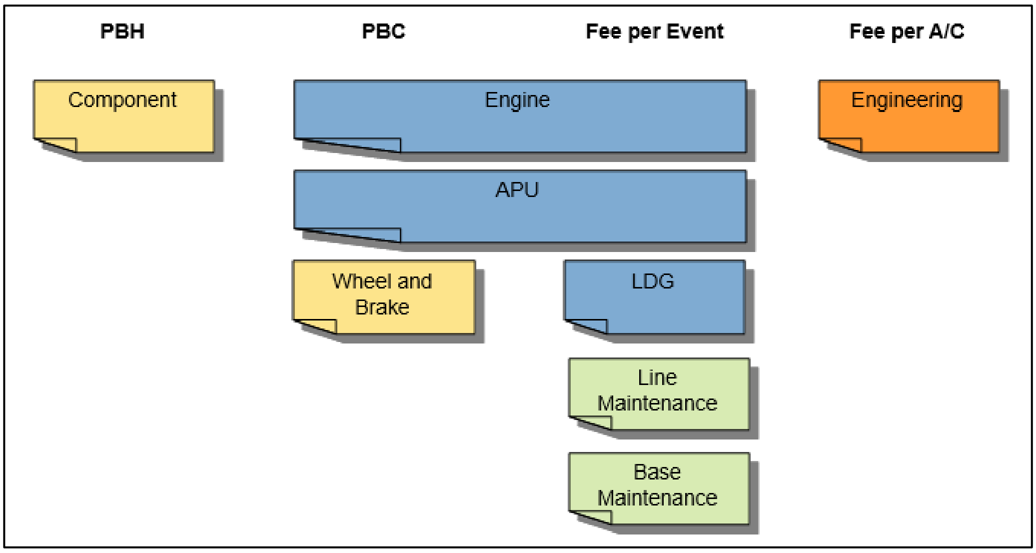


Figure 3.3 : Typical contract types per maintenance segments.

The power by the hour type of contracts are firm fixed price contracts, which are risky for the service provider in terms of budget overrun. On the contrary, the airline mitigates the risk by choosing PBH contract type from its standpoint. Equal payment over a term is also another key factor why airlines choose PBH contracts, as a method of proper estimation of maintenance costs. Airlines having high turnover, low margins, seasonality affect to be considered as well, foreseeable costs play a more important role than the amount of the costs for their financial health.

PBH is a good example of firm fixed price contracts, where the seller undertakes the risk of under budgeting the cost of maintenance for a long period. Therefore, any service provider shall undertake such risks of budget overrun during estimating and contract formation. From an airline perspective, it would not be surprise to expect service provider to add a buffer revenue budget to their estimations.

PBH contracts are financial and legal playgrounds of negotiations to undertake the risk for a substantial period. Selecting a component maintenance contract type is the airline's highly important decision point. Source selection and negotiation of the terms might be more vital for the survivability of the company and pursuing the opportunities of cost reduction. Risk index of contract types are given in Figure 3.4.

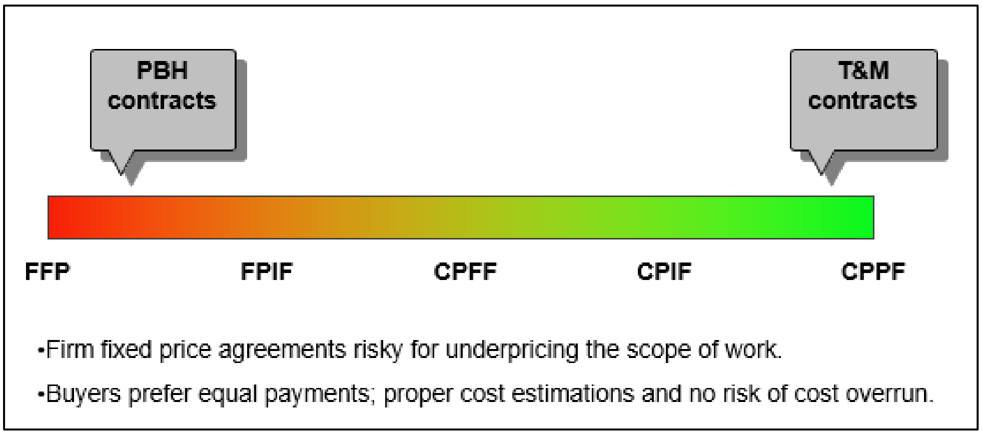


Figure 3.4 : The risk positioning of PBH agreements.

3.3 Base Maintenance in Detail

As indicated above maintenance programs are categorized into letter checks, which are A, B, C and D. As Sriram and Haghani (2001) asserted, maintenance programs consists of a sequence of checks with an increase in complexity (p. 30). Clarke et al., as cited in Sriram and Haghani (2001) stated that FAA requires four significant types of maintenance checks, which vary in the areas maintained, duration and the rate of occurrence. They are A check, B check, C check and D check. A check contains investigation of the entire vital systems for example engines, landing gear and control surfaces. It takes place every 65-flight hour or once a week. B check contains a complete investigation with regard to every detail, together with lubricating all the moving parts for example the ailerons and horizontal stabilizers. It takes place every 300-600-flight hour. Finally, C and D check are the most crucial checks. To complete the tasks in these checks, the aircraft needs to stop to operate for almost one month at a time. C and D check take place every one to four years respectively (p. 31). As stated in Figure 2.1, Eurocontrol (2008) described that C check contains the scheduled and unscheduled maintenance, run in tests, access panels opening and also structural inspection of the aircraft body. While D check, the heaviest check with the longest maintenance duration, contains the most crucial investigation on the aircraft body after paint removal and its engines. It comprises also the removal of landing gears and flaps, electric and electronic instruments and equipments, hydraulic and pneumatic components and interior furniture (pp. 3-4). On account of all the given facts, it can be said that letter checks maintenances vary on the types of tasks to be performed and the duration needed to complete the tasks. In addition to the duration and type of the task, the frequency or interval of these letter checks also varies. The typical intervals of letter maintenance checks of twelve aircraft types released by Eurocontrol in 2008 are shown in Figure 3.5.

Aircraft	'A' Check	'B' Check	'C' Check	'D' Check
B737-300	275 FH	825 FH	18 months	48 months
B737-400	275 FH	825 FH	18 months	48 months
B737-500	275 FH	825 FH	18 months	48 months
B737-800	500 FH	n/a	4000-6000 FH	96-144 months
B757-200	500-600 FH	n/a	18 months / 6000 FH / 3000 FC	72 months
B767-300ER	600 FH	n/a	18 months / 6000 FH	72 months
B747-400	600 FH	n/a	18 months / 7500 FH	72 months
A319	600 FH	n/a	18-20 months / 6000 FH / 3000 FC	72 months
A320	600 FH	n/a	18-20 months / 6000 FH / 3000 FC	72 months
A321	600 FH	n/a	18-20 months / 6000 FH / 3000 FC	72 months
ATR42-300	300-500 FH	n/a	3000-4000 FH	96 months
ATR72-200	300-500 FH	n/a	3000-4000 FH	96 months

Multiple sources, including: *Aircraft Technology Engineering & Maintenance*, *Aircraft Commerce* and *Boeing AERO*.

Figure 3.5 : Maintenance check intervals adapted from Eurocontrol (2008).

In view of the information given in the figure, it can be seen that the rate of occurrence of A and B check is determined by the number of flight hours (FH), while the interval of C check depends on FH, flight cycle (FC) and calendar months. On the other hand, the interval of D check depends on the number of calendar months. As Sriram and Haghani (2001) stated, FH and FC (number of take-off and landing) determine the frequency of the checks (p. 30). Eurocontrol (2008) also asserted that FH, FC and calendar months decide the period of the maintenance checks. Between the three of them, which one comes first will determine the need for maintenance of the aircraft. For an aircraft, which is used for long-haul routes, the check will be mostly determined by flight hours reached, ignoring the flight cycles and calendar month. For an aircraft, which operates frequently for short haul routes, the number of flight cycles will mostly determine its maintenance checks. On the other hand, if the aircraft is not used frequently, thus the number of calendar month will determine its maintenance checks ignoring its flight hours and flight cycles (p. 4).

Base maintenance checks usually contain several elements. Aircraft commerce (2011) stated that these elements are routine inspections, non-routine rectifications, component changes, ADs, SBs and EOs, cosmetic maintenance, and stripping and repainting. MPD and maintenance program job cards set up the routine inspections.

However, there will be other tasks that are considered by the operators as routine. They are for example out-of-phase (OOP) tasks, operator specific items, regular interior maintenance, smaller checks that are performed throughout the base checks, and replacement of large components such as engines, landing gear, thrust reversers and auxiliary power unit (APU). During routine inspections, some defects that need reparations may appear. The processes of rectifying these defects are called non-routine rectifications. Because of degradation of components and parts, non-routine rectifications are expected to rise with age. Nevertheless, in heavier inspections, as more accesses or structures are opened, the non-routine defects also believed to increase.

Component changes involve hard timed, condition-monitored and life limited parts components that throughout base maintenances are scheduled to be removed and inspected. Regarding ADs, SBs and EOs, the labor’s quantity that is required to perform these tasks varies. ADs and SBs can be affected by aircraft configuration and concern only particular aircraft line numbers. However, the operators apply SBs and the modifications related to them at their preferences. EOs consists of major modifications that differ not only between different fleets but also within each fleet. Some modifications related to EO are for example interior refurbishment, installation of new avionics, in-flight entertainment systems or seats.

As opposed to mandatory maintenance, supplementary of base checks are cosmetic maintenances. Some examples of cosmetic maintenances are interior cleaning, and interior refurbishment, which consists of exterior painting, replacement of seat belts, seat covers, light bulbs, panels and bulkheads. Furthermore, aircraft stripping and repainting is another element of cosmetic maintenance. In the past, this was performed in conjunction with D check. However, recently, many aircraft are stripped and repainted outside heavy maintenance checks. Some operators even repaint their aircraft once every five to six years.

4. AIRCRAFT MAINTENANCE COST MODEL

4.1 Literature Review

Eurocontrol (2008) described direct maintenance cost together with maintenance overhead cost as unit maintenance cost. It considered that unit maintenance cost represents 15% of the Block Hour Direct Operating Cost (BHDOC). The unit maintenance costs for twelve different aircraft in 2002 and 2008 are presented (pp. 6, 14). Figure 4.1 shows the unit maintenance costs of the twelve aircraft in 2002 (p. 6) and Figure 4.2 shows the unit maintenance cost for the same aircraft in 2008 (p. 14).

Aircraft	BHDOC			Maintenance proportion	Unit maintenance cost
	Low	Base	High		Base
B737-300	2 540	**4 950**	6 250	x15% =	**743**
B737-400	2 950	**5 280**	6 530		**792**
B737-500	2 540	**4 550**	5 630		**683**
B737-800	2 130	**4 040**	5 950		**606**
B757-200	3 330	**5 960**	7 380		**894**
B767-300ER[a]	4 090	**7 590**	11 080		**1 139**
B747-400[a]	8 430	**10 730**	11 970		**1 610**
A319	2 670	**5 240**	6 630		**786**
A320	2 720	**4 790**	6 860		**719**
A321	3 180	**5 690**	7 040		**854**
ATR42-300	1 400	**2 510**	3 100		**377**
ATR72-200	1 730	**3 100**	3 830		**465**

(a) Widebodies

All costs are Euros per block-hour (2002) and include burden

Figure 4.1 : Maintenance costs (include burden) per block-hour in 2002, adapted from Eurocontrol (2008).

Considering all these facts, comparing the base unit maintenance cost in 2002 and 2008, it is clear that there is a decrease in the cost values in 2008 compared with those in 2002, except for B757-200. However, since the unit maintenance cost values in the years between 2002 and 2008 are not presented, therefore it is not possible to determine exactly the cost trend. On the other hand, IATA's MCTF FY13 data shows an increase in maintenance cost for four years from 2010-2014 with the cost details from the years in between.

Aircraft	Unit maintenance costs		
	Low	Base	High
B737-300	690	740	900
B737-400	710	760	930
B737-500	570	620	770
B737-800	500	540	670
B757-200	840	900	1 090
B767-300ER [a]	930	970	1 280
B747-400 [a]	1 440	1 500	1 930
A319	580	630	800
A320	570	620	770
A321	660	720	910
ATR42-300	350	370	380
ATR72-200	430	460	460

(a) Widebody

All costs are Euros per block-hour (2008) and include burden

Figure 4.2 : Maintenance costs (include burden) per block-hour in 2008, adapted from Eurocontrol (2008).

The values displayed by Eurocontrol show direct maintenance costs per block hour for twelve different aircraft types. However, those values are already the mixture of line, base, component and engine maintenance cost. Therefore, it is not possible for example, to derive the aircraft's base maintenance unit cost only. On the other hand, IATA's MCTF FY2013 data presents the evolution of direct maintenance costs of 26 airlines with different fleets consisting of different aircraft types. IATA presented the maintenance cost per flight hour of different segment. Therefore, it is possible to observe the evolution of line, base, engine and component maintenance cost. However, the maintenance cost for a specific aircraft type is not stated.

4.2 Maintenance Cost Elements

Papakostas et al. (2010) formulated the maintenance cost per task per component related to the cost elements. The formula presented is shown in Figure 4.3.

$$\begin{aligned}\text{Maintenance cost per task per component} = \Big(\big(&\text{Equipment rate} + \text{Labour rate} + \text{Overhead rate}\big) \\ &\times \text{Operating time per component}\Big) \\ &+ \text{Component procurement costs}\end{aligned}$$

Figure 4.3 : Maintenance cost per task per component, adapted from Papakostas et al. (2010).

As indicated above in the figure, it can be argued that maintenance cost per task per component depends on the total rate of the equipment, labor and overhead, the duration required to complete that maintenance task and the costs needed to obtain and transport the component. However, in this dissertation, the maintenance cost per task per component is not going to be taken into account in the analysis. The type of maintenance cost that is going to be used in the analysis is the aircraft total maintenance cost per flight hour as presented by Eurocontrol (2008) and IATA (2014). This includes already all the maintenance cost per task per component that is needed to complete the maintenance check.

As the elements of the maintenance cost are already discussed above, those elements can be classified further into direct maintenance cost and indirect maintenance cost. Dupuy et al. (2011) claimed that airline should find an effective maintenance procedure that comprises not only the direct maintenance cost but also indirect maintenance cost to reduce the total maintenance cost (p. 2). Taking the cost elements in Figure 3.5 as an example, the equipment, labor and component procurement are examples of direct maintenance cost. These are the cost elements that are directly involved during maintenance process. On the other hand, the overhead cost is an example of indirect maintenance cost. Overhead cost is not directly involved during maintenance process but the operator still needs to pay for it. The summation of direct cost and indirect cost is what is known as the total maintenance cost.

However, to be able to classify all the direct and indirect maintenance cost elements, we will start by listing all the elements of airline’s total costs. In Figure 4.4, the pie chart of the distribution of total airline cost as adapted from IATA Airline Cost Management Group (ACMG) (2014) is shown. Table 4.1 is the tabulated data from the same source.

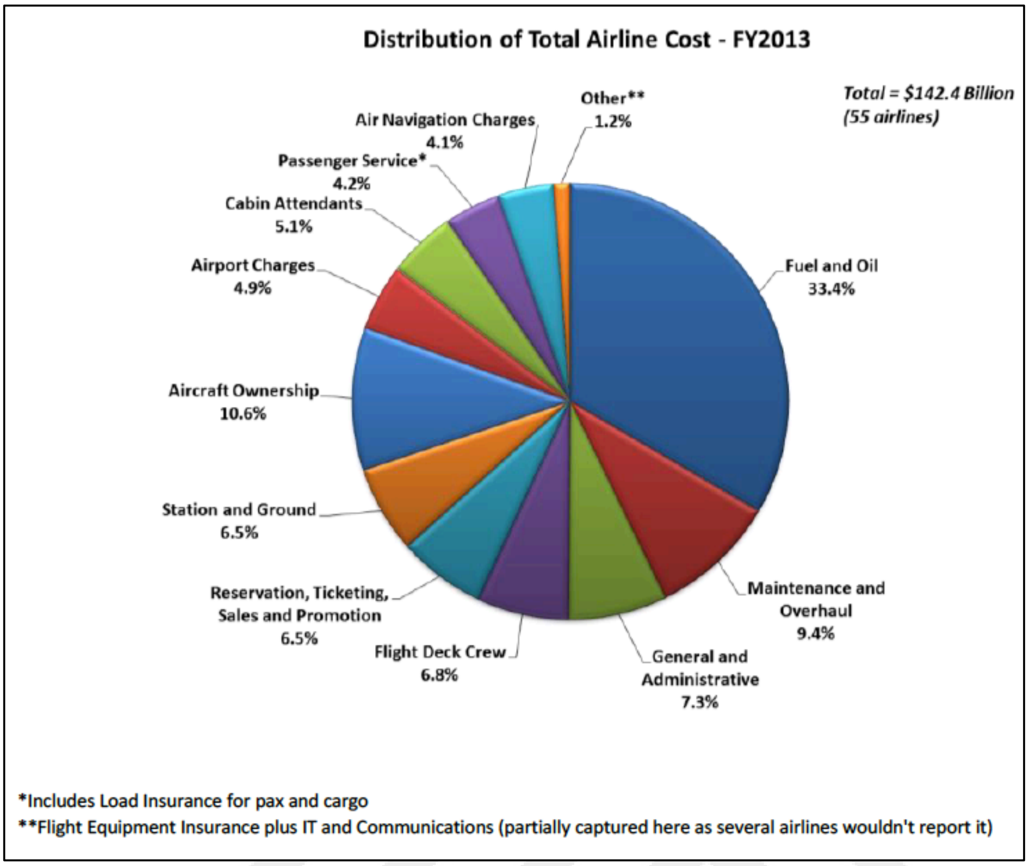


Figure 4.4 : Distribution of total airline cost, adapted from IATA ACMG (2014).

Table 4.1 : Total airline cost elements, adapted from IATA ACMG (2014).

Cost Element	Percentage	Cost Type
Fuel and Oil	33.4%	None
Aircraft Ownership	10.6%	Indirect
Maintenance and Overhaul	9.4%	Direct
General and Administrative	7.3%	Indirect
Flight Deck Crew	6.8%	Indirect
Station and Ground	6.5%	Direct
Reservation, Ticketing, Sales and Promotion	6.5%	Indirect
Cabin Attendants	5.1%	Indirect
Airport Charges	4.9%	None
Passenger Service	4.2%	None
Air Navigation Charges	4.1%	None
Other	1.2%	Indirect

Taking into account the information given in Table 4.1, it can be said that fuel and oil (33.4 %) takes the greatest percentage of the total airline cost. It is followed by aircraft ownership cost (10.6%) and maintenance and overhaul cost (9.4%).

Subsequently, all the elements of the total airline cost together with their percentage in Figure 4.4 are tabulated further in Table 4.1 with the cost type classification. The cost type column will be filled either by direct, indirect or none. The cost elements that are directly required for the maintenance process will be noted as direct. While, the cost elements that do not directly involved during maintenance process but still appear as costs to the operator, will be noted as indirect. Furthermore, if the cost elements do not appear as costs to the operator during maintenance, it will be noted as none.

In view of the information given in the table, it can be claimed that direct maintenance cost consists of maintenance and overhaul cost and station and ground cost. While indirect maintenance cost elements are aircraft ownership, general and administrative, flight deck crew, reservation, ticketing, sales and promotion, cabin attendants and other. Additionally, fuel and oil, airport charges, passenger service and air navigation charges are the cost elements that do not appear during maintenance. These costs will only appear if the aircraft flies.

Dupuy, Wesely, and Jenkins (2011) stated that direct maintenance cost accounts for 11% of the total operating cost of an aircraft. This cost is composed of maintenance crews, materials and reparation cost (p. 1). Kumar et al. (2000) stated that the cost of maintenance resources compose the direct maintenance cost. Figure 4.3 shows the equation of the direct maintenance cost (CMT) where Cs = cost of spare parts, Cm = cost of material, Cp = cost of personnel, Cte = cost of tools and support equipment, Cf = cost of facilities and Cd = cost of technical data (p. 198).

$$\boxed{CMT = C_s + C_m + C_p + C_{te} + C_f + C_d}$$

Figure 4.5 : Direct maintenance cost, adapted from Kumar et al. (2000).

In view of this information, it can be claimed that direct maintenance cost is the cost that is directly related to the maintenance activities. They are materials, equipment and labors. However, it is not necessary to present the cost of elements that are similar to each other, for example spare parts and materials (Cs and Cm), as it is done in the formula presented by Kumar et al. (2000) in Figure 4.5.

Indirect maintenance cost is a common term in many industries. Even though it does not contribute directly during the process, in this case the aircraft maintenance process, it is needed to keep the aviation industry running. Taking into account the information given in Table 4.1, it can be seen that the elements of indirect maintenance cost are aircraft ownership, general and administrative, flight deck crew, reservation, ticketing, sales and promotion, cabin attendants and other. These are the cost elements that whether the aircraft flies or not, will always cost the operator. Moreover, Kumar et al. (2000) stated that indirect cost of maintenance task has two components: cost of revenue loss as a result of the system is unavailable and the cost of management and administration personnel. Overhead cost is one element of indirect maintenance cost. Examples of overhead cost are cost of facilities, electricity, telephone, IT, training, heating, taxes, and insurance (p. 198). Papakostas et al. (2010) defined overhead as indispensable cost even though it does not directly connected with the maintenance programs (p. 608). Friend as cited in Eurocontrol (2008) stated that costs that are not related directly to the maintenance activities such as managers; staffs and administrators costs for maintenance scheduling are classified as maintenance overhead or maintenance burden (p. 5). Therefore, in view of the opinion of Kumar et al. (2000) and Friend as cited in Eurocontrol (2008), it is assumed that general and administrative, flight deck crew, reservation, ticketing, sales and promotion, cabin attendants and other element costs are combined as overhead cost. Overhead cost is also included in the unit maintenance cost data given by IATA (2014) and Eurocontrol (2008). Nevertheless, the aircraft ownership cost is not covered in overhead cost.

Kumar et al. (2000) stated that indirect cost of maintenance tasks have the possibility of being higher than direct maintenance cost. Therefore, it is important to pay attention to them (p. 198). In this study, all the cost elements that are part of indirect maintenance cost but are not included in overhead will be put together and described as downtime cost. One of its element that has been mentioned before is aircraft ownership cost. Moreover, as already asserted by Kumar et al. (2000) and Saranga (2004), one element of downtime cost is cost of revenue loss. Revenue loss happened due to the fact that aircraft stops to operate during maintenance period. This means that aircraft ceases to generate revenues for the operator. In the next chapter, in addition to the cost of revenue loss and aircraft ownership cost, one another downtime cost element will be discussed.

4.3 Maintenance Cost Model

4.3.1 A320 maintenance model

As shown in Figure 4.6, 4.7 and 4.8, Aircraft Commerce (2006) discussed that A320 family is a short / medium range narrow body aircraft that started its first delivery in 1988. Airframe maintenance can be divided into line maintenance, A checks and base check maintenance. Base maintenance checks will be comprised of routine inspections and rectification of defects that have arisen during operation. They contain service bulletins (SBs), which are sometimes driven by airworthiness directives (ADs), applied as engineering orders (EOs) and accomplished as inspections or modifications. There are also interior work in the cabin and in-flight entertainment (IFE) system, stripping and repainting. The MPD has had several revisions since the A320 entered service in 1988. The MPD is revised when the MRB or ALS is updated. The MPD is also periodically revised and when new SBs, ADs, service information letters, or operator information telexes are issued.

Despite the fundamental change in the way A320 operators can plan maintenance checks, many operators still refer to checks as generic ‘A’ and ‘C’ checks, and also have target intervals for the former A, C and structural checks. The checks have similar groups of tasks in many cases. The A check target interval is 750FH, 750FC and 120 days in the MPD issued in 2009. The check is performed when one of these parameters is reached first. C check tasks and groups are given in Figure 4.6 and Figure 4.7.

C check task groups	Task group interval
1C	15 months
2C	30 months
3C	45 months
4C	60 months
S1 structural tasks	60 months
5C	75 months
6C	90 months
7C	105 months
8C	120 months
S2 structural tasks	120 months

Figure 4.6 : C check task groups of A320, adapted from Aircraft Commerce (2006).

Normally, the line maintenance programs have pre-flight (PF), transit (TR), daily and weekly checks. These checks include routine inspections from the MPD. They are also used to clear technical defects, which arise during the operations. The total annual cost for these line and- ramp checks will be $595,000, equal to a rate of $212.

Arrangement of Base checks - TAP Maintenance & Engineering			
Check name	Number of tasks	Task groups	Check interval
C1	135	1C	20 months/6,000FH/4,500FC
C2	177	1C + 2C	40 months/12,000FH/9,000FC
C3	139	1C + 3C	60 months/18,000FH/13,500FC
C4	526	1C+ 2C + 4C + 6-year	72 months/24,000FH/18,000FC
C5	137	1C + 5C	100 months/30,000FH/22,500FC
C6	181	1C + 2C + 3C + 6C	120 months/36,000FH/27,000FC
C7	135	1C	140 months/42,000FH/31,500FC
C8	852	1C + 2C + 4C + 8C + 6-year + 12-year	144 months/48,000FH/36,000FC

Figure 4.7 : A320's C check arrangement of base checks, adapted from Aircraft Commerce (2006).

The total routine MH for the A checks are estimated as 95MH for the A1 and A3 checks, 162MH for the A2, and 210MH for the A4. The non-routine ratios for A checks are low, and range from 0.25 for the lower checks to 0.35 for the largest A4 check. The total labor for the four A checks will be about 1,600MH, while the cost of materials, consumables and parts will be $35,000-40,000. Using a generic labor rate of $70 per MH, total cost of labor and material inputs will be $150,000. While the MPD interval for the A4 check is 2,800FH, the actual interval achieved for the cycle is likely to be close to 2,000FH, so the reserve for the A checks will be $75 per FH.

The C check interval was set at 7,500FH, 5,000FC and 24 months in the 16th revision of the MRB, which is published in 2011. The S1 and S2 groups of tasks now have intervals of 72 and 144 months. Component changes, ADs, SBs and EOs, interior cleaning, interior refurbishment, and stripping and repainting add 15,000-16,000MH to the basic requirement of routine inspections and non-routine rectifications for the eight checks in the cycle. The total MH for the first base check cycle can therefore be up to 55,000MH. The total allowance for materials and consumables for the first base check cycle will be $700,000-750,000. An allowance also has to be made for repairing some of the rotables removed during checks because of inspections: $50,000 for the first C4/S1 check and $100,000 for the first C8/S2 check. The cost of materials and parts used for the repair, refurbishment and replacement of cabin items is $370,000. Finally, $50,000-60,000 would be used for the two repaints during the cycle. The overall cost of materials, parts and consumables used in the first base check cycle would be \$1.25 million. At \$50 per MH, the total cost of labor for the eight checks in the first base cycle will be \$2.75 million. The cost of materials and all parts will take the total to \$4.0 million. The standard interval during the first base check cycle is 15 months. Given that typical interval utilization is about 85%, the actual interval is assumed 13 months. The total interval for the check is therefore 104 months. At an aircraft utilization of 2,750FH per year, the cost of the eight checks is equal to a reserve of \$128 per FH (Figure 4.8).

DIRECT MAINTENANCE COSTS FOR A319/A320/A321

Maintenance Item	Cycle cost \$	Cycle interval	Cost per FC-\$	Cost per FH-\$
Line & ramp checks	595,000	2,800		212
A check	77,000	2,800		28
Base checks	3,500,000	26,000		128
Heavy components:			180	120
LRU component support				180
Total airframe & component maintenance				**635-700***
*** ±5% variation about \$668 per FH for A319 and A321**				
Engine maintenance:				
2 X CFM56-5B5/-5B6 (A319)				314-352
2X CFM56-5B4 (A320)				314-352
2X CFM56-5B1/-5B2/-5B3 (A321)				430-490
2 X V.2522/24-A5 (A319)				360
2 X V.2527-A5 (A320)				380
2 X V.2530/33-A5 (A321)				460
Total direct maintenance costs:				
A319 (CFM56-5B5/-5B6)				950-987
A320 (CFM56-5B4)				982-1,020
A321 (CFM56-5B1/-5B2/-5B3)				1,130-1,190
A319 (V.2522/24-A5)				995
A320 (V.2527-A5)				1,048
A321 (V.2530/33-A5)				1,160
Annual utilisation:				
2,800FH				
1,830FC				
FH:FC ratio of 1.5:1.0				

Figure 4.8 : Direct maintenance costs for A319/A320/A321, adapted from Aircraft Commerce (2006).

Heavy components definition cover four elements, which are wheels, tires and brakes; landing gears; thrust reversers; and the auxiliary power unit (APU). These are also called as ‘off-aircraft components’, because they have followed by separate maintenance programs. The maintenance of this group gives total of \$180 per FC for all heavy components, and equals \$120 per FH for the aircraft operated at an FC ratio of 1.5FH. Some of A320's rotable and repairable components are followed on-condition. While some may of them be tested and replaced during base checks, most of them can be removed from the aircraft relatively easily during line maintenance events. This results in an overall cost of \$170- 180 per FH.

For CFM56-5B type engine, shop visit and LLP reserves shall be considered for the FH rate. The lower-rated engines on the A319 and A320 will have a reserve of \$120-126 per EFH for the first engine overhaul. Maintenance reserves (costs) are changing between \$157 and \$176 per EFH for the second and third overhauls. On the other hand, for V.2500-A5 type engine, a performance restoration at the hot section will require 3,500-3,750MH, about \$100,000 for sub-contract repairs and \$450,000-475,000 in consumable material. Considering a labor rate of \$70 would lead the total cost of this shop visit to \$795,000- 840,000. This brings a reserve rate of \$53-56 when reflected until the first shop visit, which is at of 15,000 EFH. Adding the LLP reserves, total cost for engine maintenance happens to become \$126- 130 per EFH for these type of engines until their first shop visit.

4.3.2 B737 maintenance model

Aircraft Commerce (2010) discussed that the 737 New Generation (NG) was launched in late 1993, with an order of over 6500 in 20 years, making the 737NG the most successful of 737 families and even the entire commercial narrow body aircraft. There are four 737NG variants of increasing size, starting with the -600 and followed by the -700, -800 and -900. The 737-600 competes closest with the A318, the -700 with the A319, the -800 with the A320 and the -900 with the A321.

The line maintenance program utilized by majority of the airlines for the 737NG could be taken as standard for most aircraft types. Flight crew performs the PF and TR checks with a visual inspection and they are performed in about 30 minutes. This accumulates a total annual labor of 4,800MH. When the same labor rate, which is \$70, is used, the dollar value equivalent becomes \$335,000. The cost of materials will be between \$10,000-15,000. The total cost, which then becomes \$350,000, is equivalent to a rate of \$110 per FH.

Figure 4.9 outlines maintenance check tasks and grouping in 737NG type.

POSSIBLE TASK GROUPING OF 737NG BASE CHECK TASKS

Interval parameter	FH	FC	FC/ time	Time	TOTAL
Task group					
1C	157	1	156	58	372
2C	45	28	6	12	91
3C	3		79	18	100
4C	23	4	73	7	107
5C	8	1	30	20	59
6C		5	20	11	36
7C					
8C		7			7
Total	**235**	**46**	**364**	**126**	**772**

1C interval = 6,000FH, 3,000FC & 24 months

POSSIBLE 737NG BASE CHECK TASK GROUPING

Base check number	C1	C2	C3	C4	C5	C6	C7	C8
Task group								
1C	372	372	372	372	372	372	372	372
2C		91		91		91		91
3C			100			100		
4C				107				107
5C					59			
6C						36		
8C								7
TOTAL	**372**	**463**	**472**	**570**	**431**	**599**	**372**	**577**

Figure 4.9 : Possible task grouping of 737NG Base checks, adapted from Aircraft Commerce (2010).

In B737, operators have the flexibility to choose different intervals for A checks and package tasks in different variations with the same interval. 600FH has been taken as the A check interval to analyze 737NG's maintenance costs. The maintenance tasks falling between weekly and A checks are accounted. Total cost of these 10 checks will then become $165,000. In this case, 85% of the total interval will be utilized which will lead to 5,100FH. A check reserves then become $32 per FH.

If 6,000FH, 3000FC and 24-month interval periods are used for analysis, inspection tasks can be grouped into block checks. In the block check packaging, the highest number of task cards will be at C4, C6 and C8 checks. The total flight hour reserves for base maintenance events, which include stripping and repainting and interior refurbishment is $100-105 per FH.

The total cost of heavy components is $254 per FC, which is equal to $130 per FH when the aircraft is operated at a 1.95 FH to FC utilization. After the heavy components, rotable components can be considered as one group. Few of these components are traced with a hard-time. Therefore, most of them will be replaced during the letter checks. The remaining components are traced by on-condition and condition-monitored programs. These will be replaced within random periods and generally at line maintenance checks. The maintenance costs for rotable components are accounted with $235-255 per FH. These rates are seen in Figure 4.10.

DIRECT MAINTENANCE COSTS FOR 737NG FAMILY

Maintenance Item	Cycle cost-$	Cycle interval	Cost per FC-$	Cost per FH-$
Line & ramp checks	350,000	Annual		110
A check	165,000	5,100FH		32
Base checks	25 million	39,000FH		65-70
Stripping & repainting	85,000	16,800		5
Interior refurbishment				28
Heavy components			254	130
LRU component support				235-255
Total airframe & component maintenance				**605-630**
Engine maintenance:				
CFM56-7B20/22:	2 X $152-162 per EFH			304-324
CFM56-7B24:	2 X $165-233 per EFH			330-466
CFM56-7B24 Tech56:	2 X $152-190 per EFH			304-380
CFM56-7B26:	2 X $170-221 per EFH			340-442
CFM56-7B26 Tech56:	2 X $162-195 per EFH			324-390
CFM56-7B27:	2 X $196-249 per EFH			392-498
CFM56-7B27 Tech56:	2 x $178-233 -per EFH			356-466
Total direct maintenance costs per FH:				**909-1,128**

Annual utilisation:
3,300FH
1,700FC
FH:FC ratio of 1.95:1

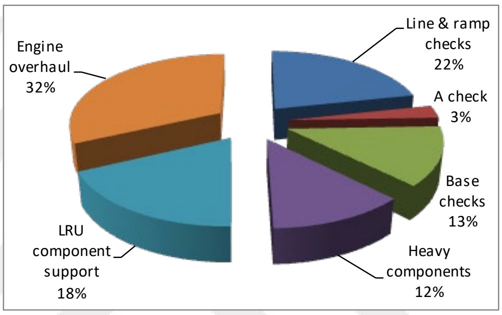
Figure 4.10 : Direct maintenance costs for 737NG, adapted from Aircraft Commerce (2010).

4.3.3 Evaluation of data

Aircraft Commerce's (2006 and 2010) segmental analysis of maintenance costs of two competitive and highly utilized aircraft type is worth evaluating in detail. Summaries of the results are given in Figure 4.11 and 4.12. So far this magazine is the sole source for maintenance cost dollar values available to the public. The method used by the article author and publication editor is interviews with airline and MRO personnel and using their feedback to put together cost assumptions based on those individual's experiences. When their calculation methods are reviewed, the following flaws in assumptions have been observed.

A320 Mx Cost Analysis per FH

Line & ramp checks	$	212
A check	$	28
Base checks	$	128
Heavy components	$	120
LRU component support	$	180
Engine overhaul	$	314



Line Mx	$	240
Base Mx	$	128
Component Mx	$	300
Engine O/H	$	314
	$	982

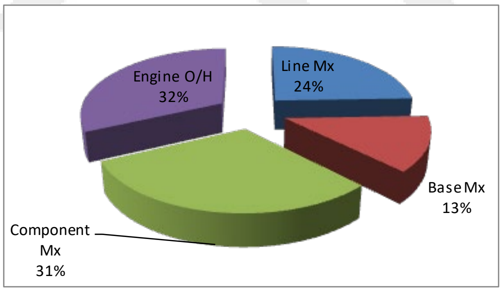


Figure 4.11 : A320 maintenance cost analysis, tabulated from Aircraft Commerce (2010).

The aircraft are assumed to fly continiously on a standard utilization pattern. In real life, such constant rate of utilizations are not observed due to operational and planning needs, still a fleet average can be calculated. Nevertheless, such averages do not apply to the small to medium size fleets, charter and ACMI operators.

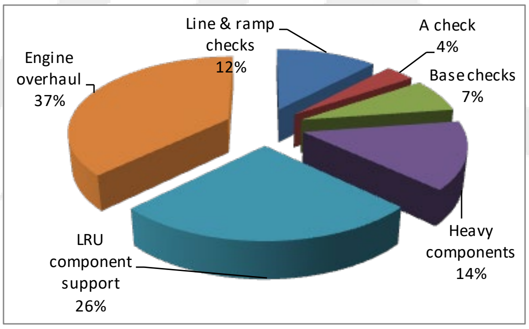
Line maintenance and A check labor requirements are calculated per input. However, such calculation does not reflect a real dollar value considering the fact that airlines with all magnitudes use internal line maintenance organizations to undertake non-base type airframe maintenance to a level. Therefore such cost study has a flaw, with the personnel cost of an airline can also be considered as an overhead.

Relatively few airlines, but the major ones have in house maintenance capabilities in various segments. Like the line maintenance, any maintenance event carried out by an intra-airline organization can not be evaluated in per event basis, from the airline cost standpoint.

While such obvious flaws exist in Aircraft Commerce's maintenance cost model approach, theirs is the only publicly available, therefore referable source of information regarding maintenance costs. To demonstrate the outcome of their maintenance cost reviews, a comparison of aircraft specific data will be helpful. Same data will be used to gauge maintenance cost assumptions and information from other sources.

B737NG Mx Cost Analysis per FH

Line & ramp checks	$	110
A check	$	32
Base checks	$	65
Heavy components	$	130
LRU component support	$	235
Engine overhaul	$	340



Line Mx	$	142
Base Mx	$	65
Component Mx	$	365
Engine O/H	$	340
	$	912

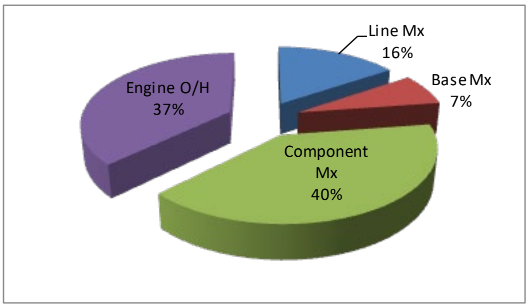


Figure 4.12 : B737 maintenance cost analysis, tabulated from Aircraft Commerce (2010).

As compared in Figure 4.13 and 4.14, the maintenance cost of B737 is lower from A320, driven by its low airframe segment maintenance costs. The reason behind this can be speculated by considering the relatively new maintenance program of B737NG and the reliability knowledge base obtained from its rival B737 classic platform. On the other hand, Airbus 320 reliability data is accumulating as every A320 flies, so the improvements in the MPD of this aircraft are observed continuously. (Such as extension of Airbus C check periods up to 36 months) In other words, if the study of Aircraft Commerce contained more recent data, we might have seen a different balance of costs between these competitor airplanes.

A320 vs B737NG - Total Mx Costs

		Line & ran	A check	Base chec	Heavy con	LRU comp	Engine overhaul
Maintenance Costs	A320	$ 212	$ 28	$ 128	$ 120	$ 180	$ 314
	B737NG	$ 110	$ 32	$ 65	$ 130	$ 235	$ 340

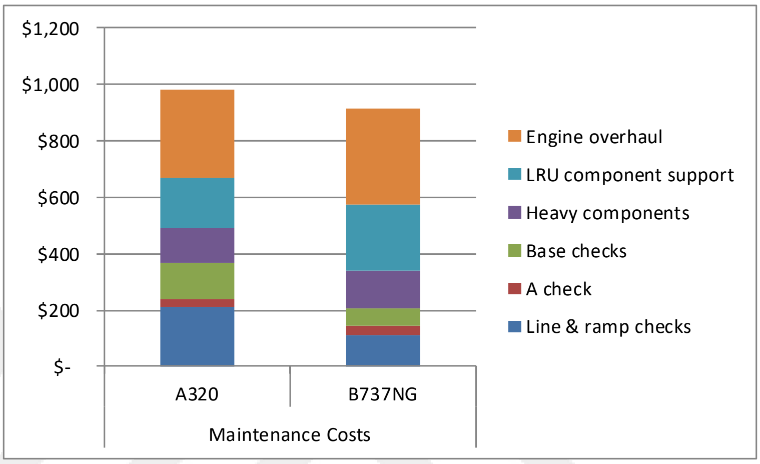


Figure 4.13 : A320 vs B737 maintenance cost comparison, tabulated from Aircraft Commerce (2010).

A320 vs B737NG - Mx Segment Costs

		Line Mx	Base Mx	Compone	Engine O/H
Mx Segment Costs	A320	$ 240	$ 128	$ 300	$ 314
	B737NG	$ 142	$ 65	$ 365	$ 340

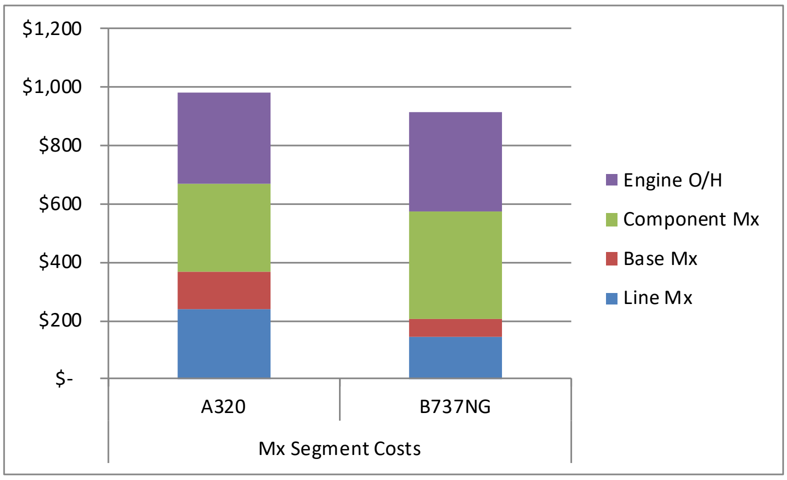


Figure 4.14 : A320 vs B737 maintenance cost comparison by segments, tabulated from Aircraft Commerce (2010).

While the B737 leads the cost advantage in terms of airframe maintenance, same platform falls behind A320 from the LRU (component) standpoint according to Aircraft Commerce. It would be naïve to relate that to the aircraft technology and design. Because, the component manufacturers provide equipment with similar technologies to both Airbus and Boeing. In addition, the reliabilities of those equipment are basic design requirement, of which the variations are covered by warranty mechanisms.

As the context of this dissertation brings another assumption for the lead of A320 in component cost data, we can look at the operation history of the two competing platforms. Having flown some 10 years before its competitive B737NG, A320 had a significant operation footprint earlier, in terms of aircraft in operation and maintenance provider variation. It is a known phenomenon that the typical market conditions apply to maintenance costs and the third party maintenance prices are at their top in early years of entry into operation. As the capabilities grow amongst various providers, competition pressures the pricing. Such is a broad but very well observed concept, which has also translated to A320 component maintenance costs.

However, is it safe and reliable to use Aircraft Commerce's data to evaluate maintenance costs? One method to understand that is to compare these analytic data with real life statistics.

4.3.4 Comparison with IATA data

IATA's MCTF FY2013 data (2014) indicates that direct maintenance cost spending of 48 airlines is \$13.1 billion and maintenance overhead spending of 34 airlines is \$2.6 billion. In total, the overall maintenance cost in FY2013 is \$15.7 billion. It is also noted that the average maintenance cost per flight hour is \$1,167 (min: \$282 and max: \$5,253). It is \$3,021 (min: \$418 and max: \$17,533) per flight cycle. On the other hand, the average maintenance cost per aircraft is \$3.1 million (min: \$0.5 million and max: \$9.0 million). Furthermore, it is also claimed that there is an increase in maintenance costs from 2010 to 2013. Even though the yearly increase went slower, there was a 32% increase of direct maintenance cost from 2010 to 2013 (pp. 11-12, 24). Figure 4.15 shows the direct maintenance unit cost growth of 26 airlines per AC, FH, and FC. Figure 4.16 shows the unit maintenance costs of 26 airlines according to the defined segments; line maintenance, base maintenance, component maintenance and engine maintenance.

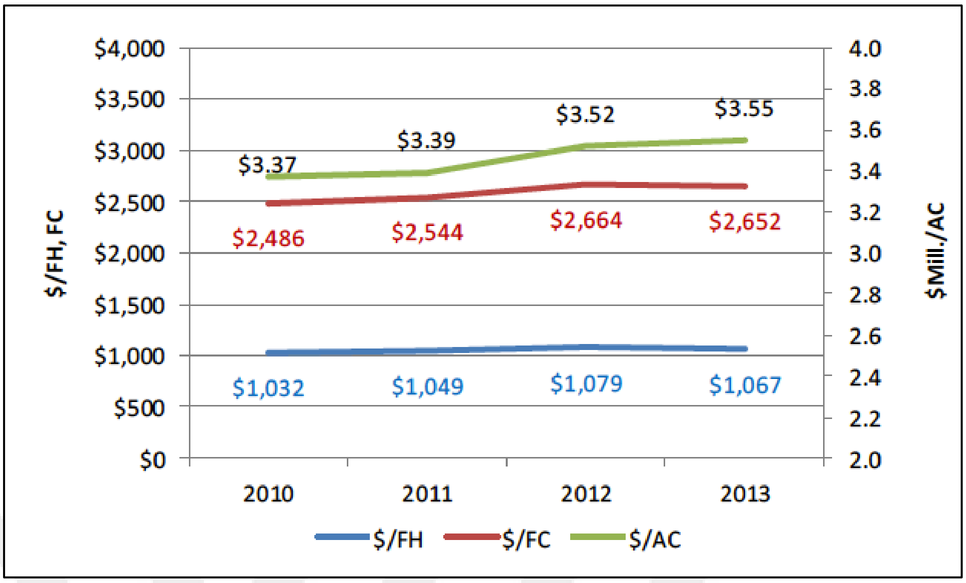


Figure 4.15 : Direct maintenance unit costs' growth of 26 airlines – FY 2013, adapted from IATA (2014).

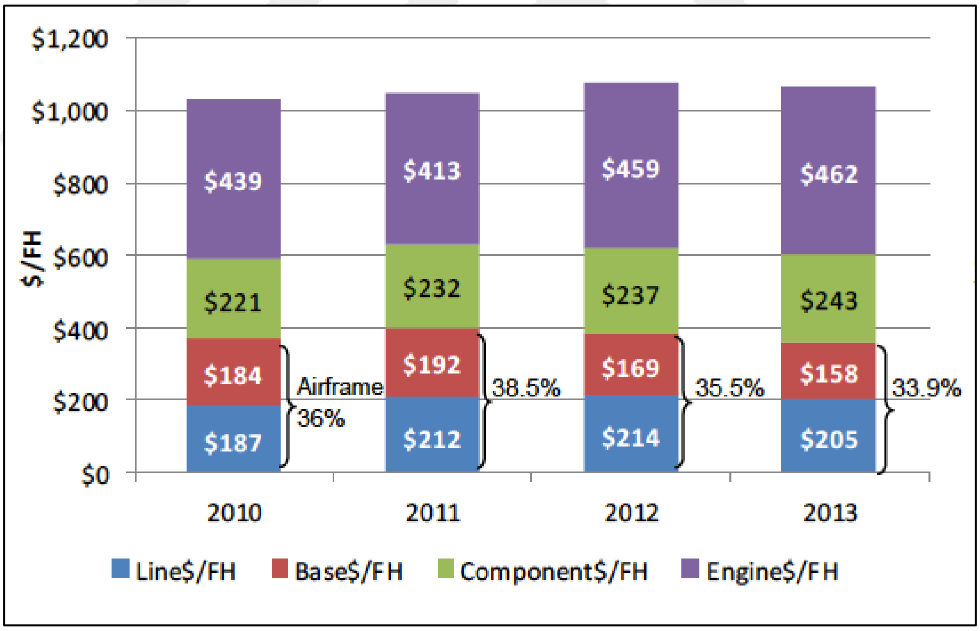


Figure 4.16 : Maintenance costs per FH by segment of 26 airlines – FY 2013, adapted from IATA (2014).

Comparison of maintenance segment costs from Aircraft Commerce and IATA sources indicate results worth to evaluate (Figure 4.17). The total per flight hour cost of maintenance for operational aircraft are in comparable levels in the first place, AC and IATA. IATA member airlines declared some significantly higher engine maintenance cost, while their indicated component maintenance costs were lower than

Aircraft Commerce's. Various reasons for such difference can be assumed, such as the differences between cost definitions for in-house maintenance capabilities. In addition, a small amount of wide body aircraft origin data is included in IATA's figures, which is also a factor for deviation.

Aircraft Commerce (A320 B737 average) - IATA Mx Segment Costs

		Line Mx	Base Mx	Compone	Engine O/H
Mx Segment Costs	Aircraft Cc	$ 191	$ 97	$ 333	$ 337
	IATA	$ 205	$ 158	$ 243	$ 462

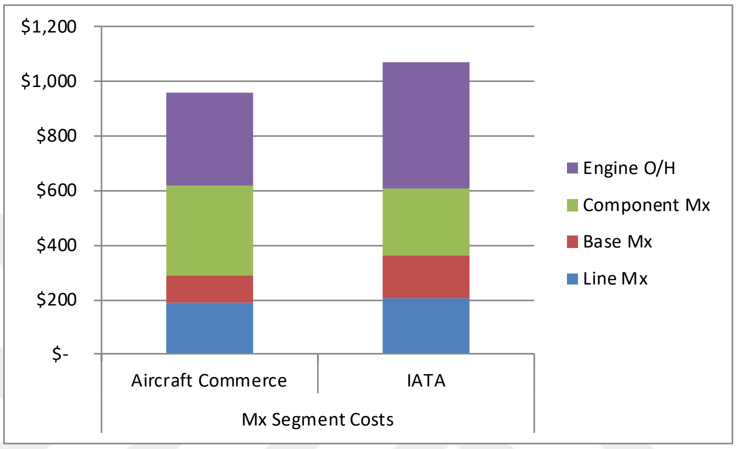


Figure 4.17 : Aircraft Commerce vs IATA maintenance cost data comparison

IATA data shall be considered as more accurate, being based on actual spending. Still the Aircraft Commerce's figures are valuable as they help to set up a future maintenance cost model for a particular aircraft platform.

4.4 Maintenance Cost Formulation

When an aircraft operator outsources its base maintenance requirements to a third party MRO organization, the cost breaks down into mainly labor and material elements. They are labor rate (LBR), MPD tasks labor (MTL), engineering order labor (EOL), non-routine labor (NRL), cosmetic items labor (CIL), MPD tasks material (MTM), engineering order material (EOM), non-routine material (NRM), cosmetic items material (CIM), transportation cost (TRC) and special tool cost (STC). Each element has a source from the maintenance program. But since a substantial portion of the elements are uncertain, the type and age of the airplane and the point of time in the maintenance history affect the magnitude of both labor and material costs at each base maintenance event (check).

Labor rate (LBR) is the dollar value per each man hour that a maintenance organization charges for its services on the aircraft. This rate changes in accordance with cost base, for example according to the geographical location of the maintenance facility. However, location is not the only factor of this rate change. Market conditions, special service requirements and seasonal factors also affect the labor rate. Base maintenance service contracts incorporate this rate for a fixed price and for non-routine and additional services. It is common that labor rate may differ within an organization, through fixed price services and different skill sets.

MPD tasks labor (MTL) represents the labor requirement of maintenance program tasks. Since MTL defines routine works, this parameter could be determined in advance by the planners. This element will be the same for each aircraft going under the exact same scope of work in a base maintenance event. However, changes will appear amongst different maintenance service providers, which is explained by the term MRO efficiency factor (MEF).

MRO efficiency factor (MEF) is a factor, which represents the ratio of the average man-hour required by a MRO to complete a maintenance task and the man-hour for that task given in manufacturer's Maintenance Planning Document (MPD). For a MRO with high ranking in terms of delivery performance, the MEF value is expected to be low. Therefore, it is acceptable to see MRO organizations with lower MEF value, have higher LBR. In other words, MRO organizations with lower LBR are supposed to have higher MEF, which increases all labor related cost elements. MEF is a value above 1, where 1 can only be reached in ideal conditions. Personnel training and experience, tool and material availability and hangar conditions are some factors that affect MEF. MEF value decreases as MRO has higher investment (in maintenance environment) and experience on a specific task or aircraft type.

MPD tasks material (MTM) is another deterministic element. The routine works and associated material requirements are pre-defined for each task, which is grouped into a scheduled maintenance check per interval limitations. Therefore, the MTL and MTM cost elements are not probabilistic. Two other deterministic elements are EOL (engineering order labor) and EOM (engineering order material). These are the labor and material costs arising from Engineering Order requirements, respectively. All these four elements can be observed to increase on an aging aircraft. However, this factor can still be determined during the check planning phase.

Nevertheless, not all the cost elements have deterministic character. Non-routine related labor and material cost elements tend to change with type, age and operation condition of aircraft. General assumptions could be made; however, the most accurate cost of these elements could only be calculated after the performance of the check.

Taking into account all the elements given above, the cost of a scheduled airframe maintenance check can be calculated by the following equation:

$$\begin{aligned} \mathrm{MTC} = \mathrm{LBR} * \big(\mathrm{MEF} * (\mathrm{MTL} + \mathrm{EOL}) + \mathrm{NFL} \; * (\mathrm{NRL} + \mathrm{CIL})\big) + \mathrm{MTM} \\ + \mathrm{EOM} + \mathrm{NFM} * (\mathrm{NRM} + \mathrm{CIM}) + \mathrm{TRC} + \mathrm{STC} \end{aligned} \tag{4.1}$$

where all the material-related variables such as MTM, EOM, NRM (Non-Routine Material) and CIM (Cosmetic Items Material) are already given in dollars. Furthermore, to identify the probabilistic character of non-routine related labor and material costs, the terms NFL, which corresponds to non-routine labor factor and NFM, which corresponds to non-routine material factor, have been used. These factors are anticipated to increase for old aircraft and should also differ for each aircraft and check type.

4.5 TAT and DT Terms

Turn-around time (TAT), which does not appear in the equation above, is the most crucial element. TAT does not contribute to direct maintenance cost but it contributes to the downtime cost of the aircraft. Assuming that the sum of the elapsed time of critical maintenance tasks are lower than TAT, then TAT can be calculated by the following equation:

$$\mathrm{TAT} \; = \frac{\mathrm{MTL} + \mathrm{EOL} + \mathrm{NRL} + \mathrm{CIL}}{\mathrm{MLC}} \tag{4.2}$$

Where MRO labor capacity (MLC) is the maintenance facility's daily labor production capacity, which depends on the number of the assigned technicians to the aircraft and the daily working hours (shift pattern).

In some cases, when there are substantial non-routine works, TAT becomes the sum of the total critical tasks (routine and non-routine) of the scheduled maintenance check. In addition, logistic factors such as long durations of material procurement of non-routine tasks could also increase TAT. In this study, TAT of a scheduled maintenance check will be incorporated in the maintenance cost with the term downtime (DT).

$$\mathrm{TAT} = \mathrm{DT} \tag{4.3}$$

Nevertheless, in practice, it can be observed that logistic factors such as long duration of materials or tools procurement of routine and non-routine tasks could also increase TAT. During routine task performances, some special access requirements such as jacking of aircraft, removal of landing gears, engines and pylons, and some very current avionic modifications affect TAT beyond the calculation of TAT using MLC. Avionic modifications, which require de-energizing aircraft electric lines, also can prevent the system tests to be accomplished.

Some non-routine cases also happen when a defect is found and special tools or materials are waited before closing this defect. Special material for structural repairs, equipment and tools for stress jacking are common examples for such non-routine related cases, which extend TAT beyond the MRO's labor capacity factor (MLC). The days spent on ground while waiting for the special materials of non-routine findings are very hard to estimate. However, depending on type of maintenance task and aircraft age, a probabilistic approach could be used to account such extensions on TAT.

When a defect is found during a scheduled maintenance event, it's rectification effort's effect on TAT relies on several factors such as the timing of finding (within the estimated TAT of maintenance), reporting duration if not covered by maintenance manuals and landing time required for special tools or material to close the defect. It is obvious that the earlier a defect is found (during a maintenance check), the less possible impact it will have on TAT. As an example, on a 20 years old passenger aircraft, corrosion findings are very likely in the areas under galleys and toilets. Structural findings, not only the corrosions, but also the scratch marks on fuselage skin, dents and lightning strike damages are generally repaired according to the SRM (Structural Repair Manual) definitions. However, the findings beyond the limit of this document require reporting to aircraft manufacturer and can only be repaired according to the repair scheme prepared by the OEM. In many cases, this reporting between the MRO and OEM continues for several days, which most likely extends the TAT of the scheduled maintenance event.

In this study, these factors will be incorporated in one parameter called MST or maintenance stop time. MST can be classified into two, scheduled and unscheduled maintenance stop time. Scheduled MST occurs during routine maintenance activities. Maintenance tasks that require other maintenance activities to be deferred are for example landing gear replacement, avionic modifications, etc. Unscheduled MST occurs when maintenance works require special tools and materials. The procurement period may cause other maintenance activities to be delayed and increase the total TAT. Therefore, the new TAT formulation is shown as follows:

$$\mathrm{TAT} = \mathrm{MEF} * \frac{\mathrm{MTL} + \mathrm{EOL} + \mathrm{NFL} * (\mathrm{NRL} + \mathrm{CIL})}{\mathrm{MLC}} + \mathrm{MST} \tag{4.4}$$

Maintenance Stop Time (MST) becomes very critical, as it is the least predictable reason for TAT extension, having the greatest impact. For MST, reporting to the OEM is a critical indicator. In all cases when the repairs are not achievable without OEM support, the likelihood for MST observance is very high. Therefore a task based historical data on which OEM is asked for solutions could be incorporated in the season based maintenance scheduling achieving realistic TAT prediction.

5. INTEGRATION OF MAINTENANCE AND DOWNTIME COST

Operators do cost calculations while making the schedule of aircraft maintenance. Usually, the calculations are done based on direct maintenance cost, which includes the costs of maintenance crews, materials and equipment. However, in addition to direct maintenance cost, there is indirect maintenance cost, which has been discussed in the previous chapter. Even though indirect maintenance cost is not directly related to the maintenance process, it plays a very important role in keeping the operation going on. One example of indirect maintenance cost is overhead or burden. As it has been agreed in the previous chapter, the elements of overhead cost are the costs of general and administrative, flight deck crew, reservation, ticketing, sales and promotion, cabin attendants and other.

In addition to overhead cost, another element of indirect maintenance cost is downtime cost. Downtime cost is subjected to the operator during maintenance period. It appears because aircraft stays on ground and ceases to operate throughout maintenance. Hurst (1995) asserted that it is important to control the rate of aircraft downing event since it makes an aircraft unavailable to fly no matter the maintenance program it has (p. 31-4). Saranga (2004) asserted that both the downtime cost caused by scheduled and unscheduled maintenance is costly. Downtime cost is a very complex component. It relies on the season type, business environment, unscheduled or scheduled type of downtime and some other factors related to the case being examined. For example, an unscheduled downtime for a commercial airline through a high peak season will require some auxiliary actions that increase the downtime cost (pp. 67, 70). Another opinion comes from Kumar et al. (2000), who asserted that it is important to note that downtime should be considered for time that the system is supposed to be working. That would mean that the scheduled or preventive maintenance does not have any downtime since the system is expected to be not working during that specified period. Only when there is a period when the system is expected to work but the system does not work, then the downtime should be taken into account (p. 199). However, this dissertation opposes this opinion because downtime does appear both during scheduled and unscheduled maintenance. By calculating downtime for scheduled maintenance for example, it may lead to maintenance cost optimization. When operator is in the process of making plan for maintenance schedule, the total maintenance cost can be calculated from the addition of direct maintenance cost and overhead cost together with downtime cost during that maintenance period. Afterwards, operator may search for different possibilities of maintenance period with different total maintenance cost. This will help operators in finding the alternatives of lower total maintenance cost for maintenance programs scheduling.

5.1 The Downtime Cost

In view of the discussions carried out in the previous chapter, one of the elements of downtime cost is aircraft ownership cost. It is a type of cost that the operator has to bear whether the aircraft operates or not. Aircraft ownership cost can be defined in two different terms, lease cost or ownership cost. Lease cost will be applied to the aircraft, which are leased by the operators from lessors. While ownership cost will be applied to the aircraft, which are owned by the operators.

Additionally, besides ownership cost, another element of downtime cost is the cost of revenue loss. When an aircraft is unable to fly, it means that it does not generate revenues as it should be and this cost is called cost of revenue loss for the operator. Kumar et al. (2000) formulated cost of revenue loss due to unscheduled downtime as shown in Figure 5.1, with CLR = cost of loss of revenue, DMT = duration of maintenance task, DST = duration of support task, DT = total downtime and IHR = income hourly rate (p. 199).

$$\boxed{CLR = (DMT + DST) \times IHR = DT \times IHR}$$

Figure 5.1 : Cost of loss of revenue, adapted from Kumar et al. (2000).

On the other hand, Saranga (2004) opposes this opinion and states that whenever a system stops to operate, whether it is scheduled or unscheduled, the cost of lost revenue (CLR) is an unexceptional and an unavoidable cost. Downtime cost is a very complex component, which relies on the season type, business environment, unscheduled or scheduled type of downtime and some other factors related to the case being examined. Both downtime cost caused by scheduled and unscheduled maintenance is costly. An unscheduled downtime for a commercial airline in a high peak season will require some auxiliary actions that increase the downtime cost, which is classified as the cost of compensation. The cost of downtime due to scheduled maintenance is calculated by the following equation:

$$\mathrm{CDTp} \ = \mathrm{CLR} * \mathrm{DT} \tag{5.1}$$

Where CDTp is cost of downtime for planned maintenance, CLR is cost of lost revenue and DT is downtime in hours.

Subsequently, cost of downtime due to unscheduled maintenance is expressed as follows:

$$\mathrm{CDTu} \ = \mathrm{CDTp} + \mathrm{ICD} \tag{5.2}$$

Where CDTu is cost of downtime for unplanned maintenance and ICD is indirect cost of downtime, which is given by:

$$\mathrm{ICD} = \mathrm{CC} + \mathrm{CW} \quad + \mathrm{CLD} \tag{5.3}$$

Where CC is cost of compensation, CGW is cost of goodwill and CLD is cost of logistic delay.

Taking all the information given above, it can be claimed that the formulation proposed by Kumar (2000) takes into account only the downtime cost for unscheduled downtime. However, it does not include the auxiliary costs that might appear due to unscheduled downtime. On the other hand, Saranga (2004) proposed the downtime cost formulations both for scheduled and unscheduled maintenance. Moreover, in addition to the cost of revenue loss, there are auxiliary costs added to the downtime cost for unscheduled maintenance. To conclude, in this dissertation, cost of revenue loss will be defined as opportunity cost.

In addition to aircraft ownership cost and opportunity cost, the last element of downtime cost is subcharter cost. There are cases where operators will try to keep operating even though the aircraft is in maintenance. There exist two possible ways of doing this. First, operators may modify the schedule of the remaining aircraft and put the schedule of the aircraft under maintenance to another aircraft. Operators may not need to modify the existing schedule if they do have spare aircraft on ground.

However, it is also arguable since it is not known whether operators keep spare aircraft just in case maintenance is scheduled for another aircraft in operation. Second, if spare aircraft is not available and schedule modification is not possible, in order to keep operating normally, operators may take another aircraft by subchartering from another operator. Nevertheless, subchartering an aircraft is obviously another cost to the operator and it is described as subcharter cost.

There are two types of operators in which each of its downtime cost model is going to be defined. They are scheduled operators and ACMI operators. Scheduled operators are operators with previously defined flight schedules such as flag carriers and low cost carriers. Gupta (2008) stated that the business model of scheduled airlines is originated in regular frequency and published schedules and prices (p. 10). On the other hand, ACMI operators provide aircraft charter service both for commercial and private purposes. Kim and Barnhardt as cited in Gupta (2008) asserted that the market type that is served by charter operators, has daily variance in the demand of origin and destination travel (p. 12). In view of this information, it is clear that the type of ACMI operators that is going to be used in the analysis is the operator that provides service for commercial purpose, for example for a group travel. This is comparable with the service provided by scheduled operators.

5.1.1 Aircraft ownership cost

IATA's MCTF FY2013 data (2014) stated that depends on the regions and the types of the aircraft, they are either leased or owned. Having said that, around 40% of the world fleet are under operational lease (p. 16). Figure 5.2 shows the percentage of world fleet under operational lease.

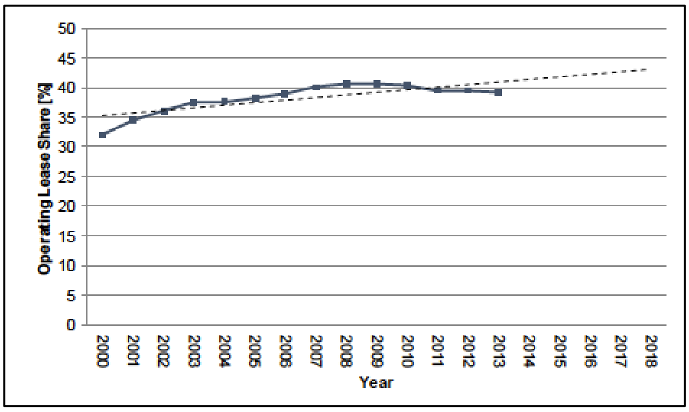


Figure 5.2 : Percentage of world fleet under operating lease, source: SGI Aviation/Ascend, 2013, adapted from IATA (2014).

Whether aircraft flies or not, its monthly lease cost is inevitable. As Aircraft Value News (2011) stated, the aircraft lease cost varies depending on its type, age and configuration (p. 3). The lease rate will also vary depending on the market condition, the lessee fleet size and its financial status. The monthly dry lease prices together with the trend analysis of narrow body jets from Aircraft Value News (August, 2011) are available in the appendix. For the sake of easiness, the rates are rearranged in Table 5.1.

Table 5.1 : Narrow body lease rates (Dry) US$ ‘000s pm, adapted from Aircraft Value News (2011).

Aircraft	Age	Rental
A318-100	2003-11	130-260
A319-100	1996-98	140-220
	1999-11	210-330
A320-200	1988-92	80-120
	1993-97	90-180
	1998-03	190-280
	2004-11	250-350
A321-100L	1994-97	90-125
	1998-02	120-220
A321-200H	1999-04	180-300
	2004-11	280-415
B717-200	1999-04	80-145
B737-600	1998-03	70-140
B737-700	1997-01	145-240
	2002-11	230-350
B737-800	1998-02	170-290
	2003-11	270-400
B737-900	2000-04	125-185
B737-900ER	2006-11	285-425
B757-200	1982-88	60-120
	1989-95	85-140
	1996-02	120-180
B757-200ER	1987-95	65-160
	1996-02	140-210
B757-300	1998-03	130-210

In view of information given in the table, it can be claimed that for the same aircraft type, the lease rate is cheaper for older aircraft. However, it is clear that older aircraft has higher maintenance cost compared to the newer ones. They are more prone to supplementary maintenance tasks since the airframe and components are getting older. This is reflected on the additional cost besides the monthly lease rates, which is described as maintenance reserves. As IATA (2014) asserted, during its operation, aircraft experience a drop in maintenance value. Therefore, maintenance reserve is a security fee paid by the lessee to the lessor to compensate for this. The amount of the reserves is determined by the flight hour, flight cycles or time to future maintenance events (p. 16). Having maintenance reserve as security fee means that the lessor will have enough cash to put the aircraft to maintenance just in case the lessee does not possess sufficient cash at the required time. If the maintenance cost is higher than the reserves paid by the lessee, the lessee will have to pay the difference. On the other hand, when the maintenance cost is lower than the reserves, the difference will be paid back by the lessor to the lessee at the end of leasing period. Nevertheless, assuming that these reserves will be given back to the lessee at the end of the leasing period, the maintenance reserves cost is not going to be taken into account in the analysis.

In order to calculate the aircraft's daily lease cost (DLC), the following formula is proposed. MLR (Monthly Lease Rate), NDM (Number of Days in one Month).

$$\mathrm{DLC} = \frac{\mathrm{MLR}}{\mathrm{NDM}} \tag{5.4}$$

Then, to calculate the aircraft's lease cost during downtime (ALC), DLC will be multiplied with downtime number of days (DT) as shown in the following formula.

$$\mathrm{ALC} = \mathrm{DLC} * \mathrm{DT} \tag{5.5}$$

When operators do not lease the aircraft but own them, instead of lease cost, ownership cost will be applied. Unfortunately, during the process of writing this dissertation, there are not many sources that define how to calculate the ownership cost. It depends on the aircraft utilization and business environment; therefore its calculation is rather complex. Heiter (2015) from Boeing showed one example of ownership cost calculation per trip for 787 Dreamliner, shown in Figure 5.3.

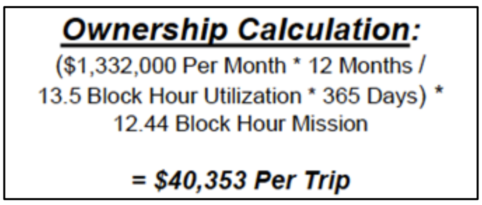


Figure 5.3 : Ownership cost calculation of 787 Dreamliner, adapted from Heiter (2015).

His assumptions are assumptions of 15 to 20 years of operation, 13.5 block hours of available daily utilization and 12.44 block hours of daily designed mission. The calculation is shown in Figure 5.3.

There is no exact information on how the cost of $1,332,000 per month for 787 Dreamliner is obtained. However, it is assumed that the monthly ownership cost was obtained from the multiplication of the aircraft's current market value with 1.009%. Klein (2015) as of March 2014 presented current and future values opinions of Boeing 787-9 value as shown in Figure 5.4 below (p. 54).

Boeing 787-9 Values as of March 2014, US$ millions

Year of Build	Current Market Value	2014 Base Value	Future Base Values with 2.0% Annual Inflation									
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
2014	132.0	132.0	127.0	122.2	117.4	112.7	108.1	103.6	99.1	94.8	90.6	86.5

The aircraft values stated herein are the product and the property of independent third-party sources, and ISTAT neither approves nor endorses the information contained herein or the use thereof for any purpose whatsoever.
Aircraft specifications: GEnx-1B70 engines, 545,000 lb MTOW

Figure 5.4 : Current and future value opinions for the 787-9, Klein (2015).

With the assumption of the 2014 value of 132 million US$ multiplied with 1.009% we obtained $1,331,880 which is much the same with the value given by Heiter (2015) in its formulation. In view of this information, it can be claimed that to calculate the aircraft monthly ownership cost (MOC), the current market value (CMV) will be multiplied by 1.009%.

$$\mathrm{MOC} = \mathrm{CMV} * 0.01009 \tag{5.6}$$

Furthermore, to calculate the aircraft ownership cost per trip, the formulation of Heiter (2015) can be used. With daily designed block hour mission (DBH) and available daily utilization block hour (ABH), the ownership cost per trip (OWT) is calculated as:

$$\mathrm{OWT} = \frac{(\mathrm{MOC} * 12 \text{ months} * \mathrm{DBH})}{(\mathrm{ABH} * 365 \text{ days})} \tag{5.7}$$

Substituting Eq. 3 into Eq. 4, the ownership cost per trip can be calculated as:

$$\mathrm{OWT} = \frac{(\mathrm{CMV} * 0.01009 * 12 \text{ months} * \mathrm{DBH})}{(\mathrm{ABH} * 365 \text{ days})} \tag{5.8}$$

However, in this dissertation, our concern will not be ownership cost per trip, but daily ownership cost. Therefore, to calculate the daily ownership cost (OWD), with NDM (Number of Days in one Month); we will use the following formula.

$$\mathrm{OWD} = \frac{\mathrm{MOC}}{\mathrm{NDM}} = \frac{\mathrm{CMV} * 0.01009}{\mathrm{NDM}} \tag{5.9}$$

Then, to calculate the aircraft's ownership cost during downtime (OWC), OWD will be multiplied with DT as shown in the following formula.

$$\mathrm{OWC} = \mathrm{OWD} * \mathrm{DT} \tag{5.10}$$

5.1.2 Subcharter cost

In case the aircraft availability does not meet the regular demand, both scheduled and ACMI operators may sub charter aircraft from another operator to fulfill the demand. One of the reasons why the aircraft is not available to meet the demand is due to maintenance. There exists two possible ways of sustaining the operations, while the aircraft is on the ground. First, operators may modify the schedule of the remaining aircraft and put the schedule of the aircraft under maintenance to another aircraft. Operators may not need to modify the existing schedule if they do have a spare aircraft on ground. However, most operators keep spare aircraft only in very rare and specific operation contracts and such application is not commonly seen in the industry. Second, if a spare aircraft is not available and schedule modification is also not possible, in order to keep operating nominally, operators may take another aircraft by sub chartering from another operator. Within this context, when an airline has to sub charter a portion of its operations to another airline, the costs occurred due to this service could be defined as another element of downtime cost.

It shall be noted that the scheduled service providers should provide service according to their predefined schedules. It is generally not an option to cancel any given flight except during bad weather conditions. Therefore, it becomes a must to use either sub charter services or a spare aircraft to cover the unscheduled unavailability, which is a direct cost of downtime.

Aircraft sub charter service providers are usually ACMI operators. ACMI's sub charter cost includes the aircraft lease, crew, maintenance and insurance costs. The costs that are not included are the operating costs such as fuel, navigation, ground handling and taxes.

In the same way that the aircraft downtime cost is, sub charter cost is also complex. It depends on the business environment, market and season condition as shown in Figure 5.5. In certain regions, the traffic is high for certain periods while for other periods the traffic is low. Muchiri and Smit (2009) asserted that between April-October, the aircraft demand is at high peak, while between November-March it is at low peak (p. 35).

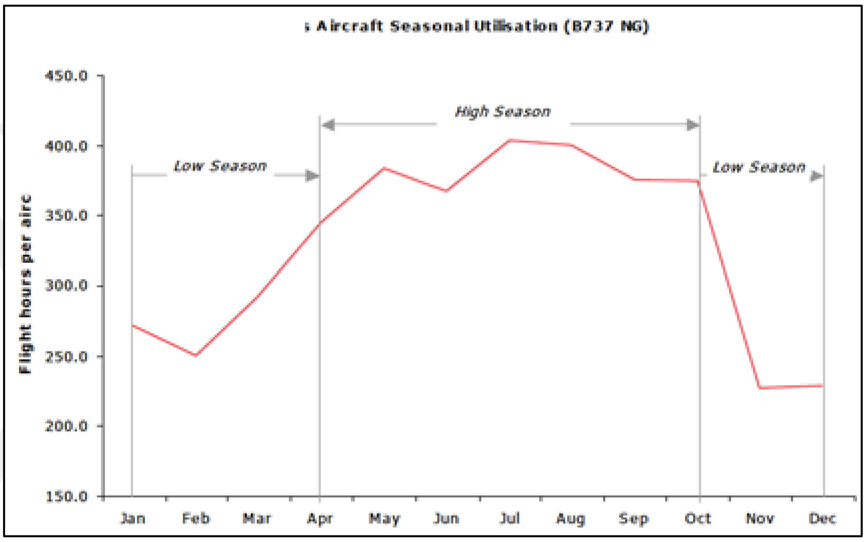


Figure 5.5 : Aircraft seasonal demand, adapted from Muchiri and Smit (2009).

Taking into account the information given above, it can be claimed that subcharter cost will vary according to season condition and business environment. When the traffic or demand for aircraft is high, the subcharter service provider may charge high subcharter price. While, when the demand for aircraft is low, the subcharter service provider may charge lower subcharter price. Sub charter prices also vary according to the operation location, operational requirements, aircraft capacity and configuration, sectors, monthly-confirmed block hours and duration of the contract.

However, once operator got the monthly subcharter cost rate (MSR) for a certain aircraft type, with NDM (Number of Days in one Month), it can calculate daily subcharter cost (SAD) by using the following formula.

$$\text{SAD} = \frac{\text{MSR}}{\text{NDM}} \tag{5.11}$$

Then, to calculate the aircraft's subcharter cost during downtime (SAC), SAD will be multiplied with DT as shown in the following formula.

$$\mathrm{SAC} = \mathrm{SAD} * \mathrm{DT} \tag{5.12}$$

5.1.3 Opportunity cost

Another method for defining downtime cost is using operator revenues that an operator would generate per flight. Dupuy et al. (2011) stated that aircraft during maintenance encounters opportunity cost as a consequence of aircraft stops to operate and thus stops to generate revenue (p. 1). This opportunity cost is mentioned by other sources such as Kumar (2000) and Saranga (2004) as cost of revenue loss. Nevertheless, it is not easy to calculate the opportunity cost. As Eurocontrol's Business Case Team (2013) asserted, the loss of possible revenue in the future is illustrated by the passenger opportunity cost, which absolutely includes the passenger value of time. This will rely on the understanding of the passenger regarding the happening delay. It is also reported that the average cost of cancelling a commercial scheduled flight is €3,700 for 50 seat narrow body aircraft type, €17,300 for 120 seat narrow body and €81,000 for 400 seat wide body. This cost comprises the service recovery costs such as passenger compensation cost, rebooking costs, future value loss such as passenger opportunity cost and operational savings (pp. 9, 14).

Value	**Aircraft type**	**Flight cancelled (€)**
	50 seat narrow body	3,700
	120 seat narrow body	17,300
	400 seat wide body	81,000
	(Adjusted from 2006 prices)	
Source	Data supplied by the airline members of the SESAR evaluation team; derived from an analysis of 2006 ECAC data.	

Figure 5.6 : Cancellation recommended values adapted from Eurocontrol (2013).

Even though these recommended values include service recovery costs and rebooking costs, which are not necessarily included in our analysis, they include passenger opportunity cost and operational savings, which are necessary for our downtime cost analysis. Moreover, at the time of writing this dissertation, this is the only report that demonstrates the opportunity cost and the operational savings together.

In this dissertation, the opportunity cost will be defined neither as the cost of revenue loss nor as the passenger opportunity cost together with operational savings. It will be defined as cost of profit loss. This is the profit that the operator would be able to generate per flight if the aircraft does not cease to operate.

For aircraft operators, market and season conditions play a very important role on determining the amount of profit of the operators. During high season usually between April-October, as shown in Figure 5.5, the revenue is high due to high demand and high utilization of aircraft. Therefore, the average profit value for a given period will be used to determine the opportunity cost due to downtime during that period.

To calculate the profit that the operator earns per flight, the load factor and the approximate profit value per passenger are required. IATA (2014) in one of its press release stated that in 2013, airline obtained a net profit of \$3.38 per passenger, while in 2014 it obtained \$6.02 per passenger. It is predicted that in 2015, airlines will earn \$7.08 net profit per passenger (para. 4). Therefore, to obtain the opportunity cost or cost of profit loss per flight (OPF), operators need to multiply the aircraft capacity (ACP) with the assumed load factor (LF) and the assumed net profit per passenger (NPP).

$$\mathrm{OPF} = \mathrm{ACP} * \mathrm{LF} * \mathrm{NPP} \tag{5.13}$$

If the operators do not have data of net profit per passenger, they may use the assumption made by IATA (2014). In this case, using the assumed net profit per passenger in 2015, the opportunity cost per flight can be defined as:

$$\mathrm{OPF} = \mathrm{ACP} * \mathrm{LF} * \$7.08 \tag{5.14}$$

There are two types of operators in which each of its downtime cost model is going to be defined. They are scheduled operators and ACMI or charter operators. Scheduled operators are operators with previously defined flight schedules such as legacy carriers and low cost carriers. The business model of scheduled airlines originates in regular frequency and published schedules and price. An airline, which is providing scheduled passenger service, is expected to generate more revenue per flight hour when compared to a charter service provider. The current charging mechanisms allow airlines to apply varying fee per seat on scheduled services thus allowing them to adapt to market conditions in the competitive market. In the context of maintenance and downtime costs, summer seasons are more valuable in the sense of flying.

On the other hand, ACMI operators provide aircraft charter service both for commercial and private purposes. Kim and Barnhart (2007) asserted that the market type that is served by charter operators for a given origin and destination has fixed demand, which varies only by day in a week. In view of this information, it is clear that the type of ACMI operator that is meant in this study is the operator that provides service for commercial purposes, for example for a travel group. This is comparable with the service provided by scheduled operators.

Since their operation type is different, it is obvious that their profit calculation is also different. A scheduled service provider is expected to generate a range of profit between \$10.000 to \$20.000 during low and high seasons, while a typical ACMI operator's profit for a narrow body airplane could be estimated as \$5000 during the low season and \$10.000 during the high season. These profit values depend on several factors such as geographical region, aircraft configuration and service level.

For a scheduled operator with a fixed amount of flight frequency, the total opportunity cost (OPCs) can be calculated by summing the opportunity cost per flight of all the scheduled flights that normally exist during the period where maintenance is planned. The equation is given by:

$$\mathrm{s} = \text{index for scheduled flight during normal period } (\mathrm{s} = 1, \dots, \mathrm{S})$$

$$\mathrm{OPCs} = \sum_{s=1}^{S} \mathrm{OPF\,s} \qquad (5.15)$$

Where OPFs corresponds to the opportunity cost per flight of a scheduled flight s during the specified period and S is the number of scheduled flights.

For ACMI operator with no fixed schedule, the total opportunity cost (OPCc) can be calculated by summing the opportunity cost per flight of all possible charter flights that normally exist during the period where the maintenance is planned. The equation is given by:

$$\mathrm{c} = \text{index for chartered flight during normal period } (\mathrm{c} = 1, \dots, \mathrm{C})$$

$$\mathrm{OPCc} = \sum_{c=1}^{C} \mathrm{OPF\,c} \tag{5.16}$$

Where OPFc corresponds to the opportunity cost per flight of a possible charter flight c during the specified period and C is the number of charter flights.

It is important to note that this opportunity cost will appear only when the operator decides not to subcharter another aircraft to substitute for the aircraft that is down for maintenance. However, in the case where the operator subcharters another aircraft to keep the operation, this opportunity cost will not appear.

5.2 Integration of Maintenance and Downtime Cost

When signing maintenance contracts with maintenance service providers, aircraft operators are using various methods to quantify their downtime cost. One of these models refers to the cost of lease, as the daily cost that incurred once lease agreement is taken into account. Another method is based on sub charter costs; that would rise when the flights of the grounded A/C shall be outsourced to a charter airline with a sub charter agreement. In another method, the loss of opportunity is also examined. In some previous work, it is called as cost of revenue loss. In this case, the potential revenue could be estimated on a seasonal basis, with two basic models: charter and scheduled operators. To be able to calculate downtime cost properly before preparing a maintenance plan, the existence of a standard model for downtime cost calculation is thereby required. Such calculation should be precise, in dollar values and reflect the seasonal effects, in order to be useful during the decision making of maintenance schedule.

The flow chart given in Figure 5.7 shows the steps required to calculate aircraft downtime cost. In the beginning, operator needs to determine the period where the maintenance is scheduled. If during that period aircraft is not in operation, then there is no downtime cost. If the aircraft is in operation, then operator needs to see if any spare aircraft is available. In the case where the spare aircraft is available, downtime cost consists of A/C (aircraft) ownership cost only. Otherwise, the type of operation of the operator will be analyzed, whether it is a scheduled operator or an ACMI (Aircraft, Crew, Maintenance and Insurance) operator. Subsequently, the operator needs to see the possibility of sub chartering another aircraft throughout maintenance. Given that sub chartering is chosen, then downtime cost will consist of sub charter cost and A/C ownership cost. However, in the event that sub chartering is not accepted as a solution, downtime cost will consist of opportunity cost and A/C ownership cost. The type of operation, scheduled or ACMI, will determine the value of opportunity cost.

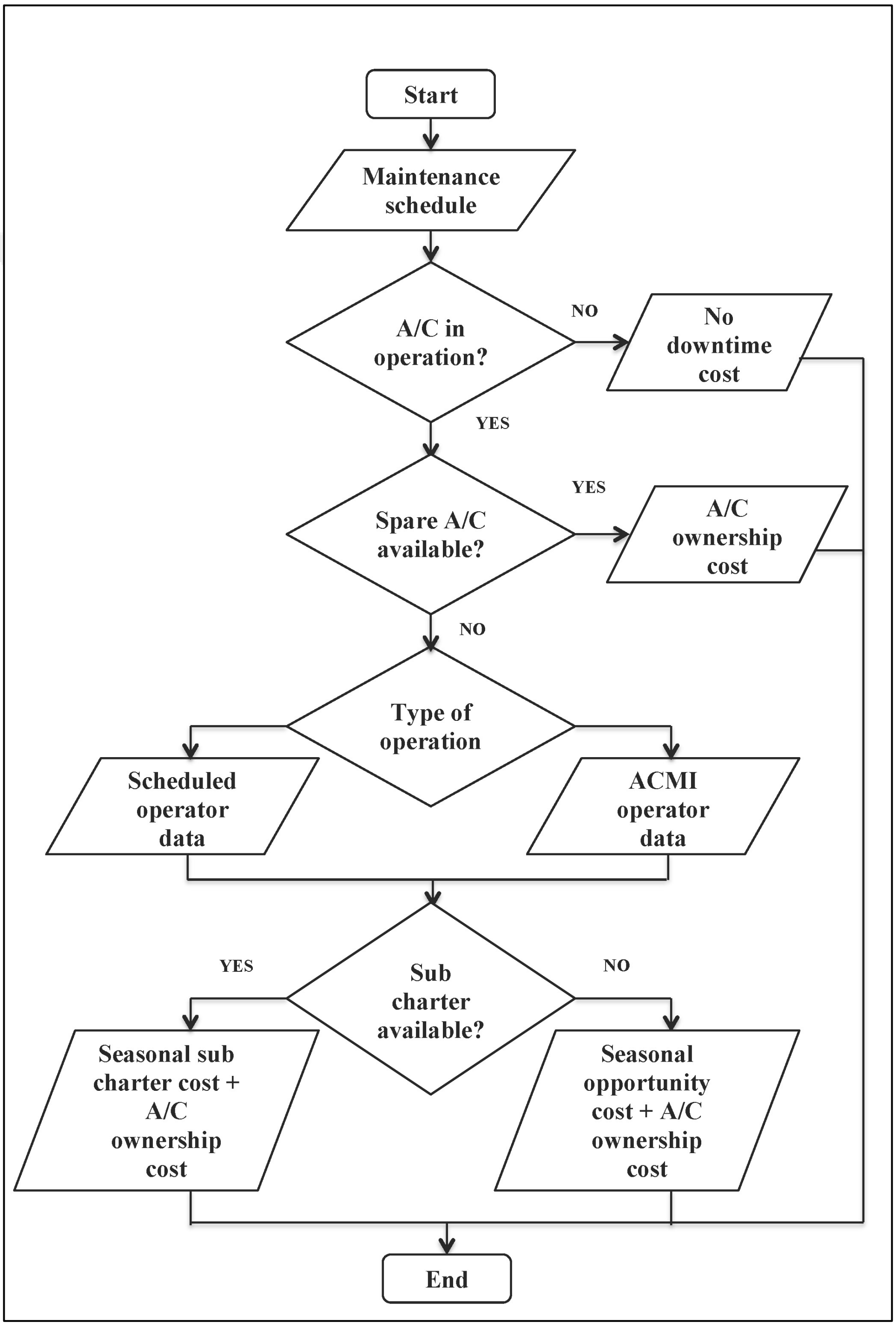


Figure 5.7 : Flowchart of Downtime cost

5.3 Introduction of Cases and Assumptions

As direct maintenance cost is not cheap, so is the downtime cost. Due to the seasonality of commercial aviation business, there may exist a certain periods where the downtime cost is higher than the direct maintenance cost. On the other hand, other periods may have lower downtime cost compared to the direct maintenance cost. A set of operation and revenue data of a scheduled operator (operator ABC) and a MRO organization (MRO XYZ) are analyzed. In the operation of the scheduled operator, two types of seasons are taken into account. These are winter season, which lasts from November to March, and summer season, which lasts from April to October. The monthly revenue of operator ABC generated by each aircraft is plotted in Figure 5.8.

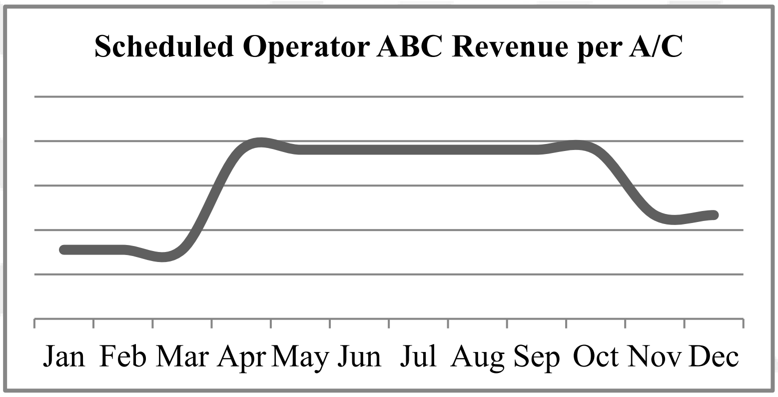


Figure 5.8 : Scheduled operator ABC revenue per A/C.

As expected, the resulting plot shows similar seasonal characteristics with the aircraft seasonal demand plot given by Muchiri and Smit (2009) as shown in Figure 5.5. In Figure 5.8, aircraft demand is at peak between April-October; therefore, this interval is classified as high season. On the other hand, between November-March, the demand is low; consequently, the interval is classified as low season. This aircraft seasonal demand plot explains why the revenue of operator ABC is high throughout summer and lower throughout winter.

The direct maintenance cost that appears to the operator during maintenance is a cost, which is offered by the MRO organization as maintenance service provider. As the revenue of scheduled operator varies seasonally, the revenue of MRO organization is also expected to fluctuate according to the season or the time of the year. In order observe this effect, the monthly revenue from base maintenance of MRO XYZ is analyzed and the result is plotted as shown in Figure 5.9.

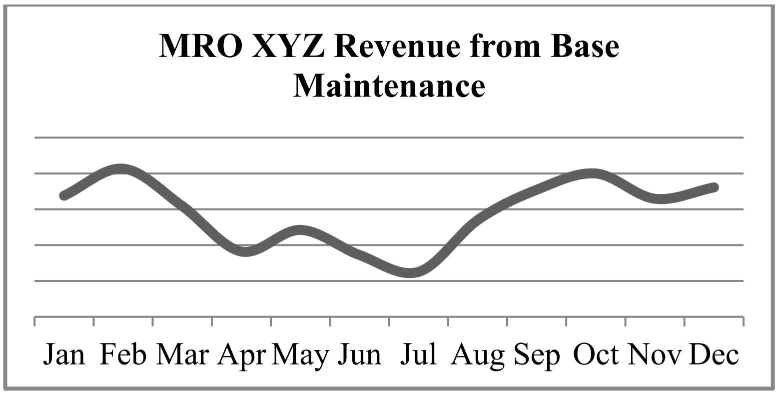


Figure 5.9 : MRO XYZ revenue variation.

In view of the information given in Figure 5.8 and Figure 5.9, it can be seen that the plot of operator's revenue is more or less the mirror image of the plot of MRO organization's revenue. Throughout high season, the revenue of operator is high, while the revenue of MRO organization is low. Figure 5.8 explains this trend in which during that period, the demand of aircraft is high and therefore instead of having their aircraft undergo maintenance; operators prefer to fly the aircraft to meet the demand. For that reason, the demand for maintenance service is low. On the other hand, throughout the low season, the demand of aircraft is low thus consequently; the revenue of operator is also low. On that account, operators prefer to perform the required maintenance during this period so that their aircraft will be at the required reliability level before high season arrives. As a result, the demand for maintenance is high and that reflects on the increase in the revenue of MRO organization.

From these figures, operators can actually see that during high season, there is a possibility of having better commercial terms of agreement, including maintenance price and rates from MRO organization, seeing that the demand of maintenance at that time is low. However, operators need to calculate the downtime cost and analyze its variation for different periods. As it has been mentioned before, there may exist a period where the downtime cost is lower than the direct maintenance cost. After that, for each period, operator may sum this downtime cost with the offered maintenance cost to have the total maintenance cost.

5.4 Total Maintenance Cost

There is no single method of calculating grounding cost of an aircraft due to maintenance. Each operator may choose a different method to use during their decision making process. However, as the profit level of an airline increases, either by the operation type or by seasonal factor, the overall effect of maintenance downtime increases, so does the downtime cost.

If it is required to choose a downtime cost model independent from operation type of the operator, subcharter cost indicates a better criterion when compared to aircraft lease cost model, since subcharter cost excludes all indirect costs that are accumulating while the airplane is not flying. Two different formulations for downtime and total maintenance cost can be suggested. One is with subcharter option (DTCs and TMCs) and the other one is with no subcharter option (DTCn and TMCn). There it is stated that opportunity cost only arises when operator chooses not to do subcharter agreement. Downtime cost of an operator with subchartering an aircraft is given by:

$$\mathrm{DTCs} = \mathrm{AOC} + \mathrm{SAC}. \tag{5.17}$$

Recall that AOC corresponds to aircraft ownership cost, which represents either aircraft lease cost (ALC) or ownership cost (OWC).
Subsequently, downtime cost of an operator with no subcharter option can be given as:

$$\mathrm{DTCn} = \mathrm{AOC} + \mathrm{OPC}. \tag{5.18}$$

Recall that OPC corresponds to the total opportunity cost of the aircraft operator.

The total maintenance cost with subcharter option is given by:

$$\mathrm{TMCs} = \mathrm{MTC} + \mathrm{DTCs} \tag{5.19}$$

Subsequently, the total maintenance cost with no subcharter option can be calculated by:

$$\mathrm{TMCn} = \mathrm{MTC} + \mathrm{DTCn} \tag{5.20}$$

5.5 Case Study

A case study with real life values can be shown briefly, which is retrieved from the review of MRO cost and airline spending in particular maintenance events. There, three conclusions are attained. The first one is that TMCn is sensitive to the variation in load factor (LF) and net profit per passenger (NPP) values. Secondly, as MEF value decreases MTC increases and in reverse DTC decreases. This is because MRO with lower value of MEF charges higher LBR with lower TAT or downtime in return. Thirdly, total maintenance cost with subcharter option is much more expensive than total maintenance cost with no subcharter option. Therefore, subcharter an aircraft is not an economical solution. As a conclusion, it is stated that for one light C check, summer is the season that yields the lowest total maintenance cost of $446,362. This provides evidence that the current maintenance scheduling mechanism, where operators prefer to put their aircraft to maintenance during low season or winter, does not give the most economical solution. This shows that there are needs in examining further the aspects of maintenance scheduling (Table 5.2).

Table 5.2 : Case study of scheduled maintenance cost in different MRO's.

Season	Variable	MRO_1	MRO_2	MRO_3	MRO_4
Winter	LBR	$60	$55	$50	$40
	MEF	1.8	1.9	2	2.1
	DT	19	20	21	23
	AOC	$158,333	$166,667	$175,000	$191,667
	SAC	$348,333	$366,667	$385,000	$421,667
	OPC	$72,641	$76,464	$80,287	$87,934
	DTCs	$506,667	$533,333	$560,000	$613,333
	DTCn	$230,974	$243,131	$255,287	$279,600
	MTC	$265,283	$259,127	$251,213	$223,073
	TMCs	$771,949	$792,460	$811,213	$836,406
	TMCn	$496,257	$502,258	$506,500	$502,673
Summer	LBR	$55	$50	$45	$35
	MEF	1.8	1.9	2	2.1
	DT	15	16	17	18
	AOC	$125,000	$133,333	$141,667	$150,000
	SAC	$420,000	$448,000	$476,000	$504,000
	OPC	$76,464	$81,562	$86,659	$91,757
	DTCs	$545,000	$581,333	$617,667	$654,000
	DTCn	$201,464	$214,895	$228,326	$241,757
	MTC	$249,454	$242,419	$233,625	$204,606
	TMCs	$794,454	$823,752	$851,292	$858,606
	TMCn	$450,918	$457,314	$461,951	$446,362

Nevertheless, case study given in Table 5.2 did not include the MST parameter. Despite the fact that MST will not bring changes to the maintenance man-hours and material cost, it will increase the downtime cost and the total maintenance cost respectively (Table 5.3).

Table 5.3 : DTC and TMC variation with MST.

Season	Variable	MST				
		0	1	3	5	7
Winter	DTCs (MRO1)	$506,667	$533,333	$586,667	$640,000	$693,333
	DTCn (MRO1)	$230,974	$243,131	$267,444	$291,757	$316,070
	MTC (MRO1)	$265,283	$265,283	$265,283	$265,283	$265,283
	TMCs (MRO1)	$771,949	$798,616	$851,949	$905,283	$958,616
	TMCn (MRO1)	$496,257	$508,413	$532,726	$557,039	$581,352
Summer	DTCs (MRO1)	$545,000	$581,333	$654,000	$726,667	$799,333
	DTCn (MRO4)	$241,757	$255,188	$282,050	$308,911	$335,773
	MTC (MRO1)	$249,454	$249,454	$249,454	$249,454	$249,454
	MTC (MRO4)	$204,606	$204,606	$204,606	$204,606	$204,606
	TMCs (MRO1)	$794,454	$830,787	$903,454	$976,120	$1,048,787
	TMCn (MRO4)	$446,362	$459,793	$486,655	$513,517	$540,379

In the previous case study given in Table 5.2, it has been shown that during winter, it is MRO1 that gives the lowest downtime and total maintenance cost both for subcharter and no subcharter option. While during summer, the lowest downtime and total maintenance cost are obtained from MRO1 for subcharter option and MRO4 for no subcharter option. Therefore, in this study, only the aforementioned values variations are evaluated. Table 5.3 proves what has been stated before. Even though MST does not affect the value of MTC or maintenance cost directly, it has a great impact on the downtime cost and hence the total maintenance cost.

6. LEASED AIRCRAFT MAINTENANCE

6.1 Aircraft Leasing

In early 1980s, aircraft leases were less than the 5 percent of the all-commercial airplanes in operation. After then, the number of aircraft increased with an accelerated pace and today it reached a substantial portion of all fleets. According to various fleet databases, almost 50% of the airplanes under operation are leased. The number of leased airplanes is more in Latin America, Europe and Asia Pacific and less in North America and Africa. The easier access to financing and the difficulties faced in same course plays a role in this segregation. This rapid growth in leasing seems to slow down in the last couple of decades. However, as the leasing companies become more accessible to financial markets, we shall expect the trend to continue at different rate.

It is a debate if the airlines have discovered the advantages of leasing options, or the macro-economic influencers have caused an obvious interest in aircraft as a commodity yielding attractive margins. However, adding aircraft to the current fleet for a defined period, without its own economic burdens and risks of owning an airplane became a typical method of fleet renewal and expansion, for the airlines. The catalogue prices of modern commercial aircraft in production are, regardless of the model or make, around 100M USD and over each. Trading of this expensive commodity in today's economical era definitely requires a financial plan. Such plan, which is the background need of leasing, is made through two main methods: Financial and operational leasing. To be aligned with the general context of the dissertation and explore the true influence of leased aircraft to maintenance costs, we will focus on operational leasing. From the maintenance cost performance, as there is no other party involved in the maintenance/operation of the aircraft in financial leasing, this type of aircraft lease will be left aside.

The outline of the following section is adapted from IATA's *"Guidance Material and Best Practices for Aircraft Leases"* document which is the aviation industry's most comprehensive reference document about aircraft leasing and its implications in all aspects. The process approach of the guideline and its coverage as aircraft leasing life cycle is matching the general approach of the dissertation. The outline is of the reference document is followed in order, incorporating real life experiences and current market conditions in aircraft maintenance.

6.2 Types of Aircraft Lease

Several types and terminologies are pronounced speaking about aircraft leasing, such as wet lease, dry lease and financial lease.

Wet lease is the process of temporary operation of an aircraft within another operator's fleet, where the commercial term is set per flight hours accumulated within a period. As the maintenance is under the responsibility of the original operator (or the owner) of the aircraft during this period, this type of leasing is not an integral part of the topic of discussion of this dissertation.

In **dry lease** however (also called as operational lease), the operator or the owner of the aircraft hands over their asset to another operator, along with the maintenance responsibility, carrying no influence to the operation. The whole discussion lies beneath the very fact that owner desires to protect the value of the asset and take back a fully airworthy aircraft at the return date with no accumulated maintenance burden. All are defined in a proper aircraft leasing agreement.

Financial lease takes place generally during new aircraft deliveries, when the airline keeps the ownership of the asset, while the substantial cost of the aircraft is financed by an institution. In this type of leasing, the operator does not return the aircraft or pay maintenance reserves. Therefore, this type of leasing is also not an influencer of the maintenance risk or opportunity for the airline. The sound and uninterrupted operation of the airline fleet, both technically and financially, is substantially affected by aircraft maintenance. Therefore, an indirect connection between all types of leasing and maintenance is always present.

6.2.1 Aircraft leasing from lessor perspective

In order to comprehend the financial risks of aircraft leasing associated with maintenance, it is essential to understand the lessor's perspective to the entire process. Leasing is a 'money making' financial transaction for aircraft lessors and their primary line of business. Some substantial maintenance costs arise in the leasing process for the lessee (operator), which are driven by lessor's aim to reduce risks and increase profits.

Operational leasing assumes responsibility for the operation and maintenance of the aircraft and legal and insurance responsibility during the lease period for the airline. However, the aircraft will remain the property of the Lessor. Lessors will aim to maximize their asset's value and therefore revenue generation potential over the economic life of the aircraft. This economical life usually covers multiple lease periods with different Lessees. The aircraft owner will also seek the Lessee to be compliant with legal requirements by the aviation authorities. For this reason, the leasing agreement enforces continuity of maintenance and its record keeping. The leasing agreements also mandate some restrictions on the geographical and operational utilization of the aircraft during the period of the lease. This contributes to the same aim, which is protecting the asset value and using the aircraft as long as possible as an economical commodity.

To preserve the commodity's economic value in time, the following can be noted as the primary objectives of the Lessor.

The depreciation of the asset's value should, under similar circumstances, correspond to that of other similar aircraft. This means that the aircraft must be used and maintained indiscriminately, but also be compatible with the Lessee's fleet requirements.

The aircraft shall be ready to be transferred between different aviation authority requirements during the lease period (to be prepared for an aircraft repossession in case of an airline bankruptcy) and at the end of leasing agreement. As the local aviation authorities have various requirement for the aircraft certifications, it is reasonable to expect the Lessor's to mandate the requirements of some common authority requirement such as FAA or EASA. From this perspective, countries' civil aviation authorities defining their regulatory framework upon these most common authorities is justified to support fluid transactions of the aircraft as assets. In addition to civil aviation requirements, aircraft customizations and configurations will differ amongst different airlines. Therefore changing such configurations at the end of lease period is an important discussion point, which comes up as an additional cost risk to the airline and this is seldom considered as a foreseeable cost driver.

The lease includes provisions for a security and solution to make sure that the aircraft owner is protected in case the agreement is terminated or a damage to the asset happens other than the regular wear and tear of the aircraft. In many cases, deposit payments and payments for maintenance reserves are considered to give confidence to the Lessor to protect asset value during an airline bankruptcy or disruption of operations. Some periodic inspections by the Lessor are mandated during the lease period, which will ensure that the commitments at the agreement are kept and maintained by the Lessee.

Table 6.1 : Objectives of aircraft lessor and lessee.

Lessor (Leasing company)	Lessee (Airline)
Value of the aircraft preserved	Aircraft operated safely
Aircraft returned on time when lease ends	Aircraft returned on time when lease ends
Marketability of the aircraft not deteriorated	Aircraft operated with low maintenance costs
Profits generated	Profits generated

The objectives of the lessor and the lessee are similar and the lease agreement signed is a token of such similarity. However, even when an agreement is in place, real life applications demonstrate a risk potential for maintenance costs for both sides. The lessor has to account that the asset (aircraft) transits between airlines through different leasing contracts. The airline has to undertake the contractual costs that arise due to the terms of the leasing agreement, which is designed and negotiated to reduce risks of the lessor.

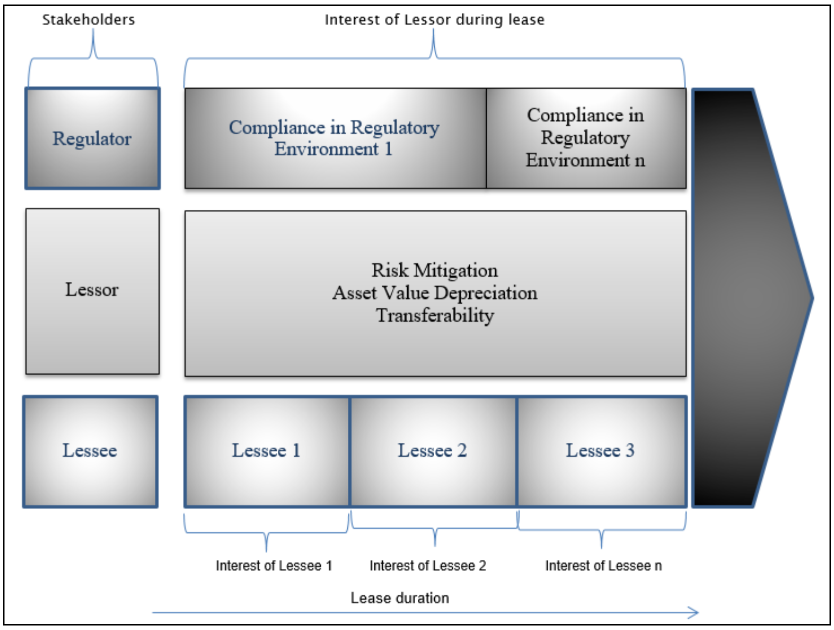


Figure 6.1 : Stakeholder's participation during lease duration.

The stakeholders of the aircraft lifecycle are the regulator (civil aviation organizations), lessor and the lessee. During the economic life cycle of and aircraft, several lessees may get involved. Even the lessor (owner of representative of the owner of the aircraft) can change during the aircraft lifecycle. All these transactions are the potential pitfalls when maintenance cost calculations are considered. Therefore, it is critical to look in detail to the individual lease process, which will be called aircraft lease life cycle of an aircraft. This lifecycle defines the real life of an aircraft for the airline when the asset is leased, not owned.

6.2.2 Aircraft leasing as a lifecycle (operator's perspective)

Airlines value an aircraft as an economic asset and analyze the operating costs it is expected to generate through its lease term. During analysis of the aircraft's operating cost, maintenance costs and dispatch reliability are also weighed in the decision framework. Fleet commonality also play a significant role given the substantial cost savings in qualified personnel training, spares inventories and modification investments that can be achieved by operating a common fleet of aircraft.

There are three main criteria having significant effect on the aircraft economics during airline's operation and playing significant role during aircraft selection.

- Aircraft Maintenance Status and Economics
- Aircraft Configuration Specification
- Aircraft Lease Rent

Lessors, or Sellers, are asked to provide detailed technical data mainly listed as below. Gathering process of those data may take time since Lessor or Seller may not have those details in one place and current operators are asked to provide those data by Lessors or Sellers. Airlines provide continues feedback about the sufficiency of received data and requests for shortfall data if any kind of data is still required.

This evaluation process includes below parts:

- Aircraft Configuration Specification
- Current Maintenance Status
- Projected Maintenance Status as of proposed delivery date
- Physical Inspection
- Reliability of the Aircraft

The lessee, while sourcing an aircraft for its operational needs and business plan, aims to maintain the aircraft with minimum maintenance cost driven by its maintenance program. The leasing contract however brings additional and somehow complex constraints for maintenance costs, such as maintenance reserves and redelivery maintenance check. The idea of this chapter is to demonstrate the magnitude and volatility of such costs, also pinpoint the pitfalls to mitigate the risks of maintenance cost budget overrun.

From the cost standpoint, an aircraft leasing shall be evaluated as a process. Each process either generates maintenance cost or influences future costs to arise. Starting from aircraft selection, pre-delivery process to include contract signature draws the general boundary of the cost driving mechanism. Once the contract is signed with its maintenance influencer clauses, a huge portion of the maintenance cost is defined in an undisclosed from. However, the monetary value of this cost is still unknown until the redelivery check is performed and the maintenance reserves are claimed. Risk items for both leasing terms will be evaluated in detail in the phases in Figure 6.2.

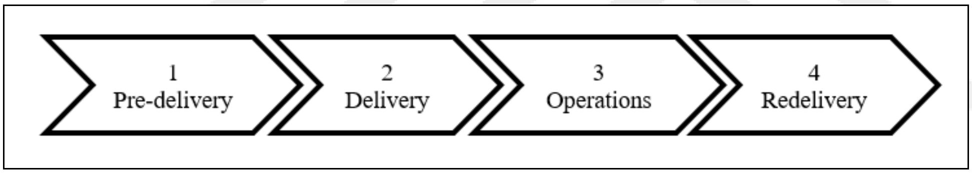


Figure 6.2 : Phases of aircraft leasing.

6.3 Pre-delivery

6.3.1 Aircraft selection

The aircraft, which is required by an airline, is selected by two main criteria out of the options from the new and used platforms available: Seat capacity and range. As the primary money making product of an airline is Revenue passenger kilometers (RPK), passenger capacity and range to travel are the key production elements. Therefore a high passenger capacity up to allowable limits and the maximum range are looked for. However, not all routes have a long distance in between and passenger demand. Therefore we see regional, mid-range and long-range aircraft platforms produced, based on the demand from airline operators.

When the type of aircraft is selected based on these main criteria, some contributing factors affect the decision, such as aircraft commonality, cost of leasing and availability. Out of an available group of aircraft, when a selection is made, the chain of events start, which will influence the maintenance, costs. It is a very critical fact that, not all aircraft are in the same maintenance status even if they are the same model and production year. Due to regional effects on some maintenance tasks and previous operator's maintenance program, same type of aircraft from different operators has a potential to generate substantially different maintenance cost.

If the aircraft is delivered from the production line and the ownership is at the airline, such difference is not applicable. However, the leasing phenomenon brings this cost pitfall, which is hidden and critical for this reason. Therefore, airlines shall deploy resources to review candidate aircraft in the light of maintenance cost generation, by reviewing Airworthiness Directive and Service Bulletin cost projections. In some cases, such hidden costs go beyond the expected and change the decision of the potential aircraft.

The airline shall decide upon an aircraft after the economic review of various options and based on specs defined on the documents provided by the Lessor. Before the airline gets into a commitment for an aircraft, the process shall involve a physical inspection of the aircraft. The aircraft technical records shall also be reviewed to make sure the proposed specs and the conditions meet the actual condition of the airplane. The inspection, which is carried out before the acceptance of the aircraft, is a more detailed one. Both inspections are very crucial as the costs that would incur during the lease may increase dramatically just to make the conditions of the aircraft relevant to the specs defined. The technical personnel who will carry out this physical and technical inspection should have prior knowledge of the airplane type and similar inspection processes. It is always challenging to locate appropriate staff for such inspections, who would also make judgments on economic impacts of the condition of the airplanes. As this review involves a great risk for future maintenance costs, consultancy companies offer this service out of their talent pool.

6.3.2 The leasing contract

When a lessor (who owns the asset) and a lessor (who leases the asset) are present, the financial and technical conditions of this relationship are defined by a leasing agreement. Before the lease starts, a time consuming process it put in place to make sure, the leasing contract is acceptable for both sides. As the airplane maintenance programs became complicated and aircraft configurations are various, this inspection process became very complicated, as well as time consuming. This applies for both the delivery and the redelivery processes. The airlines who do not budget the time and resources required for this process often accelerate the milestones and end up with a bunch of cost drivers for the future. To understand the process and be prepared is key for the Lessee to mitigate risks for the future (Table 6.2).

Table 6.2 : Summary table of leasing agreement terms affecting maintenance cost.

LOI term	Effect on maintenance cost
Delivery and lease dates. Termination of the lease options	Maintenance related cost sharing once an early termination occurs is very critical
Location of delivery and redelivery	The location is important from the maintenance provider availability standpoint
Conditions for delivery and redelivery (including LLP requirements, civil aviation requirements, procedures)	Important, but standard definition, which will change maintenance, costs. Checking the aircraft records with respect to these definitions is essential
Maintenance reserves, life definitions	Most critical definition in terms of future maintenance costs. Re-imbursement of ‘reserves’ is a cumbersome budget item for the future
Maintenance and its record keeping methods	Any restrictive definition will generate additional maintenance cost. Record keeping and redelivery will bring additional overhead cost to the airline, unless a sound system is in place
Airworthiness standards (including the AD cost sharing mechanisms)	AD’s to come, which are must maintenance actions might need to be accomplished during lease term, but will affect the aircraft for entire life. Compensation is seek for this reason
Aircraft modifications before and after lease	Modifications, which are not AD related, can also be negotiated between parties. Mod costs are substantial and can cause deviation from projections significantly
Maintenance events that are applicable for reserves	Very critical term, which will affect maintenance reserve related costs. Lessees experience and buyer power level is the key
Regulatory / registration definitions	Can affect registration / deregistration related maintenance costs

Once a lessor and a lessee agrees to enter into leasing discussions for one or more aircraft, after reviewing the technical specifications of the asset, a letter of intent (LOI) is presented to the airline for review. Therefore, LOI is the first legal step and it comes before the lease agreement to define the terms for the leasing agreement at a higher level.

While the lease agreement is the binding contractual framework for the future, the importance of the LOI should not be underestimated. It is at least the baseline for the definition of the lease agreement and reference to the negotiations on the lease. Therefore, important technical requirements and commercial definitions shall be present in the LOI and it shall be carefully reviewed and examined. The conditions, which will have implications on maintenance, related costs start being shaped in the LOI signature phase.

The key terms of an LOI usually deal with at least the following topics, some with significant and sometimes hidden effect on future maintenance cost.

It is quite striking that half of the LOI terms of an aircraft leasing, which are the basis of the lease agreement, have effect on future maintenance cost. It is also very depressing that the LOI phase is not handled as carefully as it should be during pre-delivery process by the airlines. A future maintenance cost projection is crucial before the signature of the LOI. Neither all the airlines have a dedicated organization in place to undertake this effort, nor do they have a sound advance planning to utilize maintenance cost projection before aircraft decision.

6.3.3 Maintenance reserve as a cost and security

The term maintenance reserve is a relatively new phenomenon to aviation industry and applicable to aircraft operations under lease contracts. It is a security for the lessor against financial losses in case of aircraft repossessions and often defined as a tool for the lessee to undertake major maintenance costs through equalized installments. Majority of the airlines with small to medium fleets are forced to accept maintenance reserve terms by lessors, while few flag carriers do not pay maintenance reserve. The increasing significance of maintenance reserve terms in leasing contracts is an obvious indicator of maintenance costs in the sound financial operations of the airlines.

In all operating lease agreements, the Lessee pays aircraft maintenance. The airline is responsible for the cost of maintenance, which arise as the airplane operates or just stands, such as line and component maintenance costs. In addition to these daily incurring costs, the airline shall also undertake his part for the long-term maintenance costs such as C checks and engine overhauls that would happen in the future, even after the end of its lease period. Landing gear overhauls, major modifications fall under this classification. The maintenance reserve term is born to make sure that the operator is accountable for such long-term maintenance. Depending on the system in focus, maintenance reserves are based on three fundamental maintenance intervals. Hours, cycles and time, as in all maintenance programs. The aim is to make sure relevant portion of such cost is accounted by the Lessee and perfectly covered in terms of resources required (labor and material).

There are four main maintenance reserve units to be covered by lease agreements.

- Standard period
- Variable period
- Standard fee
- Variable fee

Maintenance reserves with combination of its different types are given in Table 6.3.

Table 6.3 : Maintenance reserve events according to interval types

Fee type	Standard period	Variable period
Standard fee	Engine LLP's	
Variable fee	Airframe heavy checks Landing gear overhaul	Engine restoration and overhaul APU overhaul

As the airline pays for these maintenance reserves, they are also responsible to select the source and perform outsourcing (or perform in-house) of the maintenance activities. Once a maintenance requirement is fulfilled by the airline, such event becomes eligible to be reimbursed against the reserve, which was paid for. In other terms, reserves are paid back to the Lessee once the relevant maintenance event is performed. The previous Lessee of the aircraft might pay these reserves. In such case, the airline is entitled to collect the reserves from the Lessor, equivalent to the period of its operation. This phenomenon is also known as Lessor contribution to the maintenance reserves. In fact, it is just the transition of the reserves to the next Lessee to ensure the continuity of the maintenance of the asset. What the Lessor commits is to distribute the reserves amongst various operators as a positive result of no interruptions of the lease. In any interruption such as airline bankruptcy, the Lessor would use the same funds to maintain the airplane.

To give an example, the C check is taken. The period of the airplane C check is 6 years. The first Lessee has a leasing contract for four years, or its leasing agreement is terminated within four years. Within this period, reserves are collected and accumulated in Lessor account. After this initial four-year period, a second operator leases the airplane and operates for another four years. At the second year of second Lessee's operation, the C check will be due and second Lessee is entitled for the reserves paid by first Lessee. The second Lessee will also be eligible to collect the reserves paid by them, as the C check event will take place during its operation period. The graphical representation of this cycle is given is Figure 6.3.

In this economic model, the aircraft owner is protected by any risk of cost during all times of the leasing. As an example, in case the second Lessee goes into insolvency and cannot perform the maintenance before 6th year of the cycle, the Lessor is protected for the C check costs of the airplane. The maintenance reserves also said to support the airlines in terms of cash flow exposure to big maintenance events such as C checks and engine overhauls, as the reserves will help to overcome lump-sum cash requirements of such maintenance events.

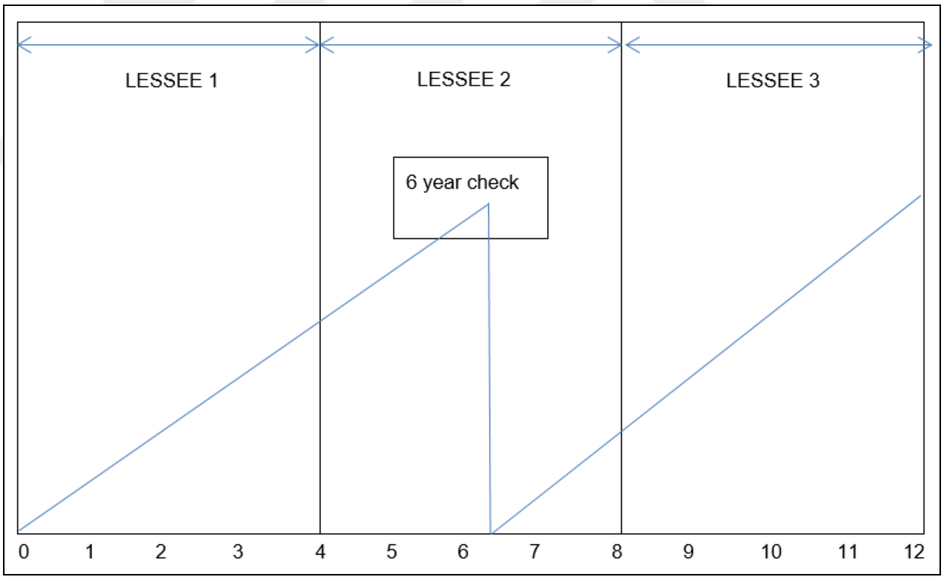


Figure 6.3 : Maintenance cost variance during lease cycle.

The aircraft owner will usually solely pay a compensation or contribution at the time of completing a maintenance event, considering that the fees to be reimbursed fulfill the eligibility requirements. The details of events to be paid are given in the lease agreement. Such definition justifies the importance of leasing agreements once again. Payment for any charges incurred out of the agreed scope and no longer factored into the underlying event fee assumption falls under the responsibility of the lessee. (Such as accidents, incidents, non-mandatory modifications, shipping, some over and above labor charges etc.). The leasing agreement will typically specify that any excess fees over and above reserve or Lessor contribution amounts will fall under the responsibility of the Lessee.

As a significant fact of Lessor's cause of existence, they will try to ensure that costs are covered in full for the maintenance events. On the other hand, it is natural to expect the airline to reduce costs and make sure the reserves are aligned with the market conditions. In the majority of the lease agreements, the reserve reimbursement is made upon presenting the evidence of the maintenance event, including the maintenance contract and the invoice. In other words, the reserve reimbursement is made based on actual cost, but not the reserves paid, while the limit is defined by the reserves paid. Therefore, it is an area of negotiation and discussion between owner and Lessee, the maintenance reserves. It is crucial to seek to agree upon some leasing agreement terms, such as the ones enabling the Lessee to collect any over-payment of maintenance reserves if the actual maintenance cost is lower than the reserve paid. The existence of such clause is very crucial, that would bring an additional cost burden to the airline or create an opportunity to make savings from another perspective. This particular debate is one of the main drivers of this dissertation in the first place. Same airplane, operated in similar conditions, even acquired with a similar leasing agreement would lead to different maintenance costs due to a single sentence or a word in the leasing agreement. While the Lessor is aiming to protect itself from cost exposure, it is necessary for the Lessee to seek all means of risk mitigation and cost reduction opportunities within the content of the lease agreement.

There are different methods to address the maintenance cost reserves. The Lessors dictate such methods looking at the credit level and financial health of the Lessee's. Some small operators, which are exposed to risk of bankruptcy, may not be eligible for the leasing in the first place and the fear of the Lessor is the risk to loose asset value and exposure to high and unexpected maintenance cost. For those airlines which are eligible to lease an airplane, their credibility and strength of financials drive the terms of maintenance reserves acceptable by the Lessor. Some of the reserve methods that are seen in leasing agreements are the following.

Maintenance reserve deposit is paid in advance to address a portion of maintenance cost risks for a period. As this is an average amount, it is highly negotiable. The amount and the time value of the money are the main discussion points as all advance payments in the industry.

Maintenance (lease end) compensation is a term used to value the maintenance cost by a dollar amount per flight hour, cycle or calendar days will be calculated based on a dollar amount equivalent to each flight hour, flight cycle or unit of calendar time which passes after a significant maintenance event or start of operation if the airplane is factory new. This term involves solid discussion and negotiation points on the condition of the aircraft and such condition can only be assumed as there is no way to precisely define such condition considering the complexity of aircraft systems and structures. Similar to the process depicted in Figure 6.3, at a certain point of time, the condition of the aircraft (and its engines) shall be determined to make a pro-rata calculation of the reserves. Maintenance intervals are commonly used as a baseline. However, maintenance programs are far more complicated than the intervals only. Furthermore, the ageing airplanes accumulate increasing maintenance requirements. The maintenance cost model depicted from Aircraft Commerce in section 6.3 indicated such change of the cost model according to age. For example, an engine's first, second and further shop visit cycles will have substantially increasing cost expectancy. Therefore, such cost expectancies shall be well defined in the lease agreement. While the Lessor would like to protect its asset and reduce maintenance cost exposure by enforcing high maintenance reserves, the difference between actual costs and reserves will have great impact to the cost structure of the airline.

Letter of Credit (LOC) is another financial tool used by the airlines to give assurance about maintenance costs. A pre-agreed total amount of maintenance costs are reflected on a letter of credit. Most of the times, such credit is provided on an annual basis. This might be a good alternative to cash reserves, but only for the airlines with reasonable credit limit. It should also be noted that, credit letters have their financial costs involved by any financial institution. Therefore, additional costs are incurred when such method is chosen. This depends solely on the size of the airline and its financial depth. For sizeable organization with high debt amounts, such financial cost is achievable and negligible. However, for those with lesser turnover, this option might be unachievable and unfeasible.

Redelivery Adjustment is an alternative of the cash reserve maintenance payments, which is accompanied by the letter of credit. In this option, the Lessor would be exposed to higher risk of incurring maintenance costs. It is therefore usually airlines with high credibility and good history record of accomplishment of proper payments.

Lessee might be required to pay an adjustment value when a maintenance event is accomplished with less time remaining than at what is expected at delivery, or the other way around when lessor may have to pay the Lessee for each event returned in better condition than at delivery.

Airlines believes that this method brings significant cost reduction opportunities, which is only applicable to operators with solid track record and financial health. A case study of the comparison between cash reserve payment and return adjustment is added at section 6.7. This case study clearly shows a cost reduction opportunity for the airline in case when redelivery adjustment is selected for maintenance reserves.

6.4 Delivery

Once the leasing agreement is finalized with the consideration of future economic and technical implications for both sides, the next step is to make sure the airplanes to be leased meet the conditions on the agreement. Delivery can be interpreted as passing of the asset from one side to the other, but its process has more in it. The leasing agreement annexes shall contain clear picture of maintenance status of the airplane including components, their maintenance intervals, AD and SB status including an eligibility plan for future applications, cosmetic areas such as cabin condition and paint of the airplane. In addition to the written status of the aircraft, how this status will be reviewed is an important point of discussion. Delivery checks being the ideal period to make the inspections, the timeline and intensity of those inspections is maybe the most crucial and influential parts of the leasing process. The timeline reserved for records and physical checks, special checks such as engine inspections are key areas to be agreed. While the previous lessee of the asset will naturally be willing to complete the redelivery process (to be reviewed in section 6.6) with the minimum cost and turn around time, it becomes a tri-party negotiation marathon on the maintenance condition of the airplane. Any defect or maintenance incompliance will bring additional cost to the new Lessee, unless discovered, noted and most important, agreed by the two parties, the Lessor and the Lessee. In other words, the airline loses the chance to claim for maintenance costs for the incompliances to be discovered during the redelivery process. Therefore, delivery is the most important timeframe of all maintenance cycle due to its high scale of implications for future maintenance costs.

A good and comprehensive inspection will require a reasonable timeframe and access to the airplane and its historical records. Setting the rights for this timeframe and level of inspection is for this reason constitutes a strategic value for the operator. Even if the discrepancies that are not affecting flight safety are discovered during the inspection cannot be fixed during the delivery window, it shall be noted and agreed with the Lessor to waive the responsibility of associated costs during the operation and at redelivery. It shall be noted that all involved in the delivery share the similar concerns and they naturally aim to mitigate risks for their own side. Goals of all parties during delivery is summarized in Figure 6.4.

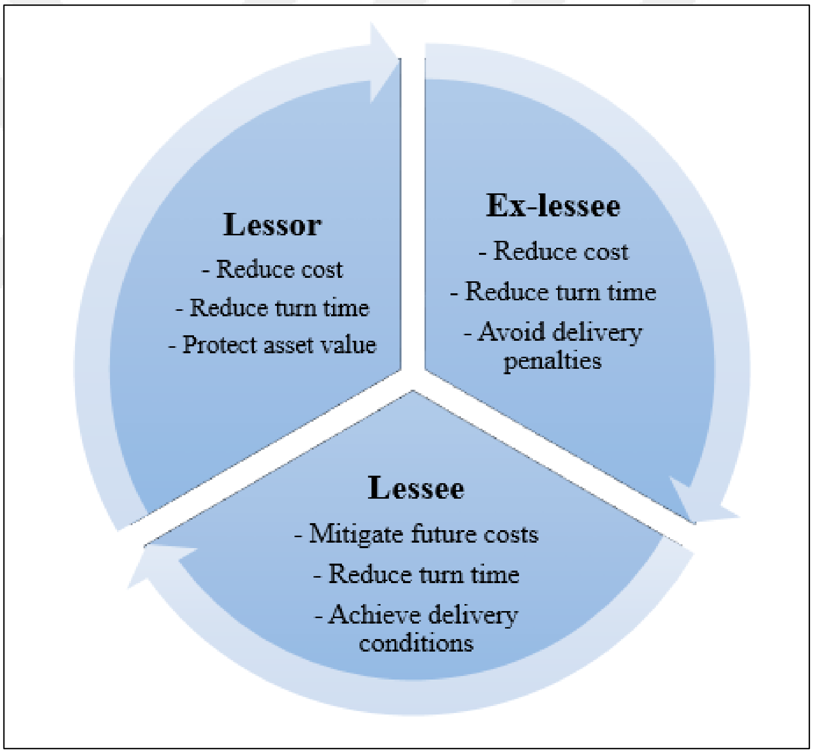


Figure 6.4 : Tri-party cycle of goals at the aircraft delivery.

One important are to be considered is the local civil aviation requirements with which delivery will be accomplished. Different aviation jurisdictions having variety of requirements within their airworthiness definitions, a change of the definition of the regulatory body to be complied would raise additional risks of costs for any of the parties. The airline shall be aware of the economic impact of the regulatory realm of the delivery in the first place.

6.4.1 Delivery inspection

While some of the goals of the Lessee's and the Lessor are common such as cost reduction, there are different ones as well. All parties will aim to reduce costs by nature, while satisfying the pre-determined conditions of the asset, written in the leasing agreement. The significance of leasing agreement becomes clear once again due to this fact. An airplane delivered to a Lessee from a previous operator will always bring discussion points on the condition, as the asset can never be the same as a newly delivered aircraft. The flight hours and cycles accumulated on the airplane will be different for every operator, while the wear and tear will vary according to location of the operation. This variance brings an ambiguity to be commercially discussed and settled. That is why delivery process is not solely a technical process, rather a commercial one. Except new and mandatory aviation authority or manufacturer requirements to be implied, the conditions for delivery are typical to the redelivery conditions of the previous operator. In many ways, leasing an aircraft is similar to renting an apartment.

The airline has a trade-off between starting the operation with the delivered airplane as soon as possible and start generating revenue and mitigating the risk of maintenance costs for the future that can arise from the unidentified technical discrepancies during the delivery. Therefore, the Lessor and the ex-Lessee are not the only parties willing to accomplish the delivery process as soon as possible. All parties having the same goal of reducing costs, it becomes a multi-dimensional and multi-objective negotiation between the parties. As a rule of thumb, this negotiation does not happen freely between all three. The Lessor undertakes a pivotal role to coordinate the effort to accelerate the process.

In addition to the basic regulatory requirements, the Lessee would want some configuration changes in the cabin, livery, entertainment and navigation standards of the airplane. For all such changes noted in the lease agreement, delivery is a good window of accomplishment. If the turn around time of the delivery is not sufficient or the lead times of the replacement parts are long, agreed specific changes can be accomplished by the Lessee during the operations period as well. There are various commercial settlement methods for those cases. A lump-sum payment can be agreed from the Lessor or subsidized within the rent of the airplane. It shall never be forgotten that such modifications delayed to the leasing period might require additional ground of the airplane. Section 5.1 of this study evaluated the grounding cost factor, which is mostly ignored during maintenance decisions. Negotiations with the Lessor for future maintenance events can also consider the grounding costs, at least as a pivotal point.

Delivery inspection is the ideal timeframe to identify the differences between agreed conditions of the airplane and the actual situation. Not all of those differences can be modified during the delivery period due to time and resource concerns. MRO capacity and material lead times are forthcoming challenges to deliver and accept an airplane according to the leasing agreement. Aircraft deliveries happening at the end of lease terms generally fall into MRO's high seasons and this timeline aligns with adverse market conditions depicted in section 5.2 of this study. Therefore, the capacity of delivery location plays an important role for the health of the delivery and consequently future cost drivers of leasing process.

As the redelivery process is a substantial cost driver for the ex-Lessee and the Lessor, these two parties may not be willing to involve the new Lessee to the delivery check. Still this might be only chance for the Lessee to identify the technical gaps and ensure full compliance against agreement terms of the leasing agreement at this very period. It is most crucial for the new user of the asset to define and agree a sound inspection period and deploy experienced staff to review both the airplane and its records against the conditions written in the leasing agreement.

6.4.2 Delivery conditions

When taking an airplane for lease, the airline operator builds on an existing fleet of similar types in many cases. Setting the delivery conditions with the Lessor and accomplishing necessary inspections to make sure that the airplane meets those conditions solely aims to ensure commonality within the fleet. This commonality includes seat and cabin layouts, paint livery, cabin equipment, cockpit instruments and their measurement units, performance configurations. These are the physical aspects of commonality. The Lessee would also like to ensure commonality with the maintenance program of the airplane with the rest of its fleet. Either in-house or outsourced engineering team will manage maintenance planning of the airplane together with the rest of the similar types and such commonality with the maintenance program is essential. Otherwise, the implications would be damaging in terms of resource requirements and bring additional running costs. Commonality is an undebatable standard to be achieved of aviation industry. Deviation from fleet commonality will not only affect maintenance costs, but also drive ancillary costs in operations such as cabin and cockpit crew, ground handling and even navigation.

As only one of various examples, an airplane with a MTOW configuration higher than the entire fleet will bring additional navigational charges, while the lower configuration will disable some operation capabilities, which will cause loss in revenues. A single weight setting in the airplane's certification documents may create risks of cost overrun and loss of revenue in future operations.

Going back to the maintenance domain of the delivery, some airplane parts are crucial to discuss in terms of maintenance costs. Engine maintenance described in 3.1.2 and time controlled components reviewed in section 3.1.3 of this study are key discussion points at delivery. In addition to those, wheels and brakes, auxiliary power unit and painting of the airplane have to be considered as a cost driver and pinpointed during delivery.

When segmented, airlines' biggest share of maintenance cost is wheels and brakes. Maintenance cost model in Section 4.2.1 clearly identifies this. However, as this is an on-condition component, it is hardly agreed upon between the Lessor and the Lessee during deliveries. Condition of the wheels, brakes and tires are vague, therefore a clear definition of the condition/life of the W&B's shall be defined in written and agreed between the parties.

Auxiliary Power Units (APU) are also maintained according to on-condition method. This means there is no periodic inspection requirement except the tracking of the life-limited parts within. An APU performing its air and electric functions without any issue may fail at any instance and regulatory bodies do not mandate a periodic inspection as this is an auxiliary system for operational comfort of the airplane. Still it is widely used and operators have certain time limitations in their MEL's to return the APU to service. It is obviously a costly process to overhaul the APU's, as it is a power turbine. Considering these facts, to mitigate cost issues in the future due to intermittent maintenance requirements, it is for the benefit of the Lessee to draw solid terms about the condition of the APU and obtain warranties. It is subject to the acceptance of the Lessor. However, APU's are solid risk points for future maintenance costs.

Structural repairs and their documentation play a predominant role in delivery discussions. There are OEM driven standards for structural repairs such as allowable size, distance between the repairs and position on the airplane. Although such standards are very clear according to manufacturer documents and directions, discrepancies amongst the industry is very common too. The Lessee shall always consider that any non-compliant structural repair on the airplane would lead to additional cost for compliance during redelivery. It can also cause immediate cost during operations, as the governing regulatory organization might not accept such repairs and require the accomplishment of the repair from scratch.

Apart from the physical compliance of the repair, its supporting documentation would lead to an excessive cost during operation and redelivery, if not acceptable or missing. Ambiguous definition of the condition of the repair, weather it is temporary or permanent, flush or patch contains substantial future cost risks in terms of actual maintenance and grounding requirements.

Most of the times aircraft owners desire to deliver and redeliver an airplane in plain base color without the color scheme, if not without touching the paint at all. However it is almost a standard to deliver in refreshed paint and there are cases when the Lessee asks and obtain right to have the airplane with their specific livery. The distinction between livery requirements brings additional cost at delivery and redelivery and plays a factor on additional grounding of the airplane.

In addition to the livery, type of the repair weather it is conventional, polished or with new paint systems is a cost driver. The Lessee would even ask a specific paint system provider to be utilized to match their current fleet, although different providers claim to provide similar colors. Still, paint is an important debate and risk factor for deliveries.

One of the key targets of an asset owner is to lower the transition costs. Transferability of the asset according to a plan or in irregular situations such as repossessions when a Lessee is in default or when its operations are disrupted are always accounted as a decision factor when placing a lease to an airline. To mitigate risks and reduce costs at Lessor's front, they choose to keep the airplane airworthy according to a particular aviation regular (EASA or FAA). This however comes with a cost and undertaking of such cost is might be a pitfall for the Lessee. The changes between regulatory standards would require major modifications in navigation or indication systems. Even some additional cabin or system tasks could arise due to the transfer between regulatory requirements. (Such as fuel system mandates in some CAA's or crew resting requirement that would change the cabin layout).

Mitigating this factor as a cost, the Lessee should first define the additional requirements that are required during delivery or redelivery and make sure the leasing contractual documents reflect these requirements. The cost burden of these requirements shall also be budgeted in advance at leasing decision and maintenance planning. Lessee would naturally negotiate to share modifications costs as long as the Lessor agrees to it. But as in all highly risky cost drivers, awareness of such cost is the most crucial to mitigate its impact to the budget and free cash flow of the airline.

Any maintenance requirement due to regulatory mandates and certification of the airplane can be hidden within a leasing agreement very easily. Identification of these hidden costs is one of the key targets of lease negotiation and contracting. It is needless to mention the extra grounding that might occur due to certification requirements. Therefore, its impact is on the high likelihood / high impact part of the risk chart.

6.4.3 Delivery check

Lessee's are represented during delivery layovers to observe the process and interact with the Lessor, maintenance provider and ex-Lessee to one extend. The interaction between the Lessee and ex-Lessee is subject to Lessor approval and generally not favorable. It contains risks of prolonging the delivery check process. The information flow and interaction between four stakeholders of the delivery check is very sensitive. Having some similar goals and conflicting ones, the working relationship between them is a factor for cost risks.

From the Lessee perspective, the following targets would eventually mitigate the risks for future costs.

Condition of the airplane, its technical documents and the leasing contractual documents shall match. The maintenance actions during the delivery check shall also comply with this condition. Delivery check inspections are also an opportunity to make sure maintenance history aligns with airworthiness standards and the aircraft that is being accepted.

While the delivery check is yet another scheduled maintenance event to follow-up the inspection results are highly important in order to ensure that the defects are rectified. However, Delivery check is not a process to clear all maintenance tasks. As a rule of thumb, the check, which is due, shall be accomplished during the delivery period. Any additional request is subject to Lessor's approval and MRO's capacity.

Recording of the condition of the aircraft is crucial, as these evidences play an important role to reduce costs at redelivery or even achieving compensations from the asset owner.

A systematic inspection pattern shall be generated for each delivery check to improve inspection efficiency and achieve ease in negotiations with the Lessor.

As defined in leasing contract, the Lessee should have to right to observe critical phases of the delivery check. Before the release of the aircraft for service, those critical maintenance actions such as engine inspections, functional tests and cabin inspections shall be witnessed.

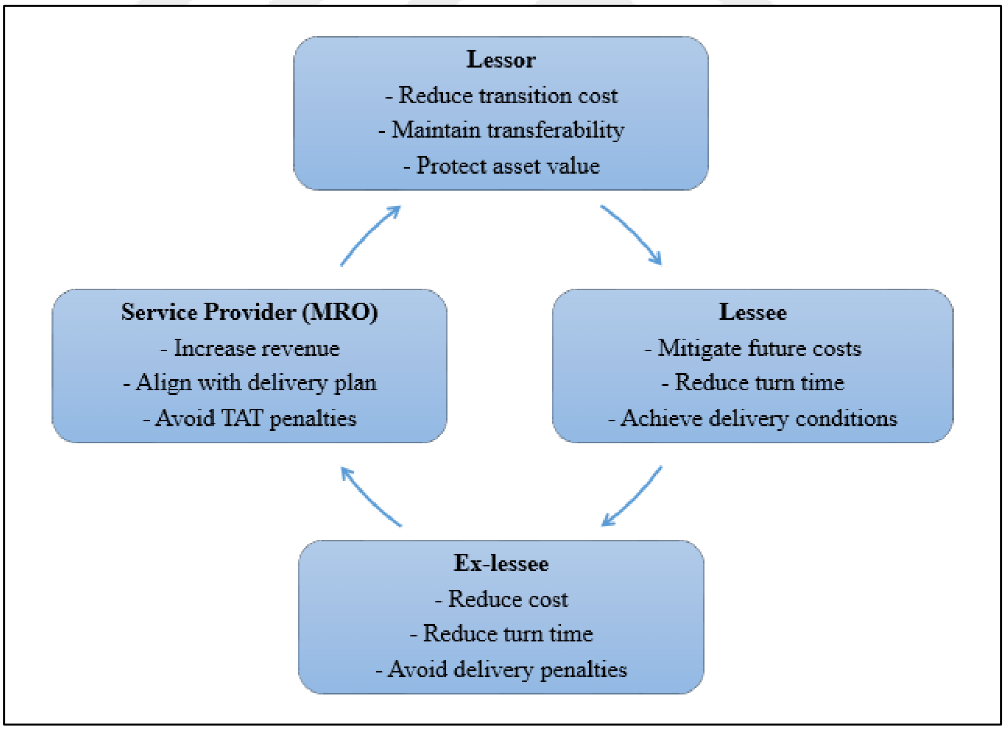


Figure 6.5 : Delivery check stakeholders and their goals.

The key milestone of a delivery check is the technical acceptance of the airplane by the Lessee. After this milestone, the Lessee accepts the aircraft by its current state and any missed discrepancies will be the responsibility of the Lessee. Therefore, all the work until the technical acceptance and the acceptance process is by far the most important phase of the delivery. A technical acceptance with most accurate technical condition of the aircraft is ideal, with a tradeoff with delivery schedule.

6.5 Operations

One the leased airplane starts operating at Lessee's fleet, two key responsibilities of the airline start. Keeping and proving the airworthiness of the aircraft and paying the dues arising from rent and maintenance reserves. As the reserves are calculated based on accumulated flight hours and cycles, monthly reporting to Lessor is required. For ensuring the airworthiness of the aircraft, the Lessor's usually deploy inspection teams on regular periods. Not keeping up with either of these two main responsibilities would create unforeseen costs out of repossessions and payment delay fees.

Some leasing agreements contain mutual responsibility for mandatory maintenance actions such as AD's. Sharing the cost of these mandatory actions would require interaction between Lessor and the Lessee. In ideal conditions, the methodology of this cost sharing shall be defined in the leasing contract, to mitigate future discussions.

6.5.1 Cost sharing

It would have been very straightforward if one Lessee keeps the airplane under its operation until the end of life. However, this is obviously not the case and most leasing terms arise from this very fact of transferability of the asset. Sharing maintenance costs is therefore quite complicated, as some of these maintenance actions will affect not only the current operator's lease period, but also future Lessee(s)'s operation as well. The fundamental principle of Lessee's responsibility of maintenance during the lease period results enforces that the Lessor shall compensate any maintenance action that would bring life to the system, structure or engine beyond the lease period. For scheduled maintenance events with periods fitting into the lease period is not a debate. It is the sole responsibility of the Lessee. However, a mandatory modification task to be performed, which falls into the lease period, will obviously affect the future life of the asset. At this point, sharing the cost of such maintenance actions becomes a critical decision factor for mitigating costs for the Lessee. From another perspective, even if the airplane was not under lease, the asset owner should have performed those mandatory tasks. Therefore, the costs shall be shared.

Sharing the cost of mandatory modifications should be an integral part of the leasing agreement in the first place. Some of the airworthiness directives are mandated with future implementation dates. This is quite an accessible information in advance. A careful engineering study of such future maintenance actions that would fall into the lease period is ideal. The cost sharing mechanism for those known events can be negotiated and determined in advance. However, there would be some future requirements that do not exists at the time of the leasing decisions. A formula for those unknown tasks shall also exist in the leasing documents to mitigate cost risks.

6.5.2 Maintenance reserves and claims

The leasing contract includes provisions for the areas of maintenance reserves. It is a matter of agreement between the airline and the Lessor. However, as explained in previous sections, reserves are generally set for maintenance segments with long intervals. These are generally D checks, engine overhauls, landing gear overhauls and APU's. Reserve areas are also common with high economic impact. Considering the fact that maintenance reserves are mechanisms of mitigation for cost risks for Lessors, it is obvious that the coverage is for high cost segments.

As the reserve calculation requires utilization information, the flight hours and cycles accumulated on the leased airplane is communicated by a report to the Lessor and the dollar value as sampled in Figure 6.6 arises. Timely payment of the maintenance reserves are as important as the rent payments. Payment delays on reserves can trigger default clauses in the leasing agreement and may lead to repossession. A repossession is very costly for the asset owner, but even more costly for the operator when legally reimbursed by the Lessor.

Description	Utilisation	Rate	Amount
Utilisation for the period from 01-Jun-2019 to 30-Jun-2019	Rate UOM		Currency: USD
Airframe D Check - Airframe	1.00 Month	32,782.00	32,782.00
Engine Performance Restoration - Engine [SN:]	360.85 Flight Hour	428.00	154,443.80
Engine LLP Replacement - Engine [SN:]	105.00 Flight Cycle	870.72	91,425.60
Engine Performance Restoration - Engine [SN:]	360.85 Flight Hour	428.00	154,443.80
Engine LLP Replacement - Engine [SN:]	105.00 Flight Cycle	870.72	91,425.60
Landing Gear Group - Airframe for [SN:]	1.00 Month	9,834.00	9,834.00
APU Performance Restoration - APU [SN:]	105.00 Flight Cycle	175.00	18,375.00
Total Amount Due:			**552,729.80**

Figure 6.6 : Maintenance reserve sample table for a commercial aircraft.

On a regular payment schedule of the reserves, once the maintenance events are accomplished, the reserves are reimbursed to the Lessee. This can either be compensation of the service provider directly by the Lessor or claiming of the service provider invoices and receiving of the funds by the Lessee. Leasing agreements contain common provisions for the reserve claims such as coverage of the payments. Collateral costs such as logistics, optional modifications, and cosmetic actions on the airplane are generally not considered under the claims for reserves.

In the real life applications, Lessors do not demonstrate a significant scrutiny against reserve claims though. As long as the claimed reserve amount matches the reserve funds collected within a period, it is a general practice to reimburse reserve claims with a proof of accomplishment of relevant maintenance event.

6.5.3 Maintenance reserve areas

C checks cover a large group of maintenance tasks and not all of them are either covered by the maintenance reserves or the can be claimed against reserves. In other words, the C or D check costs for an airline cannot be fully defined by maintenance reserves and additional costs shall be accounted. This is one very common cost pitfall for airline operators with leased fleets, especially for those who make their airframe maintenance cost budgeting according to maintenance reserves only. Cosmetic tasks, cabin interiors work and optional tasks and modifications are not covered by reserves. It is better to define the reserve coverage clearly in the leasing agreement to avoid future discussions. In order to accept reserve claims and reimburse the payments, Lessor would require evidence of the checks performed. This is an acceptable norm in the industry.

As seen in Table 6.6, engine maintenance reserves are calculated and reimbursed according to both flight hour and cycle utilizations. The reason is engine LLP's time controlled maintenance status and significant cost share. Like other time controlled maintenance segments, LLP costs can be tracked and its cost can be shared easily. For engine maintenance reserves, the most crucial risk factor is with the redelivery conditions. An economical mismatch between the reserves and lease return terms, significant and unforeseen costs may arise at the end of the lease period. Every maintenance event planning on engines shall account the conditions at the redelivery. The airline can easily be exposed to unnecessary costs due to over maintenance or adjustment penalties at the redelivery period. The leasing agreements often contain excessive delay penalties for redeliveries and there are seldom solutions for immediate engine maintenance needs. These factors may lead to catastrophic costs that would affect the cash flow of the airline.

Considering the sole aim of maintenance reserves, mitigating the risks of asset value depreciation and costs that would arise during repossessions, Lessors pay an importance to Landing gear reserves. Landing gear overhaul is a straightforward maintenance event. However, aviation regulators are quite inflexible with the back to birth (BtB) tracing of landing gear parts. Therefore, to claim maintenance reserves out of landing gears, the operators shall demonstrate great scrutiny of the landing gear overhaul process. Using of untraceable landing gear parts will be unacceptable by the Lessors and they will not reimburse the associated maintenance reserves in such a case. Selection of an agreed landing gear service provider and demonstration of the eligibility of used parts to the Lessor mitigate risks for substantial cost.

Maintenance reserves on APU's are treated with the same extend as the engines and landing gears. These high value assets affect the value of the aircraft greatly. Therefore, Lessor's will agree on reserve claims only if a legitimate maintenance performance is demonstrated with eligible and traceable spare parts.

6.5.4 Maintenance reserve fees versus real life costs

The fees to be paid by the lessee during lease period are a part of overall contract negotiations and may alter from operator to operator, while it changes in different types of aircraft and lessor. Therefore, it is crucial to understand the difference between real life costs and leasing contract requirements.

A reputable airline operating narrow body commercial aircraft undertakes the following maintenance reserves as an obligation of their aircraft lease agreement. Engine performance restoration, engine LLP, 12YE Check, 6YE Check, L/G Overhaul and APU. While these cost elements are considered as a part of maintenance reserves, the following are left out of the definition: Line and ramp checks, A checks, C checks, Wheels and Brakes, Thrust Reverser, LRU Component Support.

When the dollar values of average maintenance reserves are compared with Aircraft Commerce data as seen in Figure 6.7, we can see that the values are relevant and not too far from each other. At least, the overall annual maintenance cost estimates are quite alike.

	Leasing reserves				Aircraft Commerce data			
	Unit	Reserve	Per F/H	Annual	Unit	Cost	Per F/H	Annual
Engine performance restoration	F/H	$ 200	$ 200	$ 560,000	F/H	$333	$ 333	$ 932,400
Engine LLP	FC	$ 180	$ 118	$ 329,400				
Line and ramp checks	F/H	$ 212	$ 212	$ 593,600	F/H	$212	$ 212	$ 593,600
A checks	F/H	$ 28	$ 28	$ 78,400	F/H	$ 28	$ 28	$ 78,400
C checks	F/H	$ 51	$ 51	$ 142,400	F/H	$128	$ 128	$ 358,400
12YE Check	Mo	$ 6,000	$ 26	$ 72,000	Mo			$ -
6YE Check	Mo	$12,000	$ 51	$ 144,000	Mo			$ -
L/G Overhaul	Mo	$ 4,000	$ 17	$ 48,000	FC	$ 19	$ 12	$ 34,770
APU	F/H	$ 40	$ 40	$ 112,000	FC	$ 44	$ 29	$ 80,520
Wheels and Brakes	FC	$ 88	$ 58	$ 161,040	FC	$ 88	$ 58	$ 161,040
Thrust Reverser	FC	$ 29	$ 19	$ 53,070	FC	$ 29	$ 19	$ 53,070
LRU Component Support	F/H	$ 180	$ 180	$ 504,000	F/H	$180	$ 180	$ 504,000
			$ 999.25	$2,797,910			$998.64	$2,796,200
Annual utilisation	F/H	2800						
	FC	1830						
	Ratio	1.5						

Figure 6.7 : Comparison of maintenance reserve cost versus cost per hour values in previous chapters.

It is not a big surprise to see how close the values are. The reason is, as explained in the previous section, maintenance reserves are established not to make profits, rather to mitigate the risk of any airline bankruptcy and its affect during the lease period. It is also a tool for the leasing company to fairly distribute maintenance cost burden amongst airlines sequentially using the same asset.

Whether covered by fair maintenance reserve clauses, the riskiest phase of the aircraft leasing life cycle is the redelivery.

6.6 Redelivery

From the Lessee perspective, redelivery is the last stop in the whole leasing process. It contains biggest pitfalls in terms of cost risks, technically and contractually. Most leasing agreements enforce continuation of lease rents during redelivery periods, to make sure that the ex-Lessee puts adequate concentration and resource on the redelivery project. A majority of the leasing agreements also enforce increased rent amounts for delayed deliveries. In addition to its direct maintenance costs, a redelivery check could be very risky in terms of collateral costs to the airline. Systematic preparation for the redelivery process, a leasing contract to define redelivery conditions with no gray areas and even a certain period of early grounding of the aircraft would help to mitigate the risks of the redeliveries.

6.6.1 Redelivery conditions

Main cause of unexpected costs during the leasing life cycle is the inconsistencies within the leasing agreement and discrepancies with the condition of the aircraft. If these inconsistencies and discrepancies are eliminated, majority of the risks will be mitigated. Redelivery conditions are generally in parallel to the delivery conditions of the aircraft, except the case when the Lessee is the first user of such aircraft. If this is not the fact per the leasing contract, this is a red flag to the Lessee and shall be negotiated well in advance. Lessee's responsibility is to undertake required maintenance events during lease. Agreed redelivery conditions shall reflect this phenomenon, otherwise unforeseen costs will arise which will be borne by the airline.

The ambiguity in redelivery conditions will not only bring unforeseen and unaccounted maintenance costs, but it will also bring excessive delay penalties when redelivery checks are prolonged. Increased rents as delay penalties are common advantages that Lessor's utilize. From their standpoint, a delayed redelivery risks the continuity of the leasing of the asset and disrupt the return on investment. Lessor's being responsible for their shareholders; it is natural for them to draw their red lines against such revenue losses. Knowing the red lines of the Lessor, the Lessee shall plan the redelivery process thoroughly and put some buffer period for technical delays in order not to be affected by the delay penalty clauses. It shall be noted that every buffer or early grounding is a damage to the airline as well, due to the obvious grounding costs.

Maintenance programs help to identify maintenance milestones based on accumulated flight hours or cycles. However, the condition of systems and structures are most of the time ambiguous to decide whether it is acceptable or not. A single paragraph or word about condition of the aircraft can lead to an excessive maintenance requirement, even the replacement of the part or component. Therefore, every word at the contract counts. TAT's for such additional maintenance work and lead-time of non-routine parts can extend the redelivery check greatly, which will trigger delay penalties. No airline makes budgeting for delay penalties at redeliveries. Such unforeseen costs will disrupt the cash flow of the airline with great magnitude.

Contractual wording on leasing agreements also defines the location of the redelivery check. Lessor's aiming to protect asset value by ensuring high level of maintenance performed, they would enforce the delivery location. However, it is a significant cost driver with the ferry and fluctuating labor and material costs. As a rule of thumb, it is always better to accomplish a redelivery check at a mutually agreed location. A service provider dictated by the Lessee would trigger non-competitive pricing and eventually much higher costs. It should be at Lessee's decision to choose the redelivery location, fulfilling basic certification standards and experience log. Choosing a service center with adequate resources, which can undertake additional work, is also very important. If the non-routine findings or condition gaps cannot be rectified with a certain speed, the check will be delayed and the penalties will incur.

6.6.2 Redelivery process

Like in all projects, leasing lifecycle success relies on proper and early planning and deployment of adequate resources. Noteworthy activities during the redelivery phases are given in Figure 6.8 and cost risks are identified in Table 6.4.

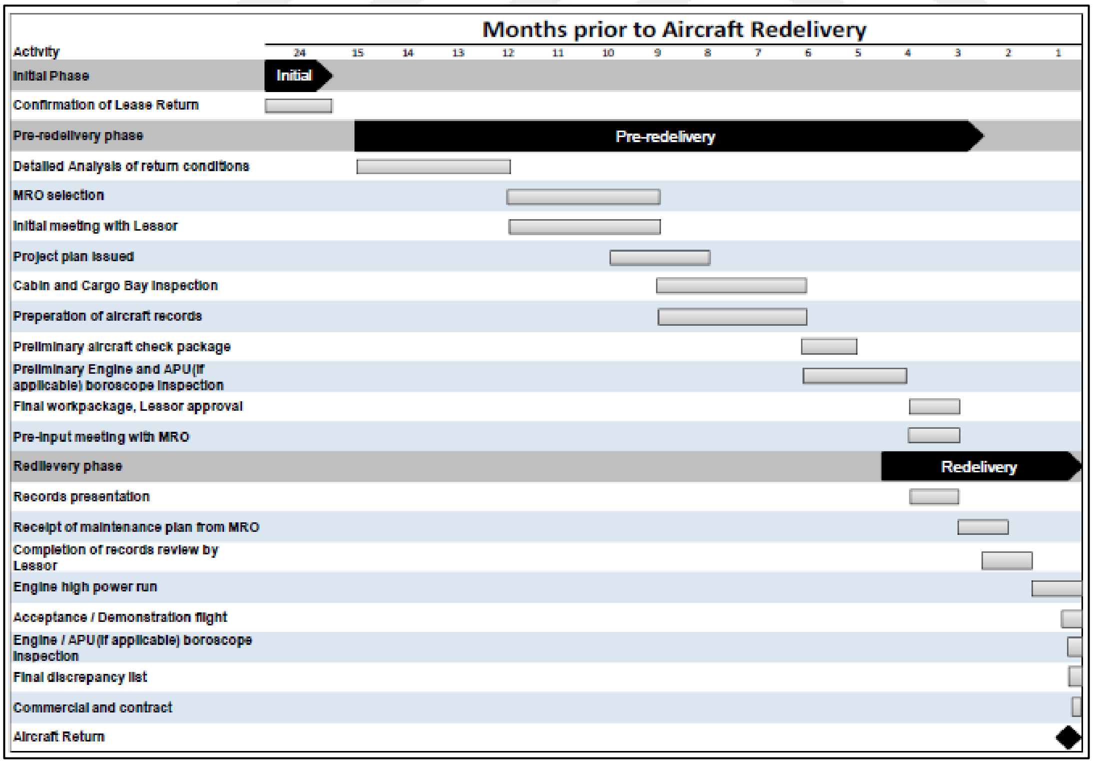


Figure 6.8 : Redelivery activity schedule, adapted from IATA Guidance Material and Best Practices for Aircraft Leases (2017).

Table 6.4 : Cost risks of aircraft redelivery actions.

Redelivery action	Level of impact	Risk on cost
Lessee's decision to finalize leasing	High	Based on return conditions, the redelivery maintenance package will be assembled according to the redelivery timeline. There is a tradeoff between early grounding of aircraft for redelivery check and grounding costs discussed earlier.
Detailed analysis of Return conditions	High	If not analyzed carefully, unmet return conditions may cause extended redelivery checks, unbudgeted costs and severe delay penalties.
MRO selection	High	As discussed in previous chapters, MRO's have different cost drivers, therefore prices. While the timing of the redelivery check also influences maintenance costs due to seasonality factor, the location also matters in terms of ferry flight costs.
Initial meeting with Lessor	Medium	It is of great importance to understand the lessor requirements to minimize unbudgeted costs and risk of delays and penalties.
Project plan issued	Medium	Pre-planning is crucial to make sure all airline resources would be available to cover the redelivery check. These resources are material in hand, monetary capacity, subcontractor MRO availability and personnel allocation.
Cabin and Cargo Bays inspection	High	Usually named as cosmetic items, cabin maintenance requires material with long lead times. Such material shall be defined and located in advance to fall into the redelivery check period. Otherwise delays and penalties will occur.
Preparation of aircraft records	High	The aircraft historical maintenance records are as valuable as the aircraft itself. Regardless of the maintenance event's performance, if its records are not presented properly, such maintenance event has to be redone. This is a great risk in terms of hidden maintenance costs.
Preliminary aircraft check package	Medium	Check package brings great risks in terms of fulfilling return conditions.
Preliminary Engine and APU borescope inspection	High	With relatively less likelihood, an unscheduled maintenance requirement on the engine or APU may cause a substantial deviation from maintenance budget. Shall be pinpointed in advance.
Final Check Package Definitions	Medium	At some point, the finalization of the check package is very important in terms of MRO's resources to deliver on time.
Pre-input meeting with MRO	High	The communication with the MRO is highly effective to mitigate risk of any delay. As the redelivery check involves at least 3, sometimes 4 parties (Lessee, Lessor, MRO and new Lessee), the correct procedure shall be in place to define lines of communication. Lacking of such coordination may cause severe additional costs and delays to the lessee.
Records presentation	Medium	The timeline of records presentation is important to enable timely review and evaluation. Last minute findings in the record pack bring severe risk in redelivery timeliness and may cause penalties.
Receipt of maintenance plan from MRO	Medium	MRO's plan for redelivery check is a baseline of incorporation of other resources from airline, lessor and subcontracting MRO's. Mismatching timelines will highly influence redelivery schedule.
Completion of records review by Lessor	Medium	Rectification of any finding in the maintenance record is a timely process and sometimes an additional maintenance item with unknown cost.

Table 6.4 (continued) : Cost risks of aircraft redelivery actions.

Redelivery action	Level of impact	Risk on cost
Engine high power run	High	Engine performance shortfalls, which can only be identified during high power, run can cause unexpected rectification requirements, need for consulting to OEM and even engine removals.
Acceptance / Demonstration flight	Medium	Aircraft performance parameters can only be seen during the demo flight. In addition, check package related defects could be disclosed. Severity of such defects can influence the redelivery date, while the cost is generally covered by the MRO as a part of warranty obligations.
Engine / APU borescope inspection	High	A last minute finding beyond limits of the power plant may cause removal and shop visit costs. With low likelihood, it is also a potential huge impact on maintenance budget.
Final discrepancy list	Medium	Final discrepancy items are generally insignificant findings. Beyond its maintenance cost impact, the delay risk is relatively low but still significant.
Commercial and contract	High	The signature of the technical acceptance of the aircraft by the lessor is the final milestone of a redelivery check. As accepted the milestone for end of lease, its penalty impact is obvious.

6.7 Case Study on Maintenance Reserves

This Case Study intends to visualize how the Maintenance Reserves payment structure affect to an Airline's maintenance costs and the sensitivity between the Cash or in Redelivery Adjustment (RA) format. Both Cash and RA concepts will be described in detail below.

In both cases, the subject Maintenance Reserves amounts will refer to the same maintenance events. These events are also identified as heavy maintenance events, and can be found in detail in Table 6.6. The payment units of subject maintenance events are also specified in Table 6.6.

Table 6.5 : Heavy maintenance events.

Maintenance Item	Unit
Airframe-8Yrs	Monthly
Airframe-10Yrs	Monthly
Airframe-12Yrs	Monthly
LG	Monthly
APU	APU Hours
Engine Performance Restoration	Flight Hours
Eng LLP	Catalog List Price

These are the Maintenance Reserve related activities also named as Heavy Maintenance Events and their units. While airframe checks of 8, 10 and 12 years are calculated by their monthly usage, the Engine Performance Maintenance reserve rates are calculated by their respective Flight Hour utilization.

In order to visualize a sample aircraft, a brief background on that specific aircraft shall be noted. These fictional operational data of the aircraft are given in detail in Table 6.7. It should be noted that these information detailed in Table 6.7 would be used as reference when calculating various MR costs in both Cash and RA concepts.

Table 6.6 : Aircraft operational data.

Aircraft operational background	
Date of Manufacture	01.03.2006
Date of Delivery to Lessee	01.01.2014
Annual Utilization (in Flight Cycles)	2,500 Cycles
Annual Utilization (in Flight Hours)	4,500 Hours
Annual Utilization (in APU hours)	1,900 APU hours
Daily Utilization (in Flight Hours)	12 Hours
Daily Utilization (in Flight Cycles)	7 Cycles
Daily Utilization (in APU Hours)	5,25 APU hours
Accumulated Flight Hours at Delivery	35,500 Hours
Accumulated Flight Cycles at Delivery	20,000 Cycles
Date of Redelivery from Lessee	01.01.2020

The cash payment structure is based on the concept of depositing maintenance reserves to the lessor on a regular basis, generally on a monthly basis. The amount paid to lessor may vary when the reserve is based on variables such as flight hours or flight cycles flown by the aircraft within the given month. However, in this study, all the cash reserves will be based the same monthly basis to compare the cash and RA on equal terms. The reserve rates are given in Table 6.8.

The RA payment structure, on the other hand, is based on the concept of providing the Lessor with a Letter of Credit issued by an appropriate banking corporation to both parties. The main difference on this concept is the fact that Lessor and Lessee (Airlines in this case) offsets the subject Maintenance Reserves based on the utilization of each Heavy Maintenance Event's unit utilized on Lessor and Lessee term. This calculation will be elaborated in later sections.

In advance of getting in detail of how the Maintenance Reserves are calculated and how each payment structure differs in total monetary amount accumulated in subject

Reserve, a constant Maintenance Reserve rate will be given to each subject Heavy Maintenance Event. The rates given to each Heavy Maintenance Event can be seen in Table 6.8.

Table 6.7 : Maintenance reserve rates.

Maintenance Item	Unit	MR Rate
Airframe-8Yrs	Monthly	\$7.500
Airframe-10Yrs	Monthly	\$4.000
Airframe-12Yrs	Monthly	\$5.000
LG	Monthly	\$2.750
APU	APU Hours	\$35
Engine Performance Restoration	Flight Hours	\$150
Eng LLP	Catalog List Price	N/A

It is worth noting that the maintenance reserve rates presented in Table 6.8 do not refer to any actual agreement signed between airlines or any lessor. On the contrary, they are denoted, in order to be run through maintenance reserve calculations. For the avoidance of complication, the flight hour to flight cycle ratios of the previous operator and airline will be taken as the same. As a result, each operator's Engine Performance Restoration Maintenance Reserve rate will be \$150.

The initial information, including how many flight hours the engine has operated since its last maintenance shop visit, its delivery date to airlines, when it is going to be redelivered etc. are given in Table 6.9. It shall be well underlined that, given engine data are sample for reserve rate calculations.

Table 6.8 : Engine history and delivery projection.

Sample Data	
As of date	01.09.2013
TSN	34000
CSN	19000
FHs since last Shop Visit	14000
FCs since last Shop Visit	9000
Delivery Date	01.01.2014
Engine TSLSV at Delivery	15000
Engine CSLSV at Delivery	10000

The values specified in Table 6.9 will be the ones used in this study to compare Cash MR and RA MR. As it can be seen at Table 6.9, the engine is considered to be operated for 15,000 flight hours since its last performance restoration.

In addition to the Engine Background specified in Table 6.9, the forecast of that Engine's Maintenance activity and its operational estimation that would affect the Maintenance Reserves accumulated for shall be specified. In the Table 6.10, sample Engine's operational forecast and estimations that would affect the maintenance reserve calculation can be found.

Table 6.9 : Engine forecast and redelivery projection.

Sample Data	
Delivery Date	01.01.2014
Engine TSLSV at Delivery	15000
Engine CSLSV at Delivery	10000
First Shop Visit Date in Term	01.09.2016
Engine FH since last SV at first SV	22000
Engine FC since last SV at first SV	13500
Redelivery Date	01.01.2020
Engine FH since last SV at redelivery SV	21000
Engine FH since last SV at redelivery SV	10500

Table 6.10 summarizes the scenario the engine will be exposed to shop visit requirement during its operation by the airline. According to this scenario, the redelivery date of the aircraft is estimated to be on January 2020. During the lease term, airline will operate this aircraft and the engine will be overhauled twice. First overhaul will happen in September 2016 and the other one just prior to the redelivery of the aircraft. At its first shop visit, the engine is estimated to accumulate 22,000 flight hours since the last shop visit, which has been conducted by the previous operator in September 2010. At its last Shop Visit before the redelivery from airline, the engine is estimated to accumulate 21,000 flight hours from its previous shop visit.

A single engine's maintenance shop visit cost is estimated to be $2,500,000. This figure is not effected by the Maintenance Reserve payment concept. Both in Cash MR and RA MR Concept, this amount will be the same.

In case of RA concept, the formula that will be used to calculate subject Redelivery Adjustment is as follows:

$$(A-B) \times M \tag{6.1}$$

where;

A = Flight hours since new or previous Engine Performance Restoration at the Delivery Date. (In our case 15,000.)

B = Flight hours since new or previous Engine Performance Restoration at the Redelivery. In this case 0, since the last shop visit will be performed along with the Redelivery event.

M = the applicable MR Rate.

If (A-B) is a negative figure, the Maintenance Redelivery Adjustment shall be paid to the Lessor by Lessee. If (A-B) is a positive figure, the Maintenance Redelivery Adjustment shall be paid by the Lessor to the Lessee.

Thereby, calculation shall be as follows:

[(15,000 – 0)* $150] = $2,250,000

This value has to be paid by Lessor to Lessee at the redelivery. Considering two shop visits, the amount that the Lessee will spend on this Engine will be:

[(2 * $2,500,000) - $2,250,000] = $2,750,000

In case of Cash Maintenance Reserve, on the other hand, the calculation will be based upon operator's flight hour utilizations. The accumulated MR amount is calculated by the flight hours utilized under the operation of ex-Lessee since its previous overhaul, which is 15,000. The flight hours utilized until the first shop visit during the airline's operation is 7,000. Two utilization figures will lead to the following calculated MR.

[(15,000 + 7,000) * $150] = $3,300,000

As one of the Cash MR concept downsides, the amount that lessor is obliged to give to lessee cannot exceed the amount of the Shop Visit cost, which is $2,500,000. Therefore, the remaining $800,000 will remain in the lessor's account and it will be inaccessible by the lessee.

At the second shop visit of the engine during the operation, which is also the redelivery shop visit of the engine, the calculation shall refer to the flight hours utilized by the airline between two shop visits. Since the Flight Hours accumulated between those two shop visits is 21,000, the accumulated MR amount shall be as follows:

[21,000 * $150] = $3,150,000

In this case, just like the first shop visit case, the contribution amount paid by Lessor will not exceed the actual cost of the shop visit itself, which is $2,500,000. Therefore, remaining $650,000 will stay in the lessor's account and will not be accessible by lessee.

As a summary, the total Cash Maintenance Reserve amount paid by the airline is going to be calculated considering two shop visits and the reserves paid against flight hour utilization during the operation. This amount shall be as follows:

[(2 * $2,500,000) + (21,000 + 7,000) * $150] = $ 9,200,000

On the other hand, the lessor will pay two Shop Visit costs worth of Cash Maintenance Reserve to the lessee. Two engine shop visits cost is estimated to be $5,000,000.

In the Cash Maintenance Reserve concept, while the Lessee is paying $ 9,200,000, the lessor will contribute $5,000,000 to the reserve account in total. As the amounts paid by lessor are capped at actual Shop Visit costs, the lessor contribution is limited to $5,000,000. Therefore, the Maintenance Reserve balance between parties will be:

[$9,200,000 - $5,000,000] = $4,200,000

This sample study shows that the RA concept is in lessee's favor. As shown in the previous sections of this study, the amount Lessee will pay in total is $2,750,000, while this amount is $4,200,000 when the Cash Maintenance concept is selected. As a result of the sample study, utilizing RA Maintenance Reserves would save approximately $1,450,000 during the whole lease period. These calculations are summarized in Table 6.11.

Table 6.10 : Engines based maintenance reserve concept comparison.

Reserve Item	Cash MR	RA MR
Total Shop Visit Costs	$5,000,000	$5,000,000
Lessor Contribution	$5,000,000	$2,250,000
Lessee Contribution	$4,200,000	-
Surplus Reserve Amount	$4,200,000	$2,750,000
Balance	- $1,450,000	

Similar comparisons could be made around MR-eligible heavy maintenance events as well. These Heavy Maintenance Events are listed in Table 6.12. This table shows how the Maintenance Reserve amounts differ among various events in terms of cash and Return Adjustment calculations. A positive value in the balance column of Table

6.12 designates that, for the subject MR-eligible event, Return Adjustment MR concept stands out to be significantly more beneficial than the Cash MR concept.

Table 6.11 : Overall maintenance reserve concept comparison.

MR-Eligible Event	Cash MR	RA MR	Balance
Airframe 8-yr Check	$540,000	$540,000	-
Airframe 10-yr Check	$264,000	$216,000	$48,000
Airframe 12-yr Check	$230,000	$250,000	-$20,000
Landing Gear Overhaul	$486,000	$442,000	$44,000
Engine #1 Performance Restoration	$4,200,000	$2,750,000	$1,450,000
Engine #2 Performance Restoration	$4,200,000	$2,750,000	$1,450,000
APU Overhaul	$440,000	$398,250	$41,750
Total	$10,360,000	$7,346,250	$3,013,750

Table 6.12 shows a big risk and an opportunity at the same time. Once an airline chooses to lease an airplane with the Return Adjustment maintenance reserve terms, this operator significantly reduces maintenance costs. In this scenario, the RA Maintenance Reserve concept turned out to be $3M less expensive during the lease term. Therefore, it should be the preferred method by the operators. The maintenance reserve structure shall be built around the Return Adjustment maintenance reserve option instead of the Cash maintenance reserve option.

Cash reserves will give the lessor a comfort to mitigate the risk of the airline's potential insolvency. Because cash reserves are paid on a monthly basis and at any instance, the lessor has access to funds to cover any maintenance costs incurred at a repossession of the asset. However, nearly the 30% cost reduction opportunity is a good cause for the airlines to negotiate the RA maintenance reserve option with the leasing companies.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion

In this study, previous studies for modelling of maintenance cost are explored. Maintenance cost related risks and opportunities, which are not commonly discussed, are brought to the attention of the reader. Every risk for an unaccounted deviation from the maintenance budget should also be considered as an opportunity to maintain aviation best practices and improve those practices. On the other hand, opportunities that are not sought are also risks to lose the competitive edge for the airlines.

The periodic maintenance performed on aircraft, its engines and components is compulsory as one of the design criteria. The end product of any maintenance event is flight hours gained by the component, engine or airframe by means of replenished reliability. This reliability will unfortunately deteriorate in time and to ensure the safety of the aircraft (and its engines and components), periodic maintenance has to be performed.

To reduce the cost of maintenance, experts have been and still are putting numerous efforts on reducing the amount/cost of resource requirement for a certain task. They also try to extend the period of any possible maintenance task and they target less amount of maintenance requirement over the lifecycle of an airplane. Both ways are progressing with some success. At some cases, statistical tools are utilized with the help of big data and faster computing, in some, predictive maintenance tools and methods are used to depend on the reliability of a component to the farthest extend.

With some new tools and methods, not singular tasks but task groups and check packages are optimized too. The concept is to extend the periods of performance of such tasks and task groups. The longer the periods (or the intervals) are; the less application will be foreseen during the life cycle of the aircraft. Less maintenance means less cost. In addition, longer interval means higher flexibility for the airline to schedule the maintenance according to flight schedules.

Having such good effort and focus at the task and maintenance check scheduling level, modern efficiency tools are deployed at the performance phase too. Workplace optimization, waste elimination and supply chain management tools and methods are helping maintenance organizations and airlines to do the maintenance with better efficiency. However, the risks and opportunities related with maintenance costs that we aimed to tackle are beyond this level.

No one would argue about the fact that maintenance costs of airplanes of different manufacturers will be different. It is also quite easy to explain that geographical conditions have an affect on aircraft reliability, so the maintenance costs will vary by the location of operation. However, when it comes to the type of operation, whether it is a scheduled operator with a large fleet or a charter airline operating the same type of airplane from the same airport but on a seasonal business plan will have different maintenance costs. It becomes a harder question. Even the fact that the airplane is owned by the airline or leased from a lessor, makes substantial difference on maintenance costs incurred by the operator.

Different business plans of airlines affect the aircraft utilization and seasonal demand. While the analysts work on an optimized reliability offer to the airline, with the most extended task card period, it is surprising to see that the real cost of maintenance relies on the season of maintenance. Similar to the airfare raising during holiday months, MRO costs increase during the low seasons of the airlines, which is generally winter periods. The reason is simple. The general rule of supply and demand. Seasonally when the grounding costs are high, the MRO rates and prices are low. Even when the tasks to be performed are the same, both the MRO and grounding costs vary. Such variation is known, but has never been modelled.

These factors affecting maintenance costs have to be the subject of a study and a debate for at least two reasons. They contain risks for budget overrun and opportunities for cost savings. Moreover, they are mostly controllable by an airline operator compared to other cost cutting efforts initiated by mostly airplane and component manufacturers.

Any researcher or analyst having the aim to reduce maintenance costs shall understand the reason why maintenance is performed in the first place. The segregation of aircraft maintenance is then fundamental to tackle each segment with different tools and methods. Various classifications can be made. This is important because each type of maintenance, whether it is line, base, engine or component, has different implications to the operations and different risks and opportunities on maintenance costs.

Line maintenance can be considered as an immediate maintenance need and its short periods and content reduces the chances of improvement with its costs. Rather the station planning and workplace organizations in line maintenance have a great affect to reduce its cost. Line maintenance also comes with an opportunity to support base maintenance in terms of equalized maintenance planning and reducing the labor requirements of the base maintenance by performing some of the base maintenance tasks at the line level. The selection of outsourcing or insourcing of line maintenance is another key contributor for cost reduction.

Base maintenance however is proposed as the most influential maintenance type to overall maintenance costs. By the actual dollar spending, it shows the other way around though. In various sources, base maintenance segment is the fourth largest maintenance cost element after engines, components and line maintenance. In this dissertation, it is deliberately suggested that once rarely considered factors such as seasonality, cost of grounding and redelivery checks are taken into consideration, base maintenance shall be taken as the foremost influential of all maintenance decisions.

Therefore, chapter 4 and 5 represented the core material of this dissertation. To solve a mathematical problem, it has to be modelled first. Chapter 4 presented the aircraft maintenance cost models that are available in the literature and proposed a "new formula" of maintenance cost from scratch. Nevertheless, in the next chapter, this model is challenged by the term "Grounding Cost". Although cost of grounding has been known and considered in decision making for years, it has never been aggregated to a common definition. Chapter 5 proposed a definition for cost of aircraft grounding and suggested integrating it to the maintenance cost model.

Maintenance cost calculation usually includes costs that are directly resulting from the maintenance process such as cost of laborship, spare parts and tools and equipment. In some of those, downtime cost is neglected with the assumption that grounding is natural phenomenon. As the main argument of this dissertation, downtime cost is introduced with its financial value and seasonality is added.

The last chapter introduced a new aviation concept; the aircraft leasing. Leasing is a financial tool to help airlines to share risks of financial exposure when owning airplanes. However, the lessors are also willing to share the risk of unexpected costs while targeting profits and preservation of asset values. For this reason, the contractual tool named "maintenance reserves" are born. Not all but significant portion of an airplane's maintenance spending is reserved to the leasing company to reduce the lessor's exposure to high costs at a planned lease end or enforced lease termination. Without integrating the maintenance reserves to overall maintenance cost related decision-making process, it is not realistic to cover all aspects of risks and opportunities.

Different from the rest of the decision-makings, risks and opportunities associated with leased aircraft maintenance and maintenance reserves are shaped during initial leasing negotiations and lease contract signature. The affect of the leasing contract cannot be overemphasized for two reasons. The magnitude of risk/opportunity and its unpredictability. In an industry where profits are low and cash flow is fragile, a financial exposure at a lease return may lead to a severe financial burden to cover such unexpected costs, if not a bankruptcy.

Few airlines with large fleets, who are able to use the economy of scale, were found to exercise an alternative method to maintenance reserves. This alternative method is called redelivery adjustment. In most of the cases, asset owners/lessors shape the contracts and the obligations within. Therefore, it may not be an available option to select this alternative method. Still a case study has been presented and it has shown clearly that redelivery adjustment contains a substantial opportunity to reduce costs.

Same airline, same aircraft, flying the exact same routes on the same schedule. Nearly 30% cost saving opportunity with a wording change in the leasing agreement. This is the key message of this study to be taken-away.

Table 7.1 : What is introduced in this dissertation?

State-of-Art	Dissertation
Maintenance cost is a relatively small portion of overall airline costs. Its effect is insignificant.	Showed that maintenance costs are more controllable than other airline costs and comprise great risks of budget overrun.
Statistics suggest that, out of all 4 segments of maintenance costs (engine, component, line and base), base maintenance seems to be the element with lowest cost.	Explained that direct cost of base maintenance is relatively low, but its impact is the highest due to its direct effect to aircraft availability.
The industry accepts downtime cost “natural” and do not take into account for scheduled maintenance planning.	Proved that downtime cost is significant and shall be calculated with an industry-wide standard formula. Such formula is presented.
Direct maintenance costs are the only drivers of maintenance source selections.	Demonstrated that downtime cost is a bigger contributor to overall costs. Therefore suggested downtime as an integral part of source selection process.
Maintenance tasks are considered to demand a standard maintenance labor and that labor is fulfilled with standard efficiency.	Showed that a maintenance cost model can converge to reality when it includes labor efficiency factor as a variable.
Current maintenance models work on a standard ratio between routine task labor and non-routine labor. Same applies to material cost estimations.	Explained the variation of non-routine labor and material factor between operators, airplane types and ages, operation regions and type of the maintenance tasks.
Maintenance cost studies pronounce number of tasks, manhours required per task and intervals of tasks or task groups.	Suggested and used real dollar value as the outcome of maintenance cost models.
Sensitivity to seasonality is neglected at maintenance cost models and formulas.	Explained that geographical location, type of operation and seasonality is a significant driver of cost variances.
As the seasonality and downtime costs are avoided in maintenance cost models, cost of maintenance does not contribute to maintenance schedule decisions.	Generated an integrated maintenance and downtime cost function to be used for decision making, where seasonality is taken into account.
Type of lease and leasing contract discussions do not look at the maintenance cost, although it comprises the biggest risk.	Depicted the entire aircraft leasing lifecycle from maintenance cost standpoint, to mitigate cost risks.
Maintenance reserves in aircraft leasing agreements are accepted as an uncontrollable phenomena. They do not have effect on maintenance costs.	Discussed various types and methodologies of maintenance reserves. Showed that reserve types and terms effect maintenance costs.
Leased aircraft selections are generally made according to leasing fees.	Explained the best practice of leased aircraft selection, comprising the comparison of lifecycle maintenance costs.
Maintenance cost reduction efforts focus in interval extension and resource efficiency improvement in general.	Synthesized a holistic approach to tackle overlooked cost risks and opportunities, which oversees downtime, aviation contracts, supply/demand interaction and seasonality.

7.2 Recommendations

Future studies shall account the holistic approach when approaching the problem of finding opportunities of cost reduction and identifying risks of budget overrun in maintenance spending of airlines in the current market conditions. Figure 7.1 outlines the elements of such holistic approach that is proposed.

In addition to ongoing studies and efforts to reduce maintenance costs based on what and how soon to maintain, the industry shall ask when and how to maintain. Moreover, under which contractual framework the maintenance shall be performed. The real world pronounces currencies, so the studies shall do.

To pronounce dollar values and commercial information on an academic paper is quite challenging. However, it is required in order to understand, explain and discuss the scale of risks and opportunities much better. Maintenance periods in months or years, number of task cards and manhours, MTBF values and reliability charts. These are the fundamentals of maintenance cost, but not all the data in the maintenance decision making. As we have discussed these fundamental terminologies, we aimed to make sure the reader or researcher can access the entire information baseline. To understand the risks/opportunities in the current market conditions better, the dollar value is required.

Dollar value is a volatile scale to deal with by nature. Its value changes by years and geography. Its seasonality is a key discussion point of this dissertation. However, on a larger scale, the escalation factor, in other term the inflation was a fact to consider. In this study, the escalation factor has been deliberately disregarded. The amount of sources with dollar data that can be used as a reference were limited. Otherwise, the irrelevance of using dollar values from couple or more years apart is obvious. For further studies, it is recommended to use it or similar years' cost data in dollars shall be used.

Another challenge of working with currency data is the limitations out of commercially sensitive and company proprietary data. Most of the commercial entities do not allow to disclose own or other companies' commercial information due to obvious legal obligations. In other words, it is not possible to reach to and disclose commercial data. From this standpoint, all the commercial data and dollar values are taken from published papers and magazines, which are also available to the public.

Sources of the few financial data that are obtained from airline or service providers are not disclosed. It is recommended to continue with the same practice to protect the anonymity of the financial information and maintain the legitimacy of the further studies.

The current academic and commercial efforts and tools are mentioned in this study. However, an analysis of the outcome of such optimization tools are not included. It is challenging, but recommended to obtain data from an airline operator and demonstrate such analysis, which shows actual dollar values.

A new maintenance cost model, integrated with a proposed grounding cost formula has been shown in this study. To validate this model in the real life conditions, a single airplane approach is not sufficient. One of the most challenging decisions for an airline is to assign airplanes to their complicated route network. The industry is generating solutions for such assignment that would optimize the aircraft availability. However, those algorithms do not take maintenance costs as a part of their cost function. Maintenance schedules are assembled reactively after flight schedules are decided. As we have seen in this study, seasonality being a driver of maintenance costs, maintenance variables shall be integrated into those optimization problems. A demonstration of such integrated optimization problem would be a productive outcome of upcoming studies.

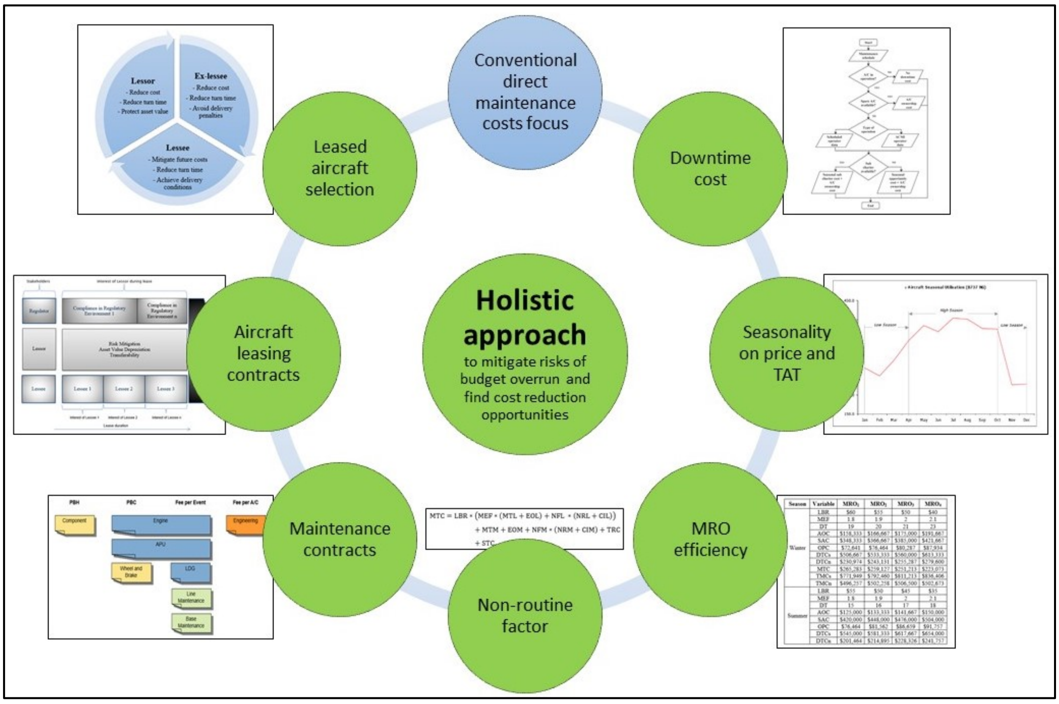


Figure 7.1 : Proposed holistic approach and its elements.

Having said that, a single airplane optimization solution will not apply to any fleet with more than one airplane. Larger fleets will turn out a more complex problem, where MRO capacities and seasonality in prices will inflate more in such instances. Assignment of airplanes to the route planning will end up with changes in aircraft utilizations. Utilization adjustment has not yet been a part of those “tail assignments”. To reach a better optimization solution, they shall be accounted in any proactive network planning.

During the literature review, several studies were seen that are addressing optimization problems based on unscheduled grounding of airplanes. In fact, there is a much wider concentration and industry consensus on the definition of cost of unscheduled grounding of airplanes. Although this phenomenon is not included in the content of this study, it is a fact and shall be considered in further studies. When an integrated maintenance cost model is simulated, such model can only be helpful to a level unless the unexpected in accounted. It is recommended to apply stochastic modeling to catch the uncertain characteristics due to non-routine originated maintenance costs and variation in aircraft’s demand according to the season and geographical region.

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APPENDICES

APPENDIX A: Comparison of Regular Component Repair vs PBH Costs

APPENDIX B: Maintenance Mathematical Model

APPENDIX C: Narrow body Lease Rates

APPENDIX A

Table A.1 : An airline operator's future PBH fees estimation.

	Months	A/C count	PBH	FH	Total fee
Year 1	January	11			
	February	12			
	March	12			
	April	12			
	May	13			
	June	14			
	July	14			
	August	14			
	September	15			
	October	15			
	November	15			
	December	15			
Year 2	January	15			
	February	15			
	March	15			
	April	15			
	May	15			
	June	16			
	July	15			
	August	15	92,00 $	216,67	299.000 $
	September	15	92,00 $	216,67	299.000 $
	October	15	92,00 $	216,67	299.000 $
	November	15	92,00 $	216,67	299.000 $
	December	16	92,00 $	216,67	318.933 $
Year 3	January	17	92,00 $	216,67	338.867 $
	February	17	92,00 $	216,67	338.867 $
	March	18	92,00 $	216,67	358.800 $
	April	18	92,00 $	216,67	358.800 $
	May	18	92,00 $	216,67	358.800 $
	June	18	92,00 $	216,67	358.800 $
	July	18	92,00 $	216,67	358.800 $
	August	19	92,00 $	216,67	378.733 $
	September	19	92,00 $	216,67	378.733 $
	October	19	92,00 $	216,67	378.733 $
	November	19	92,00 $	216,67	378.733 $
	December	18	92,00 $	216,67	358.800 $
Year 4	January	18	94,76 $	216,67	369.564 $
	February	18	94,76 $	216,67	369.564 $
	March	18	94,76 $	216,67	369.564 $
	April	18	94,76 $	216,67	369.564 $
	May	18	94,76 $	216,67	369.564 $
	June	18	94,76 $	216,67	369.564 $
	July	18	94,76 $	216,67	369.564 $
	August	18	94,76 $	216,67	369.564 $
	September	18	94,76 $	216,67	369.564 $
	October	18	94,76 $	216,67	369.564 $
	November	19	94,76 $	216,67	390.095 $
	December	19	94,76 $	216,67	390.095 $
					10.336.231 $

Table A.2 : Comparison of cost base.

	Before pool	After pool
Average A/C count	14,11	17,66
Total FC	38344	69124
Total FH	52687	108133
# of months	19	29

Table A.3 : Comparison of PBH and repair/exchange costs.

	Before pool	After pool
Exchange fee	4.811.00 $	
Repair fee	3.702.412 $	
Custom + Shipment (% 15)	1.277.012 $	
Pool fee		10.336.231 $
Pool scrap cost		712.393 $
Total	9.790.424 $	11.048.624 $

Table A.4 : Magnitude of cost savings with a new contract type.

	Before pool	After pool	Cost reduction
Average LRU cost per aircraft	36.531,43 $	21.579,34 $	-40,9%
Cost per F/H	185,82 $	102,18 $	-45,0%
Cost per FC	255,33 $	159,84 $	-37,4%

APPENDIX B

J = index for aircraft (j = 1,..,A)
k = index for maintenance program (k = 1,..,K)

Decision variables:

x_j = hours added to aircraft j at the end of planning period

$$y_{k,j} = \begin{cases} 1 & \text{aircraft } j \text{ has reached maintenance } k \\ 0 & \text{Otherwise} \end{cases}$$

H_j = Total hours on aircraft j at the end of the planning period

Parameters

I_j = Initial total flight time hours on aircraft j at the beginning of planning period
$C_{k,j}$ = Cost of maintenance (in dollars) for maintenance k on aircraft j
$M_{k,j}$ = Scheduled hours for maintenance k on aircraft j
$p_{k,j}$ = Taking a value of 1 if maintenance type k has been performed on aircraft j at the beginning of planning period and 0 otherwise
T = Average flying time of a flight
ACT = Number of flight activities in the planning period
M = An arbitrary large positive number

Mathematical Model:

$$\text{Minimize } \sum_{k=1}^{K} \sum_{j=1}^{A} \left(y_{k,j} - p_{k,j}\right) c_{k,j} \qquad (1)$$

Subject to:

$$H_j = I_j + x_j \quad \forall j \qquad (2)$$

$$\sum_{j=1}^{A} x_j \geq ACT \times T \qquad (3)$$

$$H_j - M_{k,j} \leq M y_{k,j} \quad \forall k,j \qquad (4)$$

$$H_j - M_{k,j} \geq M\left(y_{k,j} - 1\right) \quad \forall k,j \qquad (5)$$

$$I_j - M_{k,j} \leq M p_{k,j} \quad \forall k,j \qquad (6)$$

$$I_j - M_{k,j} \geq M\left(p_{k,j} - 1\right) \quad \forall k,j \qquad (7)$$

$$y_{k,j} \in \{0, 1\} \qquad (8)$$

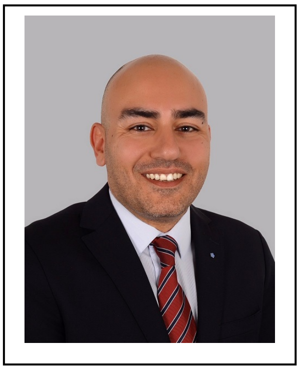
Figure B.1 : Maintenance cost model adapted from Bazargan (2014).

APPENDIX C

Table C.1 : Narrow body lease rates adapted from Aircraft Value News (2011).

Aircraft	Age	Rental (US$ '000s)	Trend Analysis
A318-100	2003-11	130-260	There are now only six A318s remaining to delivered with the order book totaling 80. Airbus has inevitably sought to increasingly market the aircraft as a corporate transport which generally offers better margins for the manufacturer. The lack of orders for the A318 in recent years is not necessarily a concern for Airbus as the cost of production is very similar to that of the A320 and yet the price that can be charged is that much less. Rentals are therefore remaining unchanged.
A319-100	1996-98 1999-11	140-220 210-330	Despite the turmoil and uncertainty created by the A320neo, the lease rentals of the A319 remain unchanged. The decision by Boeing to re-engine rather than opt for an all new aircraft may benefit the A319 as it will serve to keep the competition with the CSeries alive. Orders for the A319 continue to be limited. There is the potential for an improvement in lease rentals but this will require a move towards lower fuel prices and more widespread economic recovery.
A320-200	1988-92 1993-97 1998-03 2004-11	80-120 90-180 190-280 250-350	The lease rentals of at least the newer aircraft are remaining steady as demand for the more recent A320s remains strong. The older types are now facing weakness in the context of ageing airframe and engines. The A320 is also leased by a myriad of lessors which allows lessees a measure of bargaining power. The next few months may see a slight increase as traffic is shown to be on a consistent growth curve.
A321-100L	1994-97 1998-02	90-125 120-220	The lease rentals of the older A321s are facing continued weakness as the focus of attention is clearly on the newer aircraft. The rates for the A321-100 are unlikely to fall much further in the short term. While the market may be moving towards higher capacity aircraft once more, such appetite has not involved the -100L.
A321-200H	1999-04 2004-11	180-300 280-415	The A321-200 is at last coming into its own in terms of capacity and efficiency. Operators have appreciated that adding frequency is not necessarily the only way to achieve growth. The larger capacity of the A321 provides for greater efficiency in an era of high fuel prices. Lease rentals have the potential to rise in the coming months. The introduction of sharklets in the near term will further improve the range allowing for more transatlantic services.
B717-200	1999-04	80-145	Not the first type that springs to mind when seeking a 110 seater. Nonetheless, having reached such levels, rates are achieving a measure of stability. There are few lessors of the type so competitive forces are not so much of an issue. Boeing and Rolls-Royce became the principal owners of the aircraft.
B737-600	1998-03	70-140	The rates of the -600 have fallen so far that they have not fallen any further as yet. The vulnerability of the -600 is all too evident and the lessors need to ensure that lease rentals cover the limited residual value.
B737-700	1997-01 2002-11	145-240 230-350	Rates for the -700 remain stable despite the ever greater focus on the -800. The product life cycle of the -700 is still reasonably short as to keep supply down to manageable levels. The number of deliveries in the last few years clearly demonstrates that the type is losing its position and as such rates are not expected to increase except through interest rate changes or a change to the specification.
B737-800	1998-02 2003-11	170-290 270-400	The -800 remains the most attractive of assets as long as it has winglets and a high MTOW. The Sky Interior has proved popular but this may be of lesser interest to subsequent lessees. The rates for the moment are unchanged but there exists the potential for a slight improvement before the effects of the A320neo and B737RE are fully appreciated. More lessors are involved and given the age profile of the fleet, there are more used examples becoming available for lease.
B737-900	2000-04	125-185	The -900 has moved into the shadows as have lease rentals. The type will likely prove difficult to remarket in the face of considerable competition.
B737-900ER	2006-11	285-425	The rates for the -900ER, in common with most aircraft still in production, are experiencing a period of stability rather than volatility. The type has not proved itself so popular as might have been the case but is nonetheless a valuable addition to the B737NG family. Rates will not likely move in the next quarter. It would be expected that the margins on the -900ER lease rental would be higher but apart from GECAS, the lessors are notably absent.
B757-200	1982-88 1989-95 1996-02	60-120 85-140 120-180	The lease rentals of the B757 continue to remain stable if operators continue to seek replacements. The recent problems involving the structure of the B757 demonstrate that no type is immune from the effects of ageing. Rates are still expected to suffer in the near term.
B757-200ER	1987-95 1996-02	65-160 140-210	The B757-200ER is still viewed as attractive to a range of operators who need the operational capability of the type. Such operators may prefer shorter terms and are therefore willing to pay higher rates.

CURRICULUM VITAE



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