

**MINIMIZATION OF AIRCRAFT
MAINTENANCE COST**
(Case in Ethiopian Airlines Maintenance, Repair and
Overhaul (MRO) division)

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Declaration

I hereby declare that the work which is being presented in this thesis entitled “Minimization of Aircraft Maintenance Cost ” is original work of my own and has not been presented for a degree of any other university and all the resources of references used for the thesis have been duly acknowledged.

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ABSTRACT

The demand for air transport has increased recently. Sophisticated systems like aircraft systems operate under high reliability and safety requirements due to the existence of complex technology involvement and lethal consequences to the passengers in case of a single sub-system failure. The maintenance system of such complex systems usually consists of a variety of maintenance strategies, such as preventive maintenance, corrective maintenance, condition-based maintenance and so on. There has been the usual approach at Ethiopian MRO reliability department that investigates on how to minimize aircraft flight delay. Majority of the investigation detailed to the level of identifying specific components and the final recommendation is escalating or deescalating the maintenance program. However, the uniqueness of this research on the case company is that it analyses on how to minimize Ethiopian airlines direct operating cost, particularly maintenance cost. The academic and/or the aviation industry gain of this research is through a detailed literature review, referencing majority of the IATA's MCTF report, aviation related research articles, interview, and direct observations as employee, identify the major problem drivers using actual data, and strive to manage scientifically, using models and for the industry investigating methods to minimize those cost drivers. This research paper developed a multi-criteria decision making mathematical model for aircraft maintenance planning decision support in preparation of aircraft spare, based on the two contradicting objective functions of minimizing maintenance cost and maximizing quality. Lexicographic goal programming used to solve the problem. The feasibility of the model and algorithm is verified by the case company data.

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“ God bless you all”

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GLOSSARY

MRO	maintenance, repair and overhaul
OEM	original equipment manufacturer
FAA	federal aviation administrations
EASA	European aviation safety agencies
ETOP	extended twin engine operation
DMC	direct maintenance cost
AHP	analytical hierarchy processes
CBM	condition-based maintenance
VBM	vibration-based maintenance
ICAO	international civil aviation organization
ALC	Aircraft lease cost
OWC	Owner ship cost
IATA	International air transport associations
FR	foreign repair
MPD	maintenance planning data/document
CEP	component exchange program
TCS	total customer support
AMM	aircraft maintenance manual
LLP	life limited parts/components
LBR	labor rate
MTTR	mean time to repair
CM	corrective maintenance
PM	preventive maintenance
MTBF	mean time between failure
CM	condition-monitoring
SB	service bulletin
CPCP	corrosion prevention and control programs
AC	advisory circular
EO	engineering order
DM	decision maker

MPS	mathematical programming system
CAS	customer approval sheet
TPM	total productive maintenance
RCM	reliability centered maintenance
PMA	Part manufacturing approval
LRU/LRI	Line replaceable unit/items.
MRP	maintenance recovery periods
MEL	minimum equipment list
MMEL	master minimum equipment list
AEP	Aircraft Engineering and Planning
PSCM	Procurement and supply chain management
MCTF	Maintenance cost task force
MEF	MRO efficiency factor
LBR	Labor rate
MTL	MPD task labor
MTM	MPD task material
TAT	Turnaround time
MLC	MRO labor capacity

CHAPTER ONE: THE PROBLEM AND ITS APPROACH

1.1 Introduction

The current increasing competition and uncertain situations in the aviation industry, requires setting and straggling to achieve new strategic objectives in order to augment, create and win the competitive advantage in the industry. Now a day's majority of airlines give more attention for their existing business operations. A lot of aircraft maintenance activities related to maintenance cost like aircraft part suppliers related to their supply chain management system, on how to manage special agreements such as component exchange program (CEP) have been neglected. Therefore, the complication and less detailed observation on maintenance cost variables have a significant influence, not only on the aircraft maintenance cost but also the airworthiness of the aircraft, and quality of maintenance.

Aircraft maintenance is an overhaul, repair, inspection or modification of an aircraft or its component. It is an indispensable process within aircraft operation. The maintenance cost of a commercial aircraft has a contribution of 10-20% to the Direct Operating Cost (DOC) of an airliner as explained by (Vega, Pamplona, & Oliveira, 2016). The goal of the aviation industry MRO, is to provide a fully serviceable aircraft when required by an airline at minimum cost. In the beginning of aviation, maintenance was performed as a "necessary" action and the machines and tools required often several hours of maintenance time for every hour of flying. The modern aircraft have more simplified maintenance program to achieve the maintenance goal along with airworthiness regulations.

The maintenance process embraces scheduled and unscheduled actions carried out to return the airplane to an airworthy condition. Aircraft maintenance activities aim more on increasing the value of the aircraft reliability, safety, availability, and quality. Ethiopian airlines maintenance, repair and overhaul division provide maintenance and overhauling services, both for narrow body aircrafts such as B737-700/800, wide body aircrafts such as B787 and A350XWB, turboprop aircrafts mainly for regional flights such as Q400 and training aircrafts. The engine shops perform engine overhaul activities for engine models such as JT8D, JT3D and CFM56 families, PW2000 and PW4000 series to perform both shop maintenance and overhaul activities. There are around 100 aircrafts owned and/or leased by the company as a commercial operator.

Ethiopian mostly uses component pooling and/or purchase spare parts overseas. It prefers the OEM's parts approved by the state regulatory authority, mainly by Federal Aviation Administrations (FAA) of

USA and European Aviation Safety Agencies (EASA). The OEM's parts mostly find *long lead-time* and *higher cost* issues during purchasing and repairing as foreign repair (FR). Usually, the FR for those not contained in pool agreement is performed, and has a long lead-time, which may initiate a decision known as cannibalization, using aircraft parts from other aircraft, which have longer ground time. Cannibalization requires a double work force and unexpected malfunction during removal processes, which may result aircraft delay and/or cancellation of flight.

1.2 Background and justification

The aviation industry cannot directly compare to any transportation industry. An aircraft flight is not just simple take-off and the landing only, but also regulatory authority and maintenance requirements have to be met simultaneously. Maintenance checks must be performed in order to make sure that every aircraft leaving the ground is reliable, safe and airworthy, at the lowest possible maintenance cost. Proper maintenance management is the major parameter in order to stay under the safest transportation industry.

All aircraft maintenance must follow aircraft maintenance manual that is approved by a regulatory authority such as the EASA, FAA etc. Each airline develops its own maintenance program based on manufacturers' recommendations and considering its operating environment. Thus, two airlines may have slightly different maintenance programme for the same aircraft model used under similar operating conditions. Aircraft maintenance can be categorized as:-

- ✓ Routine or scheduled maintenance
- ✓ Non-routine or unplanned maintenance
- ✓ Refurbishment
- ✓ Modifications.

Scheduled maintenance tasks are required at regular intervals, when Life Limited Components (LLC) achieve the given age or due to regulatory authority documents like Airworthiness Directives (AD).

The most common routine maintenance is visual inspection of the aircraft prior to a scheduled departure known as pre-flight inspection or walk around by pilots and/or technicians to ensure that there are no visible problems (e.g. cracks, and hatches). Routine maintenance can be classified as:-

- Overnight maintenance, under the current concept of equalized checks
- Hard time or life – limited maintenance
- Progressive inspection

Overnight maintenance normally includes low-level maintenance checks, minor servicing and special inspections done at the end of the working for about one to two hours to ensure that the airplane is operating safely.

Hard time components require periodic overhaul or replacement of affected systems/ components and structures and it is flight hours, cycle or calendar limited. That is, as soon as the component age reaches the stage of hard time it will be by replaced a new or overhauled component. Most of the rotating engine units are hard timed, also known as Life Limited Parts (LLP). The three basic reasons why they are known by the name LLP are; the parts operating area impossible to inspect in situ; their times to failure are strongly age-related and; their failure has an unacceptable high risk of catastrophic consequences as explained on (Augustine B.S.M, 2007).

Progressive inspection is time related maintenance tasks classified into convenient ‘block’ so that the maintenance workload becomes balanced with time and maintenance can be accomplished in small ‘bites’ making equipment more available. There are different types of progressive inspections, Pre-flight, A Check, C Check, and D Check (Enterprise, 2016).

Aircraft Maintenance costs have several characteristic that attract attention, the cost index depends over a period of time or flight hours, for example, a major event such as a D check will take more resources to complete than check A and the cost also be greater. In order to satisfy the aforementioned maintenance categories and/or maintenance types, airlines are increasing their focus to analyse related maintenance costs while delivering higher service levels. the major difference lies on the term MRO efficiency factor (MEF). MRO efficiency factor (MEF) represents the ratio of the average man-hour required by a given MRO to complete a maintenance task and the man-hour for that task given in manufacturer’s Maintenance Planning Document (MPD). A MRO organization considered high ranking when measured 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.

This research reviewed different literatures on maintenance cost drivers, maintenance optimization principles, with special attention on the maintenance cost optimization criteria, objectives and

case company a far more comprehensive understanding of the factors affecting direct maintenance cost and required actions to minimize the associated cost.

1.5.2 Specific objectives

Some of the specific objectives of the research are to:

- To investigate the current maintenance strategy in Ethiopian Airlines.
- To identify the major cost determinants during aircraft maintenance activities of Ethiopian.
- To analyze and recommend the way forward, targeting on identifying the major cost drivers, to develop a tool which assists for decision support during maintenance planning and scheduling processes.

1.6 Significance of the research

This research is mainly concerned with the exaggerated maintenance cost in Ethiopian MRO division. A great emphasis is given to identification of the major cost determinants in the case company and methods to minimize their impact.

With respect to Ethiopian total operating cost, aircraft maintenance cost is the second and/or third highest cost next to flight operations cost index and fuel cost. Ten percent may not seem significant but when total operating costs can be in the hundreds of thousands or millions of dollars, then even 1 percent minimization of cost will become significant. If a cost category is significant, that alone will catch the attention of the executive management of the company.

1.7 Scope

These researches focused on identifying the major cost determinants of the case company at the base maintenance of Ethiopian Airlines MRO division. Its scope is to develop a decision support model with respect to the major cost drivers.

1.8 Limitations

First, data required for this research is accessed indirectly, and disclosed by de-identification for the purpose of keeping the confidentiality. The extensive determination of the major cost drivers is far more important than the data used to come up with a total cost figure. The research was more concentrated on identifying the causes and building the mathematical model considering the reality and existing situation of the case company.

Secondly, although some general definitions or concepts are discussed in this research, the research draws its boundaries around the Base maintenance department, not for line maintenance.

Another issue concerning the limitations is related to validating the model using the specified solution algorithm contains a hectic iteration steps, procedures and this requires software engineers involvement by utilizing the solution algorithm to develop a simple validation and/or verification tool.

1.9 Methodology

Research can be classified based on its purpose. Historically there are three major purposes of research (Zaidah, 2007). These purposes are to explore, describe, or explain the phenomenon of interest.

<i>Exploratory</i>	<i>Descriptive</i>	<i>Explanatory</i>
<ul style="list-style-type: none"> • To investigate little understood phenomena. • To identify or discover important categories of meaning. • To generate hypotheses for further research. 	<ul style="list-style-type: none"> • To document and describe the phenomenon of interest. 	<ul style="list-style-type: none"> • To explain the pattern related to the phenomenon in question. • To identify plausible relationships shaping the phenomenon.

Table 1.1: Classification of research

One of the purposes of this research is to identify the major cost determinants that affect direct aircraft maintenance cost of Ethiopian Airlines MRO through exploration, and to optimize the maintenance cost without affecting safety, reliability and quality.

There have been numerous studies performed by the Operations Research analysts to minimize costs in order to allocate scarce resources. However, the value of these studies is questionable unless the costs represented are true or actual. Therefore, after having explained the need to investigate the direct maintenance cost of Ethiopian MRO in the problem statement, I looked at some of the research and studies performed in this area, and presented various models titled on maintenance cost minimization, but majority of them were statistical models, some of them were accounting models and some are computer simulations. This paper presents detailed description of the methodology followed to identify the major cost determinant by *interviewing aviation experts in Ethiopian airlines*. The literature review includes research papers, aviation journals and mainly IATA's MCTF reports of recent years which are directly concerned on aviation maintenance cost reduction target as well as to build a credible mathematical model. The profiles of aviation experts are shown in the appendix.

1.9.1 Description of methodology

A basic yet effective methodology is chosen to meet the objective of the research. The research assessed the major cost determinants in order to come up with a true cost driver of aircraft maintenance by comparing aviation related articles, books, thesis papers and IATA's reports. The following analytical steps are used to achieve this goal.

- ❖ Finding the major cost factors
- ❖ Analyzing their importance over each factor

Finding the factors was actually performed through literature review of previous years IATA's Maintenance Cost Task Force reports, researches done in this particular area, and parameters considered for calculation of case company's direct maintenance cost, experts interview by examining the existing case company's maintenance processes lay out and observations as an employee of the case company.

1.9.2 Why AHP

To determine specific maintenance optimization criteria, several prioritization methods are observed such as analytic hierarchy process (AHP), binary search tree (BST), *planning game (PG)*, *100 points method* and I preferred most is AHP due to its promising approach for prioritization, because *it yields the highest reliability of the results, it is fault tolerant and the consistency of the decision maker is checked*. Moreover, AHP uses relative judgments between the different elements, which is faster and yields more reliable results than making absolute judgments (Saaty, 2008). The analytic hierarchy process is a well-known prioritization method that is also used in maintenance decision making (Saaty, 2008). When using AHP, a decision maker (DM) first gives linguistic pairwise comparisons, they are numerically quantified by selecting a certain numerical scale, and finally a priority vector is derived from the numerical pairwise comparisons.

Steps for AHP utilization:

- ❖ Determination of major maintenance cost factors to be ranked in the process of case companies' maintenance strategy and explaining the idea to the interviewed experts;
- ❖ Review of literatures for the major cost factors;
- ❖ Performing detailed interview with selected aviation experts working in the case company.
- ❖ Elaboration of the interviewee's idea on the most voted cost factors;
- ❖ Determination of the weights of each cost factor based on interviewee vote, literature review and actual cost data;
- ❖ Creation of a matrix using the cost factors applying principles of AHP as a decision support tool;
- ❖ Determining the ranking of the cost drivers and selecting the major cost driver for modelling.

The application of AHP principles allowed prioritizing the major cost drivers as per their weight.

1.9.3 Data Source and Collection methods

There are six main sources of evidence applied in this research. These sources of evidence are *documentation (Maintenix software), archival records, interview, direct observations, participant-observations, and physical artifacts*. Based on their comparative strengths, using one source as a backup over other, all sources of evidence are considered valuable for this research. The raw data is collected from directly concerned sections of Ethiopian airlines budget and finance department, AEP, PSCM, base maintenance hangar.

Primary data collection

Direct cost data collection is from the case company maintenance activities backup system known as Maintenix software as a primary data collection source and method.

Other formal and informal communications used to reveal the latest price status of some aircraft components/parts, which is not clearly identified due to some weak sides of the software features.

Interview is performed especially for those concerned higher management staffs of the case company, which are frequently communicating with the major suppliers of aviation parts including maintenance managers, directors and purchasers.

Secondary data collection

Secondary data source is literature review. Different IATAs MCTF yearly reports and documents found in the case company documentation section and electronic information source including internet was used to obtain aviation related articles and journals.

This research aims to determine the main factors especially those directly related with direct maintenance costs and influence the case company aircraft maintenance cost. To achieve the research objective application of mathematical programming of operational research techniques, specifically Lexicographic Linear goal programming (LLGP) approach is utilized after identifying the major cost factor using AHP. Paired comparisons produce weighting scores that measure their importance using cost as a criterion.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

One of the major indispensable processes in the aviation industry is the maintenance process, which is an overhaul, repair, inspection or modification of an aircraft and/or its component. Similar to any biological life on the earth, aircraft systems have a certain period of lifetime. When we break down these periods into smaller sections, it is possible to see process is much more complex than a short sentence. Aircraft systems incur different types of costs during their operation or service life. This cost is summarized in the following categories: *Research and Development*, *Investment*, *Operations and Support*, and *disposal* all of which constitute the life cycle cost (LCC) (Ezik, 2003). The life cycle of an aircraft system begins with the determination of requirement and continues through the engineering and manufacturing development, production and deployment, and operations and support phases to the eventual disposal.

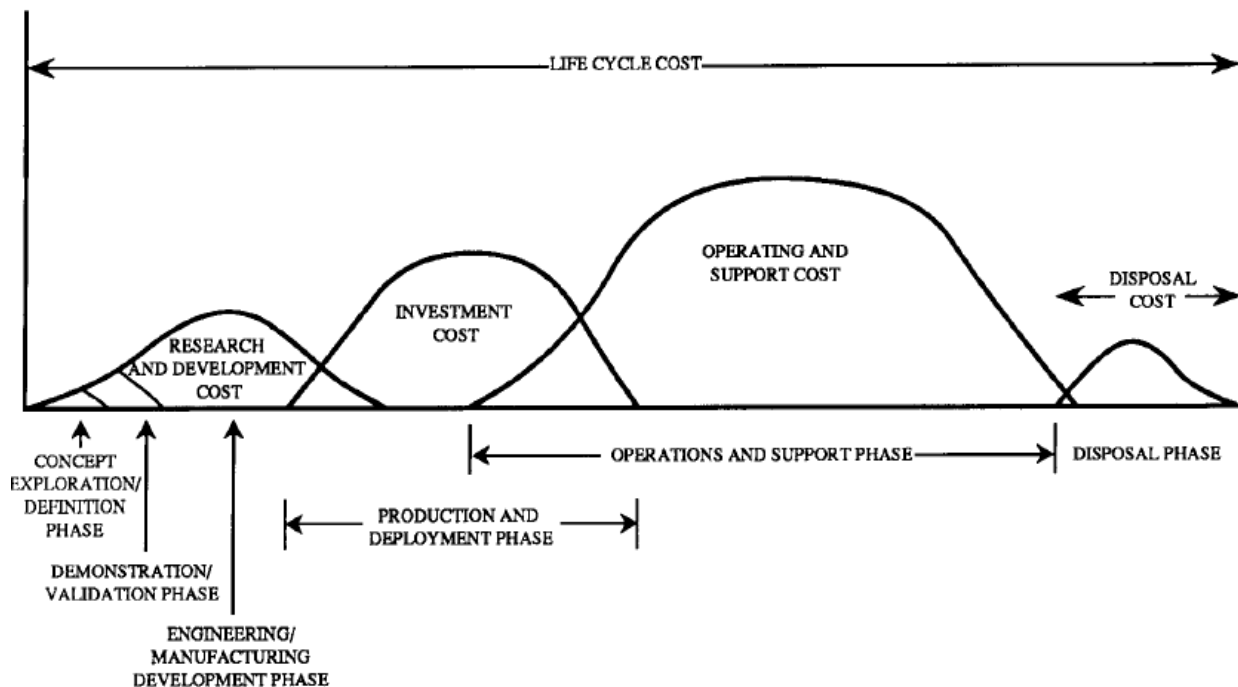


Figure 2.1: Different phases of life cycle program (Ezik, 2003).

Figure 2.1 plots a general picture of how various phases of a particular system's life cycle program relate to Life Cycle Costs. Similar to any process of development, aviation engineering systems have a remarkable complex phenomenon, because of large amount of parts organized by complex functional links between the components to meet the ends of highly complex missions of aircraft airworthiness.

The maintenance cost plays a significant role in the airline direct operating costs especially during the maturity and aging stage. It is quite evident that as aircraft delivered they hardly need any maintenance apart from routine lubrication and servicing, this is often referred to the aviation industry as the newness effect. If the aircraft needs some maintenance during that initial 4-5 years since EIS, then aircraft would be rectified under warranty with almost no cost to the airline. The age of the body of the aircraft is not an indicator of the age of aircraft since, aircraft age can be estimated/calculated using flight cycles or flight hours and all aircrafts do not fly the same distance, do not flight the same flight hours or cycles (Vieira, 2016). The values of the parameters *reliability* and *availability* depend on the components of the technical systems (ages, interaction between each other), the applied maintenance policy and the operating environment (Cristea-Gabriel RAU, 2011). The success of the mission could be assured, from the point of *reliability* and *availability* parameters, when the engineering systems would have performed its functions without critical failures.

The objective of PM policies is to reduce the probability of failure or degradation of the complex systems, through simple preventive maintenance and related activities. CM comprises a set of activities (repairs and part replacements) performed after the failure or at the unexpected degradation of equipment' functions in order to restore its state.

The main objectives related to maintenance are:

- ➔ Ensuring system's basic functions (*availability, efficiency, and reliability*);
- ➔ Ensuring system life through proper connections between its components (asset management);
- ➔ Ensuring safety for human operators, environment and system itself.

A design parameter of an engineering system is its maintainability, expressed by the probability that a PM or a repair to be performed in a given time, under stated conditions.

Figure 2.2 below show the place of the maintainability in relation to the overall performances of a complex engineering system. The dashed line separates the desired objective from the outcomes of the compromise between system parameters; *maintenance cost is one of the system parameters*. The conclusion is that there is the need to establish a compromise between the two design parameters, reliability and *maintainability*, in order to achieve the desired availability sought by all operators of the systems (Darli Rodrigues Vieira, 2016).

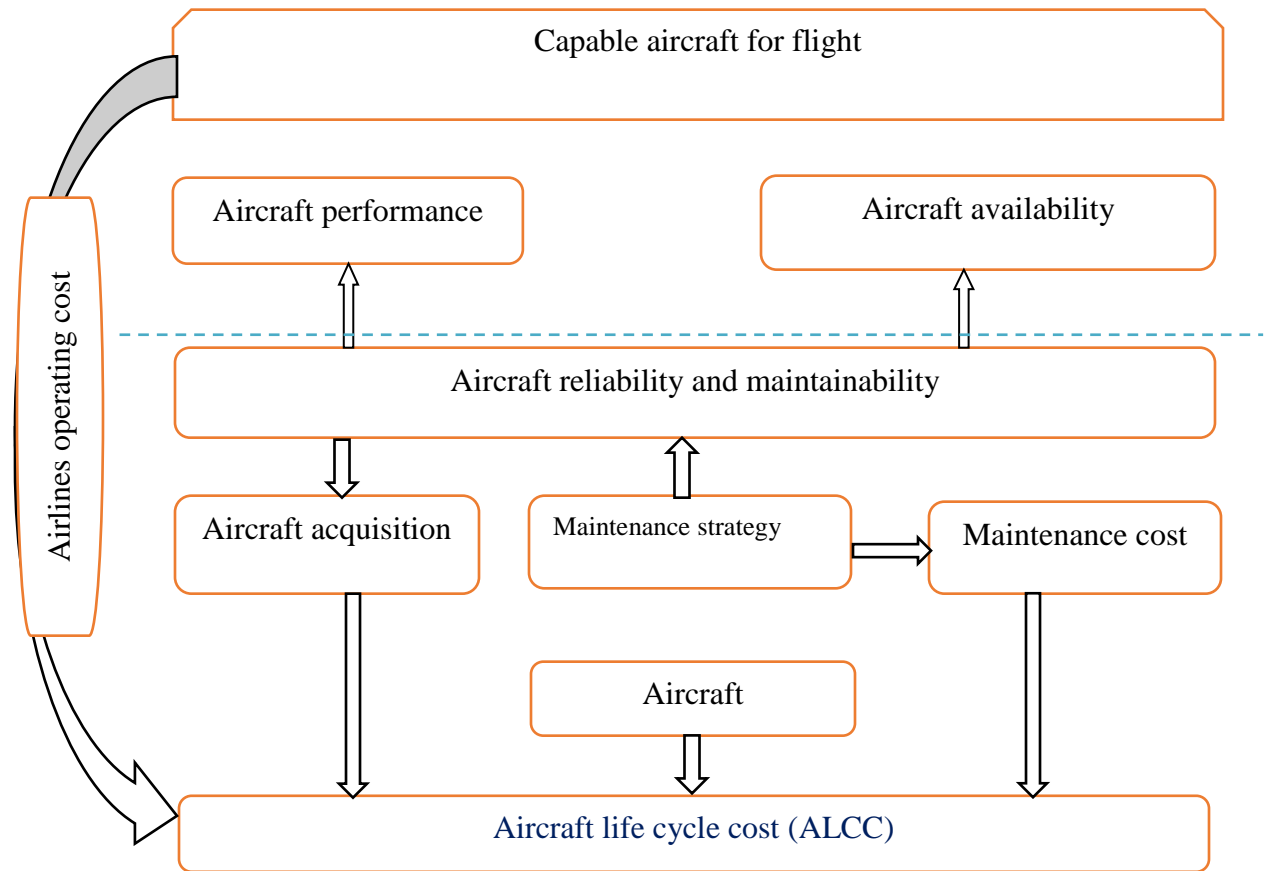


Figure 2.2: Relations between *maintainability* and other parameters of the aviation system (Cristea-Gabriel RAU, 2011)

As explained (U. PeriyarSelvam, 2013) Maintainability objective is projected as a maximum cumulative time of immobilization (Unavailability) T_{ci} , for a specified period. This parameter is the sum of required period of times for CM (index c), and PM respectively (index p):

$$T_{ci} = N_c * M_c + N_p * M_p$$

Where:

N_c = number of required CM;

N_p = number of required PM;

M_c = average time for CM;

M_p = average time for PM.

N_c , is a parameter for reliability specified and known for each case. If the evaluation of the other three parameters gives values that do not meet the projected T_{ci} , one will change the system design or the maintenance policy on the extent of costs anticipated.

2.2 Maintenance planning and scheduling

Aircraft maintenance planning and scheduling constitute planning, control and execution of materials (spare parts), operations (inspection, disassembly and assembly activities) and resources (labor, machines, transport equipment, etc.). As explained (MOHAMED BEN-DAYA, 2000) Maintenance Planning and Scheduling is one of the most important elements of the maintenance function. They are prerequisite for effective maintenance control. The maintenance planning and scheduling models can be classified based on *function* or *horizon*. The functional classification results in planning and scheduling models. The horizon classification results in long, medium and short term models.

The major airline cost drivers from aircraft operations planning and scheduling perspective:

Operations Planning - Cost Drivers

- Schedule Design perspective
 - ✓ Commercial or marketing Objectives / Schedule Design Complexity.
- Asset Management perspective
 - ✓ Aircraft Assignment and Utilization
 - ✓ Flight Crew Staffing, Training, and Utilization
- Planning Components perspective
 - ✓ Block time Standard
 - ✓ *Required Ground Time and Resources*
 - ✓ Aircraft Maintenance Requirements
 - ✓ Schedule Reliability Objectives
 - ✓ Schedule Recovery Options

The *long and medium* term models address maintenance capacity planning and spare parts provisioning for maintenance. The short-term planning models focus on resource allocation, monitoring and control.

2.2.1 Maintenance Capacity Planning

Maintenance capacity planning is the determination of the optimal level of resources (workers, skills, spare parts, equipment and tools) required for meeting the forecasted maintenance load. the major parts are the determination of the optimal mix of skills and cost effective spare parts provisioning policy.

2.2.2 Allocation of Resources

Instead of using the old concept of Mean Time between Failure (MTBF) parameter as a metric to measure reliability, the current aviation industry using Maintenance Free Operating Period (MFOP) and time since installation (TSI) to satisfy more the TAT of the aircraft and reduce its Life Cycle Cost. A properly planned maintenance can easily allocate resources to complete planned job cards or tasks (MOHAMED BEN-DAYA, 2000).

2.2.3 Scheduling Preventive Maintenance

Aircraft preventive maintenance is defined as maintenance of aircraft or its systems before fault occurs. The main requirement of preventive maintenance is to minimize the consequences aircraft failure. It improves aircraft reliability, decreases cost of component or part replacement and aircraft downtime by decreasing the number of none-routine. Properly performing aircraft preventive maintenance provides a high level of aircraft availability. Optimal application of aircraft preventive maintenance schedule is an economical thought, which results the optimum benefit. The maintenance program and associated tasks are already planned for each aircraft fleet and must be performed in a specified time.

2.3 Aircraft Maintenance Cost

2.3.1 Aviation MRO Operations

Over the years, the nature of the challenges on the aviation industry correspondingly challenged MRO industry as well. The initial challenge for the MRO industry was purely '*production goals*'. These goals were driven primarily by the concentration on core competences. How airline-operated MRO organizations tended to be 'most competitive' within the early years of product manufacture because of their substantial inventory and geographic presence, which gave them the ability to serve customers around the clock. However, in the later stages of the life cycle of parts the economies of scale, obtaining licenses from OEMs to maintain and repair specific systems and specializing in state-of-the-art inventory control measures to reduce costs, favors independent MRO organizations. Although the life cycle of the product(s) to a large extent dictated who was most likely to carry out the maintenance operation(s), based on their core competence, the main challenge however, was purely focused on production goals.

The overall challenge for the MRO industry is now very different. The ever changing market forces from the initial 'production' goals, MRO organizations need to increase the margin between stock and value by considering every possible resource to maximize operational efficiency and minimize cost i.e. optimize and streamline business operation. This means that the aviation MRO industry have to manage effectively how it minimizes overall maintenance costs, and reduces aircraft turnaround times (TAT).

As explained in (IATA M. , 2014), airlines reported a total of \$17.6 billion for their Technical Division spend: this is \$15 billion for Direct Maintenance Cost and \$2.6 billion for Overhead. \$15 billion represent almost 24% of the world MRO spend for 17% of the world fleet.

At present, maintenance cost of a commercial aircraft makes a significant contribution to an aircraft cost of ownership. (Urdu, 2015) decomposes Total Maintenance Costs (TMC) into Direct Maintenance Costs (DMC) and Indirect Maintenance Costs (IMC). Direct maintenance costs are the expenditures that are directly performed on the aircraft during the maintenance, meaning the labor and spare part costs directly involved on the aircraft. The indirect maintenance costs are the expenditures which are not directly performed on aircraft during the maintenance.

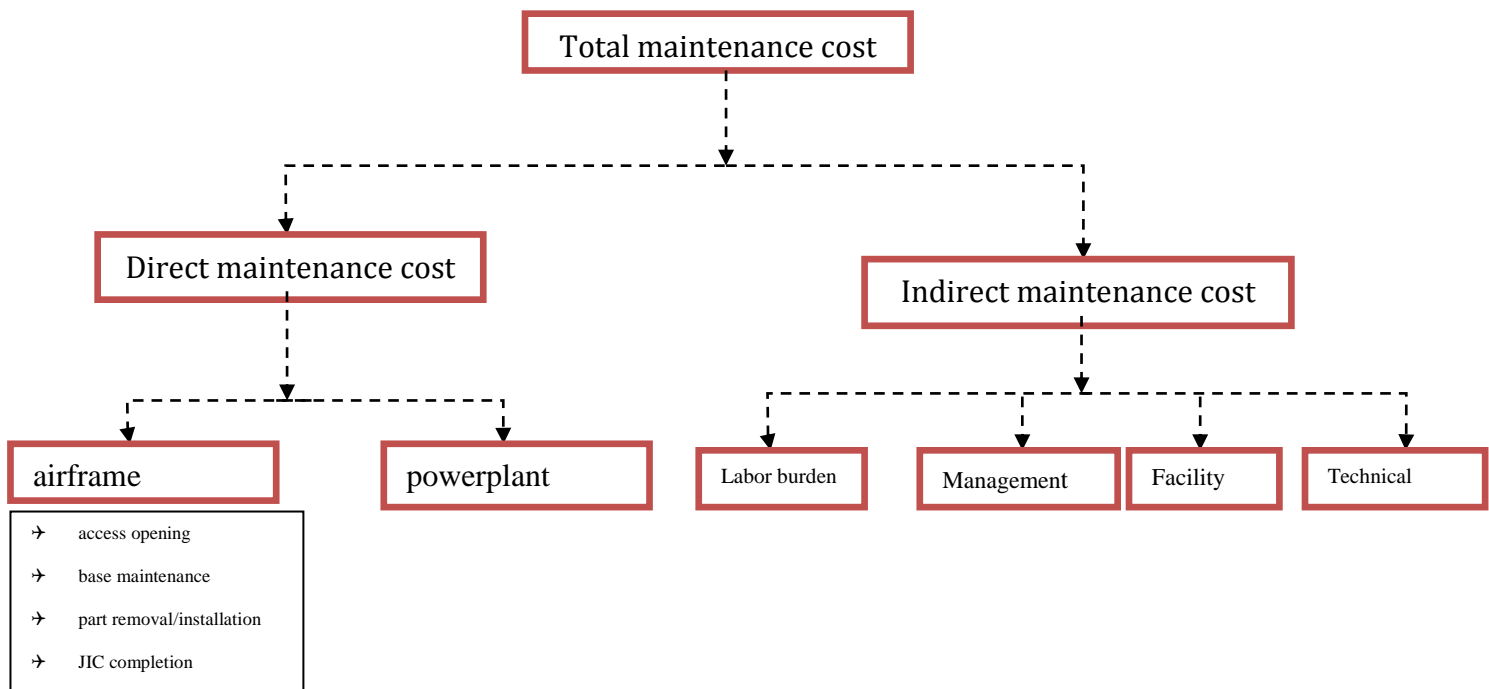


Figure 2.3: Total maintenance cost break down (Urdu, 2015)

2.4 Controllable and uncontrollable maintenance cost factors

2.4.1 Controllable cost factors

Regular preventive maintenance is required to allow for upgrading of the component and the condition of the aircraft. Thus, it is very important to understand the factors that contribute to maintenance effectiveness, how these factors contribute, and to what extent they contribute.

The factors related to maintenance planning are two types, i.e., controllable factors, which can be reduced by applying an optimizing technique and uncontrollable factors, on which the cost cannot be controlled but can be optimized to some degree with certain limitations (MOHAMED BEN-DAYA, 2000). These main aircraft maintenance-planning related factors are the aim of the research paper.

Maintenance Scheduling

Maintenance scheduling is one of the main factors that affect maintenance planning and costs as explained (www.reliasoft.com/newsletter), since the operation of an aircraft changes from one season to another, seasonal demand can vary. Therefore, it is important to choose the most convenient time when aircraft demand is low to schedule the aircraft for maintenance.

Maintenance Strategy or Policy

With the general understanding as explained (www.reliasoft.com/newsletter), In order to perform aircraft maintenance, there are several strategies or policy options available to management, and many alternative decisions must be considered. These strategic or policy options can be outlined in two main approaches, i.e., the reactive approach (breakdown) and the proactive approach (condition-based and time-based) or block hour and phase maintenance approach. All types of maintenance strategies or policies could be applied to every item on the aircraft, but only one will yield optimal results. However, it is sometimes necessary to integrate various types of maintenance strategies or policies.

Therefore, selecting the optimum maintenance strategy or policy is very important in maintenance planning because it can have an impact on the total maintenance cost.

Aircraft design and construction

Aircraft design and construction have a significant factor, and they have a key role in influencing future maintenance planning and costs. Therefore, this factor must be studied in depth to assess its importance. For example, the fuselage of an aircraft made of composite material has the advantage of light weight, but it has the disadvantage high level maintenance skill requirement, which means skilled technician will be required. Therefore, aircraft body damage or delamination of honeycomb panels must be replaced more frequently, resulting in higher costs.

Another example, as explained (Cristea-Gabriel RAU, 2011), since, maintainability is a design parameter, the removal/installation and repair with respect to time and accessibility is of the one that affects the maintenance cost.

2.4.2 Uncontrollable factors

Aircraft age

Aircraft age is one of the main factors that affect maintenance planning and cost. Technical aging is the inherent effect of age on the aircraft over time. Materials degrade with time, and each aircraft sub-assembly ages at its own rate depending on calendar time, flight hours or and cycles. The total aircraft's aging is found by the combination of the aging of all its individual components (IATA, Maintenance Costs for aging aircraft, 2018).

Technical aging is influenced by the following factors, which define the airline's context:

- Scope of the maintenance (MPD, cabin, specific operator program, modifications)
- Maintenance program (check interval: block concept, semi or fully equalized)
- Maintenance planning: tasks packaging, out of phase tasks
- Maintenance and engineering: organization, staff, number of mechanics, shift
- Maintenance practices and policies
- Operating parameters: aircraft utilization and operations
- Aircraft performance, reliability
- Geographical location (region) and operational environment (temperature, humidity, salt, dust, pollution, etc.)

As explained on (IATA, Maintenance Costs for aging aircraft, 2018) the following technical aging parameters can be measured:

- Number of Routine tasks
- Number of Non-Routine tasks
- Finding rates
- Part replacement rates
- Grounding time (A/C operational availability)

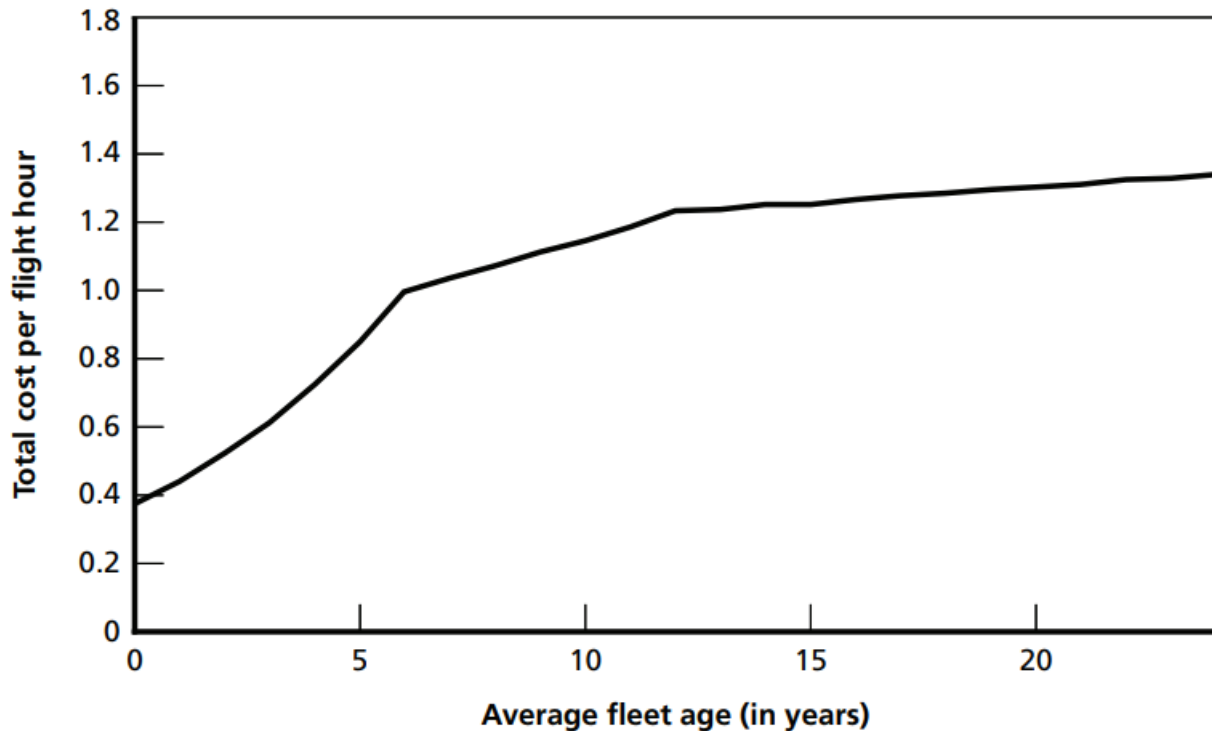


Figure 2.8: Aircraft age effect on maintenance cost (www.rand.org)

In general, Maintenance provides crucial support for heavy and capital intensive industry like the aviation, by keeping the aircraft in a safe operating condition. Therefore, maintenance plays the main role in sustaining long-term profitability and competitiveness for an organization (Kelly A., 1997).

2.5 Review of aircraft maintenance cost elements

Before analyzing mathematical modeling formulation of aircraft maintenance cost optimization, this section of the literature review provides an overview of aircraft maintenance major cost elements, which provides information on:

- What are the major cost elements?
- How is their overall contribution to aircraft operating cost?

Maintenance costs are great interest for the scheduled operators of an aircraft and also for aircraft manufacturers. Both want to know the origin of these costs in order to control, while improving operational reliability without affecting the safety of the aircraft.

When computing maintenance cost coming from a manufacturer and different airlines for the same type of aircraft, one can be confronted with quite different figures. This comes from differences in terminology and accuracy of reporting procedures, from influence of various parameters. As described on (IATA, 2016) 49 airlines reported for direct maintenance cost of \$15.57 billion and 43 airlines reported maintenance overhead of \$2.63 billion. The report also asserted that per flight hour (FH) the average maintenance cost is \$1,071, per flight cycle (FC) it is \$2,637 and per aircraft is \$3.5 million. The table 2.2 below describes the major cost factors referencing the IATAs report from 2009 until 2015. Based on data the component managed through Total Customer support, FR and purchasing process contributed a lot with respect to In-house repaired and labor cost.

SaltoLlu, et al, 2016), elements that affect the maintenance cost are equipment and facility costs, supplies and logistics costs, labor cost, and overhead. Therefore, these requirements result in higher cost for performing C check, compared to A check.

Direct maintenance cost, which is composed of cost of maintenance crews, materials, and parts repair and replacement, accounts for 11% of the total operating cost of an aircraft IATA MCTF (2009). That direct maintenance cost consists of cost of maintenance resources, which is given by:

$$D_{MC} = C_{SP} + C_{CEM} + C_{MP} + C_{TSE} + C_F + C_{TD}$$

Nomenclature

- C_{SP} is cost of *spare parts*,
- C_{CEM} is cost of *consumable or expendable material*,
- C_{MP} is cost of *maintenance personnel*,
- C_{TSE} is cost of *tools and support equipment*,
- C_F is *cost of facilities*, and
- C_{TD} is cost of *technical data*.

When aircraft operator like Ethiopian airline, perform maintenance at own base the, the cost breaks down mainly into labor, spare parts and material, foreign repair, component pool (CEP or CSP) and maintenance reserve.

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, market conditions, special service requirements, and seasonal factors and the case company labor rate is negligible with respect to the industry standard.

MPD task labor (MTL) represents the labor requirement of maintenance program tasks. Since MTL defines routine works, the planners could determine this parameter in advance. 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 defined by the term MRO efficiency factor (MEF).

MRO efficiency factor (MEF) as explained by (Inalhan, 2016) 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. 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 experiences on a specific task or aircraft type.

MPD tasks material (MTM) is another deterministic element. The routine works and associated material requirements are predefined for each task, which is grouped into a scheduled maintenance check per interval limitations. Therefore, MTL and MTM cost elements are not probabilistic.

The cost of scheduled aircraft maintenance check for the case company can be calculated by: –

$$MTC=LBR* (MEF* (MTL+EOL) +MTM+EOM$$

Nomenclature

- LBR- labor rate.
- MEF- MRO efficiency factor
- MTL- MPD task labor
- EOL- engineering order labor
- EOM- engineering order material
- MTM- MPD task material

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

$$TAT=MEF* (MTL+EOL)/MLC$$

As described on (Inalhan, 2016) 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, their experience and the daily working hours.

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.

2.6 Challenges in aircraft spares

Managing Spare Parts plays a vital role in any asset intensive organization, like airlines. One of the unique challenges of airline operations is that every key asset such as Aircrafts, Crew, Inventory, Spares etc. is on the move or dynamic.

Component maintenance costs (CMC) are a major issue for maintenance departments in airlines all over the world. According to the Airline Maintenance Cost Executive Summary for fiscal year 2014 published by the IATA, components make up the second largest portion (24%) of airlines' direct maintenance costs (IATA, Maintenance Cost Management, 2015). Owing to the volatility of prices of aviation parts, supplier's change the prices regularly and these changes are often decided based on the lead time demanded and the proprietary nature of the part. Airline commercial planners, aircraft maintenance planners, and material Planners are under pressure to cut costs, but at the same time to ensure that aircrafts are not grounded due to the non-availability of spare parts, thereby losing the revenue.

2.7 Aircraft Component Management

In the aviation industry especially operators, managing aircraft component such as purchasing, repair and overhaul represents a complex management. Many factors contribute to this complexity, including aircraft configuration control with multiple fleet types, common aircraft models with multiple configurations, aircraft ageing, modifications via mandatory regulatory directives and manufacturer service bulletins, parts availability and repair cycle in consistencies. Additionally, commercial agreements such as leasing requirements and component pooling arrangements add more complexity in managing the costs of component maintenance. Similar to outsourcing aircraft heavy maintenance outsourcing of aircraft component repair and upgrade have shown a significant degree of transformation and have significant contribution in escalating maintenance cost (IATA, MCTF, 2015). Ethiopian airlines had own shops to repair or rebuild components such as landing gear accessories, auxiliary power units, electrical system components, hydraulic-pneumatic system components, and various power plant components. The aviation industry is bounded by strong aviation regulations, policies and asset requirements such as expensive test benches in order to become an approved repair shop by both local regulatory authorities, ECAA and foreign regulatory authorities such as FAA, EASA.

Airlines look for component support solutions to gain advantages of flexibility, little administration cost, significant cost difference with respect to the requirement of the initial investment cost.

2.7.1 Component Pooling

Component pooling can support airlines with the advantage of less total capital than owning operators own parts. An operator that is considering entering into a component pooling arrangement with a service provider should also review the impact of existing modification policy and reliability-initiated programs that were in place prior to the component pooling arrangement (IATA, Component Maintenance Cost Management, 2015). Capital cost or leasing cost to ensure access to a pool of units is another driver as well as an area of risk. Component maintenance costs are directly related to the expenses that occur during the annual accounting cycle during reporting the case company aircraft maintenance cost. However, certain capital investment may be required to ensure proper operation such as the requirement of test bench; they include investments in tools, spare parts, and training and even facilities enhancements.

2.7.2 Use of Alternate Parts (PMA)

Aviation operators are required to operate at the maximum performance targeting to reduce their operating cost and/or maximize their profit margin without compromising their full compliance with all regulatory requirements and safety standards. As explained on (IATA, Alternate Parts (PMA), 2015) one means of reaching their target is to implement a strategy that makes use of approved replacement parts and repairs available from sources other than the OEM. From the point of view of the airline operators; this research paper gives more attention in using such alternate parts in order to achieve maintenance part cost savings by use of alternate replacement parts having PMA and approved (non-OEM) repairs.

Maintenance materials and parts account for approximately 4% of the aviation industry's total cost structure. Considering only on maintenance costs, aircraft purchased parts account for about 30% of all costs. The component overhaul and refurbishment sectors account for the largest portion of all material costs.

The aviation industry has always dependent on the OEMs, who design and sell aircraft, engines and components, to support their products in service during their lifetimes that may span from 20 to 30 years or more. The International Civil Aviation Organization (ICAO) specified, and the national

regulatory agencies have mandated, that the operating airlines and Maintenance, MROs follow instructions for continued airworthiness (ICAs) and other support documentation provided by the OEMs. Most aviation operators are allowed, nevertheless, by their local regulators, to make changes to maintenance schedules and procedures, to develop modifications and repairs and to introduce alternate parts, PMA. All such changes must be documented and shown to meet or exceed the original certification standards. The airline must follow internal processes and procedures approved by the local regulator. In some cases, changes must be individually approved by the local authority that may rely on the guidance of the authority that approved the original aircraft Type Certificate.

During the past 10 years, the OEMs have increasingly seen the “aftermarket” as a source of revenue and potential profit, IATA, Guidance Material and Best Practices for Alternate Parts (PMA) (2015). Airlines have experienced annual price increases for spare parts exceeding 3% and in some cases exceeding 5%. In the MRO area, this results in a need to identify strategies that reduce aircraft part. One such strategy that has been adopted by an increasing number of large airlines is the use of alternate approved replacement parts from third-party suppliers having PMA. A related strategy is to introduce use of approved repairs that restore worn or damaged parts to their original specifications such as LHT. The availability of alternate parts and repairs provides choices for airlines and results in market competition that has a moderating effect on OEM prices.

IATA's, Guidance Material and Best Practices for Alternate Parts (PMA) (2015) have shown that the prices of PMA parts are typically 20-30% less than the equivalent OEM prices. In some cases, price reductions of more than 40% compared with OEM list prices have been reported.

2.8 Concept of Beyond Economical Repair (BER)

After a component is removed by an unscheduled or scheduled maintenance event, the component is routed to the shop internal/external for repair or overhaul. BER is defined as the ratio of repair cost to the value of the part at which a part is scrapped or repaired. If this ratio exceeds a predefined value, the part is considered as BER and will be scrapped. A typical value for this threshold is set at 60-70% of the cost for replacement (i.e. catalog list price).

As Per (IATA, Maintenance Cost Management, 2015) under certain conditions, the cost of rectification of a part is nearly as high as the residual value of the part itself. In such cases, it is common to rely on airline policy (65% for the case company) to “scrap” or discard the component, since it is beyond economic repair (BER).

2.9 Measuring the quality of aviation spares

Airlines need to operate with utmost efficiency. They always continuously strive to reduce operating and maintenance costs while, at the same time, always be in full compliance with all regulatory requirements and reach ever-higher safety standards. One way to achieve these objectives is to implement a strategy that makes use of approved replacement of parts and repairs available from sources other than the OEMs.

Per (IATA, Alternate Parts (PMA), 2015) in aircraft maintenance, a component is defined as any self-contained part, combination of parts, subassemblies or units, which perform a distinctive function necessary to the operation of a system. Maintenance costs associated with repairable part can be classified into on-wing performance which is highly dependent on operator’s reliability data to define component life limits and soft limits and off-wing support which is fully dependent on OEMs performance. Component maintenance costs (CMC) are a major issue for maintenance departments in airlines all over the world. According to IATA MCTF annual report (2013) the Airline Maintenance Cost Executive Summary for fiscal year 2014 published by the IATA, components make up the second largest portion (24%) of airlines’ direct maintenance costs (DMC). (IATA, Alternate Parts

(PMA), 2015) explained about aftermarket support of aircraft parts, the aviation industry has always dependent on the OEMs, who design and sell aircraft, and components, to support their products in service during their lifetimes that may span 30 years or more. ICAO specified, and the national regulatory agencies have mandated, that the operating airlines and Maintenance, Repair and Overhaul organizations (MROs) follow instructions for continued airworthiness (ICAs) and other support documentation (including maintenance manuals and parts catalogues) provided by the OEMs. With appropriate consideration of this starting point, most airlines are allowed, nevertheless, by their local regulators, to make changes to maintenance schedules and procedures, to develop modifications and repairs and to introduce alternate parts. The airline must follow internal processes and procedures approved by the local regulator.

FAA website (FAA, 2016) explains every item installed on an aircraft and engine have to obtain a type certificate (TC) or supplemental type certificate (STC) to confirm approval from the state of design regulatory authority such as FAA, and EASA. The most common type of approvals is known as TSOA or PMA. TSO is the minimum required standard issued by regulatory authorities for specified components or parts to be used on civil aircrafts and are eligible for use on certified products, which can be identified by a name plate. In general, the TSOA is a necessary condition for installation on aircraft, but not an enough condition. Every part used in a FAA certified aircrafts must have the TSO markings or PMA stamps on it otherwise, it is not airworthy.

Parts Manufacturer Approval (PMA) is rather unique design and manufacturing approval process developed by the US FAA (Federal Aviation Administration) in the 1950s and still widely used today.

The term applies to several different situations:

- A company independently designs a replacement for an OEM part and obtains FAA approval of the design and the associated manufacturing and quality control process using the PMA approval procedure.
- A company develops a modification to an aircraft, engine or component and obtains approval by STC (Supplemental Type Certificate). The kits or parts produced for the modification have PMA approval and are identified as such.
- A supplier is authorized by the OEM to manufacture and sell replacement parts under a license agreement. These parts are also identified as PMA parts.

Based on the aforementioned certificate availability and the additional conformance of all regulatory authority requirement such as FAA and referencing (IATA, Alternate Parts (PMA) , 2015)

aviation spares or components can be rated for quality. In this thesis paper, aviation spares can be rated as:

- a) If the part is purchased from the OEM, or provided by component pool agreement with the OEM, or foreign repaired by the OEM or in-house repaired per the approval from the OEM have value five (5) is given.
- b) If the part is purchased from a company having TSOA/PMA approval, or provided by component pool agreement with the TSOA/PMA approval, or foreign repaired by a company having TSOA/PMA approval, or in-house repaired per the approval from a company having TSOA/PMA approval have value four (4) is given.
- c) If the part is purchased from a company having approval by ECAA, or provided from a company having component pool agreement with ECAA approval, or foreign repaired by a company having ECAA approval, or in-house repaired per the approval from ECAA have value three (3) is given.
- d) If the part is purchased from a company having approval by other state aviation authority, or provided from a company having component pool agreement with other state aviation authority approval, or foreign repaired by a company having other state aviation authority approval, or in-house repaired per the approval from other state aviation authority have value two (2) is given.
- e) If the part is bogus item, which do not have certificate from OEM, or from TSOA/PMA, or from ECAA or from other state civil aviation authority or cannibalized from other aircrafts, the value one (1) is given.

2.10 Aircraft Maintenance Program (MP)

In the early days of aviation, primarily pilots and mechanics developed maintenance programs. They assessed an aircraft's needs for maintenance based on their individual experiences and created programs that were simple and free from analysis.

The introduction of the airlines as a new method of transport demanded new regulations and broader involvement of the Regulatory Authorities in maintenance requirements. During this era not only were regulations put in place but programs were started to monitor reliability and safety. The entry of the large jet aircraft (B707 and DC-8) in the fifties focused public attention on the need for safer and more reliable aircraft. The aircraft manufacturer became the source of maintenance program development.

Maintenance Planning Document (MPD)

The Air Transport Association of America (ATA) administers and maintains this document to provide guidance on the development of maintenance procedures for new aircraft. Specifically, it states:

"It is the objective of this document to present a means for developing the scheduled maintenance tasks and intervals which will be acceptable to the regulatory authorities, the operators, and the manufacturers. The scheduled maintenance task and interval details will be developed by coordination with specialists from the operators, and the Regulatory Authority of the country of manufacture".

The MRB Report outlines the initial minimum scheduled maintenance/inspection requirements to be used in the development of an approved continuous airworthiness maintenance program. The Maintenance Planning Document (MPD) contains all the MRB requirements plus mandatory scheduled maintenance requirements that may only be changed with the permission of the applicable airworthiness authority. These supplemental inspection tasks are detailed in the aircraft's Certification Maintenance Requirement (CMR) and Airworthiness Limitation (AWL) documents, Figure 2.9 below. The MPD document provides maintenance planning information necessary for operators to develop a customized maintenance program (MP). The document lists all recommended scheduled maintenance tasks for every aircraft configuration.



Figure 2.9: Maintenance planning document (Enterprise, 2016)

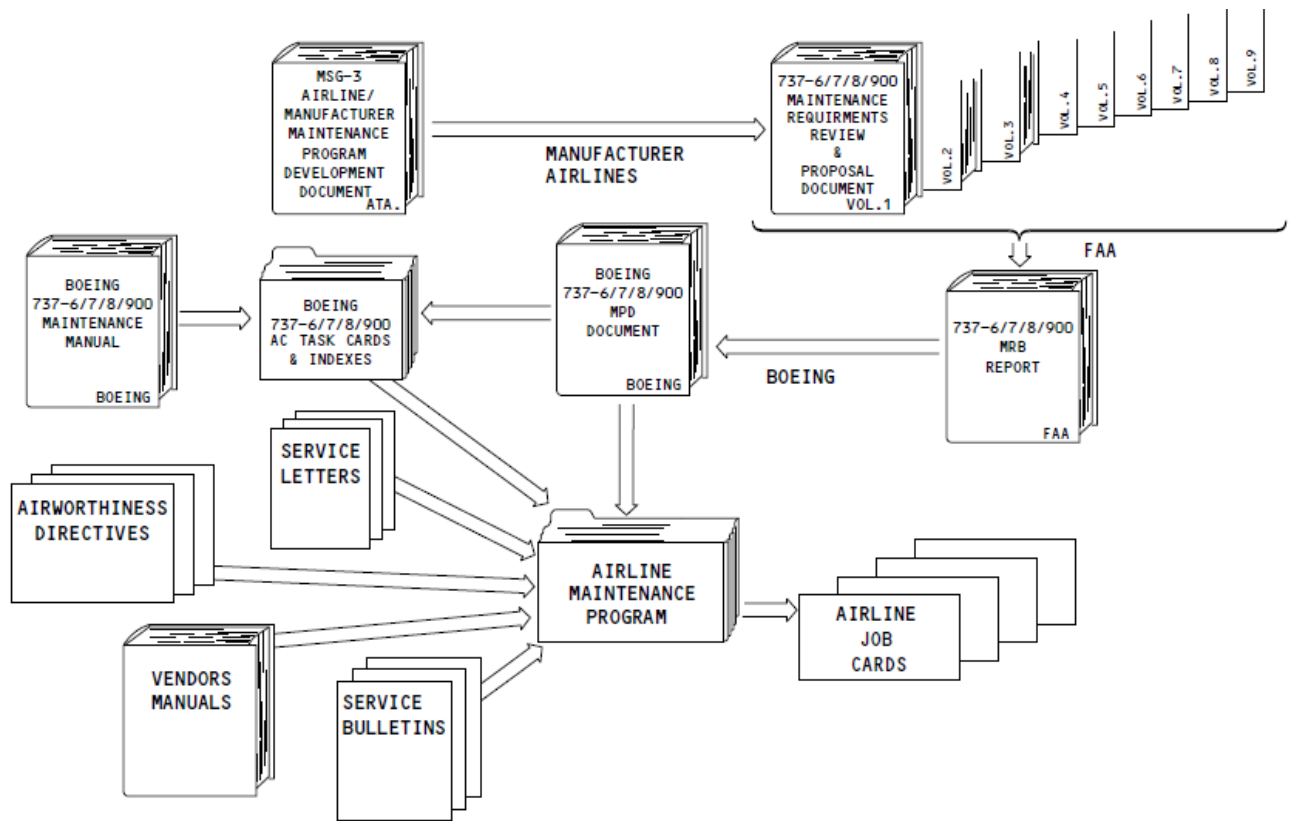


Figure 2.10: maintenance program development process (Enterprise, 2016)

2.11 Supply chain features of the aviation industry

Due to changing structure of the aerospace industry by switching from traditional vertical programs to those with multi-national operations distributed in several stages (including production, after sales, maintenance, repairing and reconditioning) come inevitably greater challenges. The complexity of the industry lies in the supply and management of the design/production and after sales. Introduction of the new technologies, growth and the compliance requirements have created difficulties in the management of the supply chain. Also it is essential to have an effective communication in order to clarify the requirements and needs throughout the stages (MOCENCO, 2015).

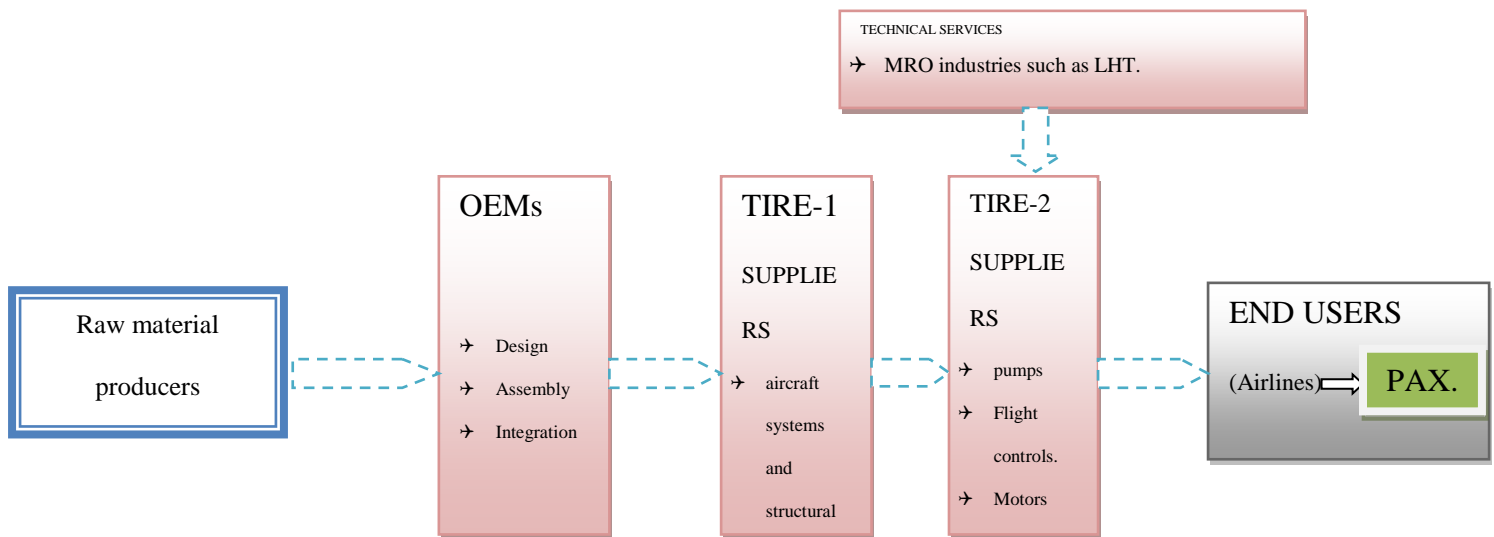


Figure 2.11: An overview of aviation supply chain (MOCENCO, 2015)

In addition to the supply chain of an aircraft as illustrated in Figure 2.11 above; the suppliers deliver materials or maintenance services to airlines. Later, the airline delivers services to passengers.

2.12 Aircraft maintenance checks

All the tasks defined through the maintenance development process will ultimately need to be allocated into scheduled work packages. Tasks with similar intervals are then grouped into a number of maintenance packages, each with its own interval. For commercial aircraft these intervals range from daily walk-around checks, to service checks performed at line maintenance station, to major checks performed at maintenance bases. In the airline industry, a letter check is the alphabetic designation given to scheduled maintenance packages. The three most commonly used letter checks consist of as explained on (Enterprise, 2016):

I. A-Check

The A-Check generally consists of a general inspection of the interior and exterior of the airplane with selected areas opened. The A-check is typically performed biweekly to monthly.

II. C-Check

The C-Check is typically scheduled every 12- 20 months depending on the operator, airplane type and utilization. Examples of C-check tasks include functional and operational systems checks, cleaning and servicing, attendance to minor structural inspections and Service Bulletin requirements.

III. D-Check

The D-Check, or Heavy Maintenance Visit (HMV), occurs every 6-12 years, depending on the airplane type and utilization. Usually the aircraft is taken out of service for several weeks. During this check the exterior paint is stripped and large parts of the outer paneling are removed, uncovering the airframe, supporting structure and wings for inspection of most structurally significant items. In addition, many of the aircraft's internal components are functionally checked, repaired/overhauled, or exchanged.

2.13 Maintenance Check Packaging

2.13.1 Block hour check

The block hours check packaging method is focused on the principle of grouping tasks which require frequent repetition under a letter check (i.e. “A”, “C”, & “D” Checks). This method produces a small number of relatively large work packages having the disadvantage of a relatively long maintenance ground time. Each letter check generally incorporates all the work covered by preceding checks, plus the tasks assigned at that letter-check interval. Thus each letter check often requires an increasing amount of man-power, technical skills, and specialized equipment. Figure 2.11 below illustrates a sample block check schedule. The size of each block indicates the ground time required to perform maintenance.

Block hour Check Advantages:

- Simplifies planning & scheduling of work packages
- Accomplishment of modifications
- Rectifications of non-routines
- More efficient sequencing of long jobs

Block hour Check Disadvantages:

- Large and scattered manpower requirements
- Longer ground time

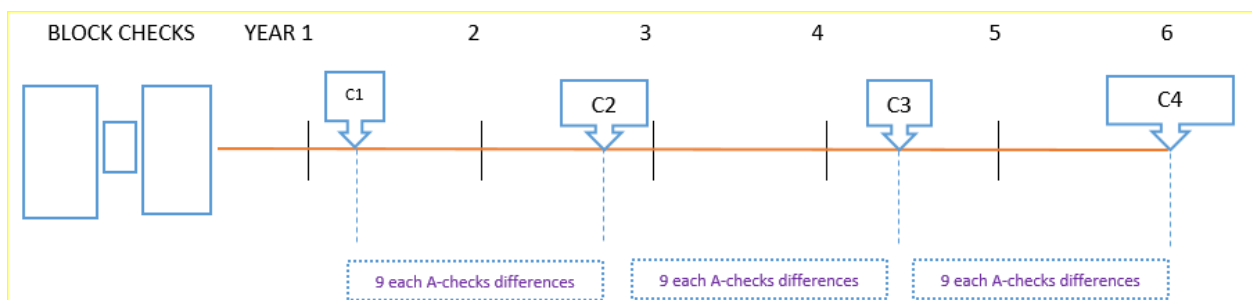


Figure 2.12: Block hour maintenance program (Enterprise, 2016)

2.13.2 Phase check

The phased check, sometimes referred to as *equalized* or *segmented check*, apportions tasks to smaller packages that may be accomplished more frequently than the packages in a block hour check see Figure 2.12 below. An operator, for example, may phase or segment, portions of its heavy maintenance tasks equally over the appropriate number of C-Checks. Usually, the objective of this subdivision is to even out the maintenance workload over time and shorten the length of each period of aircraft downtime. Peaks and valleys in man-power requirements are minimized by moving tasks from one check package to another. *The overall result of an equalized maintenance program is that the total number of scheduled maintenance downtime can be reduced over an aircraft's maintenance cycle.* The equal size of each block indicates the ground time required to perform maintenance is equally distributed.

Phase Check Advantages

- Reduced ground time
- Increased airplane availability
- Flexibility of grouping tasks

Phase Check Disadvantages

- Increases production planning & scheduling
- Limited time for accomplishment of major modifications
- Limited time to identify & rectify non-routines maintenance.

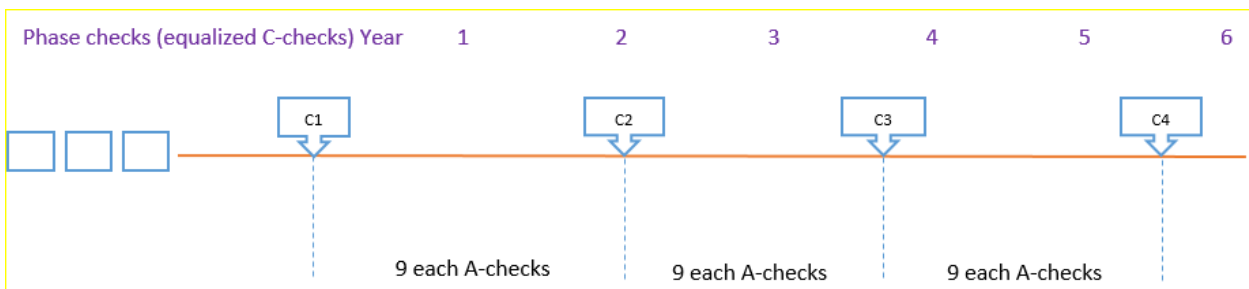


Figure 2.13: Phased maintenance program (Enterprise, 2016)

Operational Units:

- Flight Hours (FH): elapsed time between wheel lift off and touchdown
- Flight Cycle (FC): one complete take-off and landing sequence
- Cycle (CY): Engine cycles\

2.15 Maintenance Optimization

Maintenance optimization models are mathematical models whose aim is to find the optimum balance and quantification between the drawbacks (Maintenance cost and quality) and benefits of maintenance, while taking all sorts of constraints in to account.

Maintenance optimization models can either be *qualitative* or *quantitative*. Qualitative models include TPM, while quantitative models include *deterministic*/stochastic models such as Markov decision, Bayesian models and integer programming. Recently, several mathematical models are being utilized in maintenance scheduling. Majority literatures reviewed on maintenance optimization models stated that there are a number of case studies published which show that mathematical models are a good means to achieve both effective and efficient maintenance.

Modeling techniques and types

As per (Velten, 2009) maintenance optimization models can be classified as, *continuous* or *discrete* optimization, *static* or *dynamic* optimization, *deterministic* or *probabilistic* optimization, *constrained* or *unconstrained* optimization and *single-objective* or *multi-objective* optimization. Maintenance specific modeling decisions are; component or system perspective and finite or infinite planning horizon. Some maintenance optimization models for finite time periods exist, but these models are still an underexplored area of maintenance optimization.

Models can be classified based on: -

- Their structure,
 - a. *Iconic models*. That represents the system as is by scaling it up or down. That is, it is an image.

- b. Analogue models. Those models, in which one set of properties is used to represent another set of properties, are called analogue models. After the problem is solved, the solution is reinterpreted in terms of the original system.
 - c. Symbolic (Mathematical) models. Employs a set of mathematical symbols (i.e., letters, numbers, etc.) to represent the decision variables of the system. These variables are related together by means of a mathematical equation or a set of equations to describe the situation of the system. The solution of the problem is then obtained by applying well-developed mathematical techniques to the model or software.
- Their purpose, used to explain its usefulness
 - a. Descriptive models. Explains some aspects of a situation based on observations, survey, or Questionnaire results or other available data. The result of an opinion poll represents a descriptive model.
 - b. Predictive models. Which can answer ‘what if’ type of questions, i.e. they can make predictions regarding certain events.
 - c. Prescriptive models. Finally, when a predictive model has been repeatedly successful, it can be used to prescribe or authorize a source of action. For example, linear programming is a prescriptive (or normative) model because it prescribes what the managers ought to do.
 - Their nature of environment,
 - a. Deterministic models. Such models assume conditions of complete certainty and perfect knowledge. For example, linear programming, transportation and assignment models are deterministic type of models.

- b. Probabilistic (or Stochastic) models. Used to handle such situations in which the conditions of managerial actions cannot be predicted with certainty. However, it is possible to forecast a pattern of events, based on which decisions can be made.
- Their behavior,
 - a. Static models. These models do not consider the impact of changes that takes place during the planning horizon, meaning, they are independent of time.
 - b. Dynamic models. Here time is considered as one of the important variables and admits the impact of changes generated by time. Also, in dynamic models, not only one but a series of interdependent' decisions is required during the planning horizon
 - Their nature of solutions,
 - a. Analytical models. Models which have a specific mathematical structure and thus can be solved by mathematical techniques. For example, general linear programming models as well as the specially structured transportation and assignment models are analytical models.
 - b. Simulation models. They also have a mathematical structure but they cannot be solved by purely using the 'tools' and 'techniques' of mathematics. A simulation model is essentially computer-assisted experimentation on a mathematical structure of a real time structure in order to study the system under a variety of assumptions.

- The use of digital computer,
 - a. Analogue and Mathematical models combined. Sometimes analogue models are also expressed in terms of mathematical symbols.
 - b. Function models. Such models are grouped on the basis of the function being performed. A program representing a sequence of operations (like, in computer programming).
 - c. (Hi) Quantitative models. Such models are used to measure the observations. For example, degree of temperature, a unit of measurement of length value, transformation models which are useful in converting a measurement of one scale to another (e.g., Centigrade vs. Fahrenheit conversion scale).
 - d. Heuristic models. These models are mainly used to explore alternative strategies that were overlooked previously, whereas mathematical models are used to represent systems possessing well defined strategies. Heuristic models do not claim to find the best solution to the problem.

2.16 Multi-criteria optimization model (MCOM)

Before formulating the mathematical model, the case company list of processes and sub-processes on how to manage aircraft part purchase, foreign repair, in-house repair, and component pool agreement using supplier, input, processes, output, and customer (SIPOC) explained.

Table 2.3: Tactical purchase list of processes (Enterprise, 2016)

ETHIOPIAN MRO TACTICAL PURCHASE LIST OF PROCESS		
NO:	MAJOR PROCESS	SUB PROCESS
1	Aircraft Parts Purchase Process	1.1 Component part purchase
		1.2 Expendable part purchase
2	Aircraft Parts Repair Process	2.1 In House Repair (Waiting for Part)
		2.2 Foreign Repair
3	Aircraft Parts Exchange Process	3.1 Component exchange program (CEP)
		3.2 Flat rate exchange
		3.3 Exchange plus cost

Approved supplier, and repair stations deliver new and/or overhauled aircraft component or part to Ethiopian MRO and Ethiopian MRO delivers maintenances service to the airline owned, external customer, and third party customer aircrafts such as Rwanda Air, and to the airline cargo transport aircrafts with a defined time period. These scheduled maintenance requirements may need repair/overhaul or replacement of affected aircraft systems/components/structural parts or inspection of the aircraft as a whole by referencing the OEM maintenance manuals for MP tasks, OEM SBs or regulatory documents ADs to prepare a document known as Engineering Orders (EO) or routine tasks which allows cost expenditure to mandate Ethiopia MRO to perform the required aircraft maintenance activities to the level of in-house repair, and/or foreign repair based of the capabilities certified by regulatory authorities.

The Ethiopian MRO has plan for future maintenances, which conform to the annual and/or semi-annual flight plan of the commercial marketing department. Commercial marketing and Ethiopian MRO base maintenance managers to their respective area of concern must make a decision, using a strong decision making tools.

The symbolic model aims to assist the Ethiopian MRO base maintenance managers in planning aircraft maintenance checks in coordination with aircraft maintenance planning and record control and PSCM section. Intervention by Ethiopian MRO base maintenance manager has crucial importance when complex situations like large number and type of aircraft parts/component, in-house and foreign repair conditions become mandatory.

2.17 Why goal programming

Nowadays, in areas that require higher level decision making, majority of DMs are more concerned on their own sense than considering economic issues. It is necessary to do their best to make as much cost conscious approach as possible to minimize the total aircraft maintenance cost. One of such methods is to apply mathematical programming technique. Linear programming method is only used for specific a goal which is either to maximize or minimize, but real world situations may vary based on the behaviors and philosophy of the airline. In order to optimize multi-objective mathematical model a unique and improved methodology is required which is known as goal programming, an extension of linear programming.

Goal programming(GP) is one of the techniques in analytical framework to deal with multi-objective decision making (MODM) problems, using simplex method for finding optimum solution of a multi-dimensional objective function with a given set of constraints which are expressed in linear form and to provide optimal solutions to multiple and conflicting objectives (Orumie, 2014). The solution procedure of a linear goal programming models can be performed by minimizing the deviation of

determined target according to their priority and weight coefficients defined by decision makers; this implies goal programming has a close relationship with decision-making in practice and the results of multi-objective problem solutions are affected by the decision maker. The only drawback of multi-objective goal programming method is requirement of fairly detailed priority information on the decision-maker's preferences.

Goal programming method manages a set of contradicting objective to minimize the difference between the target and the realized results; and re-formulating the original objective as a set of constraints with target values and two auxiliary variables (ρ and Π) known as deviation variables which represent the distance from the target value in either direction.

If the undesired or non-achievement is driven to zero, then it means that actual attainment of the goal has been accomplished. In general, the main idea of goal programming is to convert original multi-objective into a single goal.

There are two algorithms for solving goal programming problems. Both methods convert the multiple goals into a single objective. The resulting model results a satisfying solution which may not be optimum with respect to all the conflicting objectives of the problem, but yields only an efficient and satisfactory result instead of optimum solution to the problem, because in real world cases it is not common to always satisfy every goal, so GP attempts to reach a satisfactory level of the multi-objectives under consideration. The first one is weighted goal programming or non-preemptive goal programming methods, the single objective function is the weighted sum of the conflictions representing the goals of the problems, that is, it considers all goals simultaneously within a composite objective confliction, comprising the sum of all respective deviations of the goals from their aspiration levels (Orumie, 2014). The deviations are then weighted according to the relative importance of each goal. To avoid the possible bias effect of the solution to different measurement unit goal,

normalization takes place (i.e. the model minimizes the sum of the deviations from the target). The second is as explained on a preemptive goal programming which is a hierarchy of priority levels for the goals, so that the goals of primary importance receive first priority attention, those of secondary importance receive second-priority attention.

Generally, goal Programming will be an appropriate technique concerning this thesis for decision analysis in order to achieve multiple conflicting objectives of cost, and quality of aircraft spare parts under their respective constraints. The modeling approach does not attempt to maximize or minimize the objective function directly as in the case of conventional Linear Programming. Goal Programming model seeks to minimize the deviations between the desired goals and the actual results to be obtained according to the assigned priorities.

Goal programming is primarily a satisficing technique, where decision makers aim to reach a set of defined goals and if they reach those goals, then they are satisfied. This is different from the concept of optimizing. Human beings are more interested and able to reach goals than in the abstract concept of optimizing each outcome of the decision problem. Meeting goals as closely as possible is the main aim of the goal programming technique that is why it is called Satisficing technique. Although goal programming can produce Pareto-inefficient solutions, this is mainly due to poor formulation and modeling of the decision maker's preferences and target levels by the analyst building the goal program (Belaid Aouni, 2001).

Satisfice: An old Scottish word referring to the desire, in the real world, to find a practical solution to a given problem, rather than some utopian result for an oversimplified model of the problem.

Goal programming is one of the posteriori techniques, where the solution process takes place first and the decision maker preferences are then drawn out from the generated set of solution, and most commonly used method for solving multiple objective decision problems. As stated (Ehrgott, 2003)

the decision maker or can be considered as a satisficing, which is a decision making strategy that necessitate searching through the available alternatives until the required target is met.

Lexicographic goal programming is one of the variants of GP, which orders the unwanted deviations in to a number of priority levels. This method of GP analysis is called lexicographic or preemptive GP. A lexicographic minimization may be defined as a sequential minimization of each priority while maintaining the minimal value.

2.19 Ethiopian MRO overview

Ethiopian MRO is a division of Ethiopian airline and is established in 1957 to provide MRO services for aircraft, engines and components of Ethiopian and third party customers. Ethiopian MRO has four main hangars used for airframe maintenance.

- B757/B777/A350(A closed-door hangar),
- B767/B787s hangar to accommodate both airplanes at the same time (closed-door hangar),
- B737 hangar (open-door hangar)
- Turboprop or Q400s hangar (open-door hangar)

The major functions of Ethiopian maintenance, repair and overhaul (MRO) are as follows:

- Line Maintenance
- Base maintenance for Airframe Heavy Maintenance
- Engine Overhaul
- Components Overhaul
- Modifications as per approved capability list

Ethiopian MRO is utilizing “**Maintenix**”, a state of the art MRO management IT system also Selected by Boeing for Gold-care program.

Ethiopian MRO has the capability to perform full airframe checks, engine maintenance such as PW2000 series, PW4000 series, CFM56-XX engines, and Heavy Maintenance on Boeing, Airbus and Bombardier model aircraft at its base station.

Base Maintenance

Airplane Base maintenance is place where maintenance than require more ground time than which needed by line maintenance and/or which does not fall under the line maintenance category, especially heavy checks such as C checks. During those checks major and minor aircraft systems are being evaluated together with complex and time consuming tasks such as corrosion prevention, structural work, replacement of major components, interior refurbishment, etc. Of course, all this work needs to be done in a closed hangar and requires in-depth planning.

Line Maintenance

As per EASA Part 145 regulation (Agency, 2017), line maintenance is any maintenance tasks which can be performed outside of a hangar (under open skies) except for situations in which the weather deteriorates to such conditions, that a hangar becomes mandatory, including activities associated with routine turn round and servicing of aircrafts up to components which are known as LRU – Line Replaceable Unit and including A Checks

Ethiopian MRO provides line maintenance services to domestic and foreign airlines in Addis Ababa Bole International Airport according to the agreement of IATA standards which is classified as,

- Full technical handling (Transit/Preflight Check, daily check, weekly check, etc.)
- Assistance (Fuel, Headsets, etc.)
- On-Call Handling

Aircraft Types Line Maintenance Capability

- Boeing aircrafts 787,777,757,767,737
- Airbus aircrafts A350-900
- Bombardier aircrafts Q400

Ethiopian MRO Maintenance Planning Background

Maintenance at Ethiopian MRO is categorized into Line Maintenance, and Base Maintenance. Line maintenance is performed at short intervals and it differs based on fleet type such as B737 (1hrs to 3hrs), A350 (2hrs to 4hrs). Every base maintenance visit is planned in a so-called hangar slot. Base maintenance is performed for maintenance greater than line maintenance aircraft ground time.

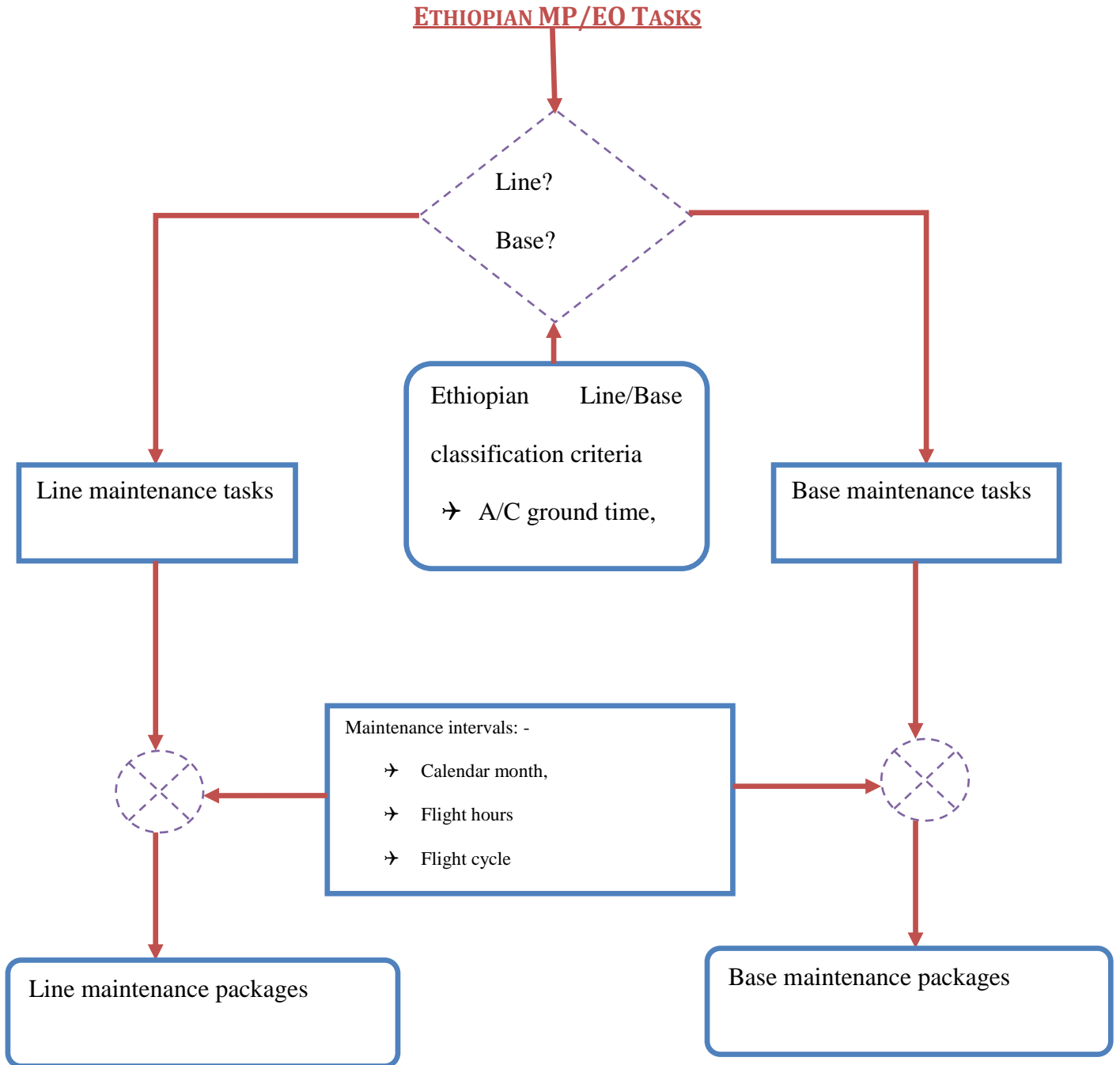


Figure 2.17: Method of classifying Line/Base maintenance task packages

2.20 Summary of Literature Review

Until now definitions of different aviation specific terminologies, type of aircraft maintenance, maintenance cost disclosure difference in different airlines, aircraft maintenance and associated major cost drivers have been investigated in depth. Identification of the major maintenance cost drivers with respect the current aviation industry trend and experience investigated. All the above literature is reviewed in order to compare and identify the major maintenance cost drivers in the industry, and can be used to compare with the case company particularly.

One of the observations in aircraft maintenance activities is that, more attention is given to the technical know-how, safety and satisfaction regulatory authorities criteria. With respect to maintenance planning and scheduling, minor attention is given to parameters which an airline can control, or optimize when maintenance cost is concerned. Referencing the IATAs reports, review of maintenance cost elements, component pooling, foreign repair has shown greater percentage and seen as the major cost drivers.

The decision made with AHP is in order to determine priorities with respect to cost as a criteria and level of importance in reaching the goal.

Pair wise comparison

Considering the Theory of Discrete Multi-Criteria Decisions, AHP has been one of the first methods developed, having been created in the 80's by (Saaty, 2008). Its main attraction is to incorporate both quantitative and qualitative criteria in its analysis.

Pairwise comparisons involve all the nodes. The nodes at each level is compared with respect to their contribution to the nodes above them. The result of these comparisons is entered in to a matrix or templet which is processed mathematically derive the priorities for all the nodes on the level. Since there are three alternatives (a/c spares, labor and maintenance reserve) to be compared with respect to cost as a criteria and assign relative weight to the other alternative. AHP fundamental scale in assigning the weight is used, as shown in the table 3.2 below.

Table 3.2: AHP fundamental scale of pairwise comparisons (Elisa Battistoni, 2013)

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

Table 3.3: Random consistency index (Elisa Battistoni, 2013)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Defining, Ranking, and Normalizing of criteria

The major cost drivers considering cost as a criterion:

- Cost of aviation maintenance personnel
- Aircraft spares and CEP/CSP and FR
- Maintenance reserve.

The interviewees should choose three cost determinants that are considered more important among the others. Considering n elements to be compared (C_1, \dots, C_n), a_{ij} denotes the relative weight or priority of C_i over C_j . $A = (a_{ij})$ is a square matrix of order n with the constraints $a_{ij} = 1/a_{ji}$, for $i \neq j$, and $a_{ii} = 1$. Such a matrix is known as a *reciprocal matrix*. When the weights are transitive, they will be consistent and $a_{ik} = a_{ij} \cdot a_{jk}$ for all i, j , and k . In this condition, $A \omega = \lambda \omega$, ω is an *eigenvector* (of order n) and λ is an *eigenvalue*. For a consistent matrix, $\lambda = n$. Human judgments are inconsistent to a greater or lesser degree, and therefore in matrices concerning human judgment, the condition $a_{ik} = a_{ij} \cdot a_{jk}$ will not be reliable. In such a case, $A \omega = \lambda_{\max} \times \omega$ and $\lambda_{\max} \geq n$. The difference between λ_{\max} and n is an indicator of the inconsistency of the judgment.

The consistency index (CI) can be measured by $(\lambda_{\max} - n) / (n - 1)$. The consistency ratio (CR) is calculated as follows:

$$CR = CI/RI,$$

Where RI is the random consistency index as shown in Table 3.3. If the CR exceeds 0.1, the set of judgments may be *too inconsistent* to be reliable, and a CR of 0 means that the judgments are *perfectly consistent*. This work is performed using a Microsoft Excel AHP template.

When the weights are transitive, they will be consistent and $a_{ik} = a_{ij} \cdot a_{jk}$ for all $i, j,$ and k . In this condition, $A \omega = \lambda \omega$, ω is an *eigenvector* (of order n) and λ is an *eigenvalue*.

For a consistent matrix, $\lambda = n$. Human judgment are inconsistent to a greater or lesser degree, so the condition $a_{ik} = a_{ij} \cdot a_{jk}$ will not be reliable. In such a case, $A \omega = \lambda_{\max} \times \omega$ and $\lambda_{\max} \geq n$. where ω is an *eigenvector*

$$CI = (\lambda_{\max} - n) / (n - 1)$$

$$\begin{pmatrix} 1 & 0.5 & 3 \\ 2 & 1 & 4 \\ 0.333333 & 0.25 & 1 \end{pmatrix} \begin{pmatrix} 0.32024 \\ 0.55714 \\ 0.12262 \end{pmatrix} = \begin{pmatrix} 0.96667 \\ 1.68810 \\ 0.36791 \end{pmatrix}$$

$$= A \omega$$

$$= \lambda_{\max} \times \omega$$

$$= \lambda_{\max} \begin{pmatrix} 0.32024 \\ 0.55714 \\ 0.12262 \end{pmatrix} = \begin{pmatrix} 0.96667 \\ 1.68810 \\ 0.36791 \end{pmatrix}$$

This implies that

$$\lambda_{\max} = \left[(0.96667/0.32024) + (1.68810/0.55714) + (0.36791/0.12262) \right] / 3$$

$$= 3.01631$$

Consistency index (CI) for $n=3$

$$CI = (\lambda_{\max} - n) / (n - 1) = 0.01631/2$$

$$= 0.008155 = 0.00816$$

3.2 Routine maintenance decision making model

Proper integration and management of the supply chain of an airline operation can lower the maintenance cost significantly. Due to the higher process complexity and the high material/part cost, however, the shorter path/time to minimize aircraft downtime often comes with a significant increase in direct maintenance cost. The implementation of cost-effective supply chain strategies is one means to meet this challenge.

As shown in figure 3.4 below, maintenance packages are organized by classifying the maintenance tasks in to convenient checks, to minimize the TAT of the aircraft, to keep the maintenance work load level, for better hangar utilization.

The OEM MPD and customized Ethiopian MPD explains a more detailed requirement, which includes access panel opening in order to perform inspection and lubrication of selected aircraft systems, components, to remove hard time components as per the reference JIC, to perform modification referencing the OEM SBs/ADs, to perform operational checks of emergency equipment's, to perform BITE of flight controls etc. which can be categorized under A or C checks.

In addition to proper compliance of scheduled tasks per MPD, aircraft maintenance includes performing modification/inspections in order to ensure incorporation of regulatory document AD or OEM document SBs under the umbrella of ICAO fundamental objectives, recommended practices and procedures to ensure a safe aircraft flight.

The continued action is preparing resources based on the type and number of maintenance check.

3.3 Mathematical model formulation

Modeling is a process of turning a problem in to a mathematical statement; which might be expressed in words, pictures etc. it includes which part of the original problem to retain and which part to discard, in addition to naming variables.

The mathematical model is formulated for aircraft maintenance planning decision support in preparation of aircraft spare. The case company must perform A check every 600 to 700FH and C-Check in every 6,000FH depending on the model and utilization of the aircraft. Each check contains several task cards, which indicate labor, required tools, spare part, and job card instruction steps. The aircraft material procurement process is separated from man powers and tools.

Predictive maintenance can help airlines to reduce costs and downtime. Airlines can take better advantage of the increasing amount of aircraft operational data available to support decisions and adjust maintenance planning. Using the idea explained (Amornsawadwatana, 2012) and analyzing to the case company by considering the actual situation in the company, the proposed model formulation is as follows:

→ Indices and Notations

Indices

I =Number of checks types (A 1, A2, A3...., C checks),

i = 1, 2, 3..., k

J =Number of inspections task cards and/or modification job cards or EOs.

There are I number of checks types such as A1, A2, C1, C2 checks, and with their corresponding job cards J , which are categorized based on the aircraft utilization as a function of flight hour or flight cycle.

j = 1, 2, 3..., n

→ Design or decision Variables

Defining the decision variables, there are four decision variables.

$X_{1[i,j]}$: the quantity of parts that Ethiopian MRO base maintenance manager *chooses to purchase*

$X_{2[i,j]}$: the quantity of parts that Ethiopian MRO base maintenance manager chooses to *receive using CEP or CSP*.

$X_{3[i,j]}$: the quantity of parts that Ethiopian MRO base maintenance manager chooses *FR options*,

$X_{4[i,j]}$: the quantity of parts that Ethiopian MRO base maintenance manager *chooses for in-house repair* component /part.

→ Cost Parameters

$C_{1[i,j]}$: purchasing price per unit of the aircraft part in birr.

$C_{2[i,j]}$: Average flat rate CEP/CSP price per unit for the aircraft part in birr.

$C_{3[i,j]}$: Foreign repair price per unit for the aircraft part in birr.

$C_{4[i,j]}$: In-house repair price per unit for the aircraft part in birr.

$C_{5[i,j]}$: Quality value of purchasing from OEM or from TSOA/PMA, or from ECAA or from other state aviation authority or do not have certificate the aircraft part ,(5,4,3,2,or 1) respectively.

$C_{6[i,j]}$: Quality value of CEP from OEM or from TSOA/PMA, or from ECAA or from other state aviation authority or do not have certificate then the selected aircraft part, (5,4,3,2,or 1) respectively

$C_{7[i,j]}$: Quality value of Foreign repair from OEM or from TSOA/PMA, or from ECAA or from other state aviation authority or do not have certificate then the selected aircraft part, (5,4,3,2,or 1) respectively

$C_{8[i,j]}$: Quality value of In-house repair from OEM or from TSOA/PMA, or from ECAA or from other state aviation authority or do not have certificate then the selected aircraft part, (5,4,3,2,or 1) respectively.

Objective Functions

I. ECONOMIC OBJECTIVE:

As mentioned above, the economic objective will be gained by minimizing the maintenance costs.

$$\text{Minimize } Z_1 = \sum_{i=1}^K \sum_{j=1}^n C_{1[i,j]} X_{1[i,j]} + C_{2[i,j]} X_{2[i,j]} + C_{3[i,j]} X_{3[i,j]} + C_{4[i,j]} X_{4[i,j]}$$

II. QUALITY OBJECTIVE:

$$\text{Maximize } Z_2 = \sum_{i=1}^k \sum_{j=1}^n C_{5[i,j]} X_{1[i,j]} + C_{6[i,j]} X_{2[i,j]} + C_{7[i,j]} X_{3[i,j]} + C_{8[i,j]} X_{4[i,j]}$$

Design constraints

Constraints that represent limitations on the behavior or performance of the system are termed behavior or functional constraints.

In general, from the collected data for the major cost determinants out of part purchase, CEP,FR and in house repair it is observed that price per component for CEP and FR including the transportation cost is more and better to limit the number of component pooling options.

In order to discourage the use of CEP/CSP, utilization of such component pooling, if the system forces to use, the quality will be reduced highly.

→ Based on the quantity of letter checks, the type of letter checks and scheduled aircraft utilization rate, *the quantity of parts* required per scheduled checks must be at most 2 (two) for lower checks (“1A”, “2A”, “3A”, “4A”, “5A”, “6A”, “7A” and “8A”.) and four (4) for higher system zonal checks (“1C”, “2C”, “3C”, “4C”, “5C”, “6C” and “8C”) and structural C checks (“S-1C”, “S-2C”, “S-3C”, “S-4C”, “S-5C”, “S-6C”, “S-8C” and “9C”) shall be provided through *CEP and/or FR*.

$$\sum_{i=1}^K \sum_{j=1}^n X_{2[i,j]} + X_{3[i,j]} \leq 2 \dots\dots\dots A \text{ check}$$

OR

$$\sum_{i=1}^K \sum_{j=1}^n X_{2[i,j]} + X_{3[i,j]} \leq 4 \dots\dots\dots C \text{ check}$$

→ Based on the quantity of letter checks , the type of letter checks and scheduled aircraft utilization rate, the *quantity of parts* required per scheduled checks must be at least 6 (six) for lower checks (“1A”, “2A”, “3A”, “4A”, “5A”, “6A”, “7A” and “8A”.) and twelve (12) for higher system zonal checks (“1C”, “2C”, “3C”, “4C”, “5C”, “6C” and “8C”) and structural C checks (“S-1C”, “S-2C”, “S-3C”, “S-4C”, “S-5C”, “S-6C”, “S-8C” and “9C”) shall be provided through *purchasing and/or in-house repair*.

$$\sum_{I=1}^K \sum_{j=1}^n X_{1[i,j]} + X_{4[i,j]} \geq 6 \dots\dots\dots A \text{ check}$$

$$\sum_{I=1}^K \sum_{j=1}^n X_{1[i,j]} + X_{4[i,j]} \geq 12 \dots\dots\dots C \text{ check}$$

→ Per (IATA, Guidance Material and Best Practices for Alternate Parts (PMA) and Approved (non-OEM) Repairs (DER), 2015) Airline surveys have shown that the prices of PMA parts are typically 20-30% less than the equivalent OEM prices. In some cases, price reductions of more than 40% compared with OEM list of prices have been observed. Considering 35% for the case company and if the system chooses OEM part purchase the total cost of maintenance will be increased by 35% per component. Using PMA parts/components instead of OEM parts/components will minimize the total maintenance cost at least by 65% ($C_{1PMA} = 35\%C_{1OEM}$)

$$\sum_{i=1}^K \sum_{j=1}^n C_{1PMA [i,j]} X_{1[i,j]} + C_{2 [i,j]} X_{2[i,j]} + C_{3[i,j]} X_{3[i,j]} + C_{4[i,j]} X_{4[i,j]} \geq 65\% T_{COST}$$

→ Per (IATA, Best Practices for Component Maintenance Cost Management, 2015) and the case company policy manual (Enterprise, 2016) a part will be scraped, if the ratio of the *foreign repair cost* to the *value of the newly purchased part* is greater than or equal to 65%. The maintenance manager most likely will choose to purchase the part.

$$\sum_{i=1}^K \sum_{j=1}^n C_{3 [i,j]} X_{3[i,j]} \leq 0.65 \sum_{i=1}^K \sum_{j=1}^n C_{1 [i,j]} X_{1[i,j]}$$

→ Each aircraft check *contains at least* one life limited part change and/or modification task with or without none routine finding

$$X_{1[i,j]} + X_{2[i,j]} + X_{3[i,j]} + X_{4[i,j]} \geq 1 \quad \forall(i, j)$$

→ none negativity of the cost and quality parameters

$$C_{1[i,j]}, C_{2[i,j]}, C_{3[i,j]}, C_{4[i,j]}, C_{5[i,j]}, C_{6[i,j]}, C_{7[i,j]}, C_{8[i,j]}, X_{1[i,j]}, X_{2[i,j]}, X_{3[i,j]}, X_{4[i,j]} \geq 0$$

3.4 Solution method using lexicographic linear goal programming (LLGP)

The basic approach of goal programming is to establish a specific numeric goal for each of the objectives, formulate an objective function for each objective, and then finding a solution that minimizes the (weighted) sum of deviations of these objective functions from their respective goals. As explained on (Orumie, U.C. and Ebong, D. 2014) a preemptive goal programming is a hierarchy of priority levels for the goals, so that the goals of primary importance receive first priority attention, those of secondary importance receive second-priority attention. This is known as lexicographic (preemptive) or non-Archimedean goal programming. Here each objective is optimized one at a time subject to a pre-defined ordering established by the decision makers.

As explained in (Hordofa, 2016) around 75% GP applications use lexicographic Goal programming (LGP), 20% use the Weighted Goal Programming (WGP), and the remaining 5% use the MINI- MAX (Chebyshev) option. These goal programming variants have the advantage of changing the multiple goals into a single objective function.

The basic methods of solving preemptive goal programming problems are two types, one is called the *sequential procedure*, and the other is the *streamlined procedure*. The sequential procedure solves a preemptive goal programming problem by solving a sequence of linear programming models. Instead of solving a sequence of linear programming models, like the sequential procedure, the streamlined procedure finds an optimal solution for a preemptive goal programming problem by solving just one linear programming model. *Thus, the streamlined procedure is able to duplicate the work of the sequential procedure with just one runoff the simplex method.* This one run simultaneously finds optimal solutions based just on first-priority goals and breaks ties among these solutions by considering lower-priority goals.

Table 3.7: General structure of goal programming model (Orumie, U.C. and Ebong, D. ,2014)

Goal	Deviation variable to be minimized in Z ₁ or Z ₂	If goal is achieved
$a_{ij} X_j \leq b_i$	ρ_i	$\rho_i = 0, \eta_i \geq 0$
$a_{ij} X_j \geq b_i$	η_i	$\eta_i = 0, \rho_i \geq 0$
$a_{ij} X_j = b_i$	$\eta_i + \rho_i$	$\rho_i = 0, \eta_i = 0$

To express the overall objective mathematically using *auxiliary variables* ρ , and η , these new auxiliary variables have the following interpretation

$$\rho_i = \begin{cases} \rho_i & \text{if } \rho_i \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$\eta_i = \begin{cases} |\eta_i| & \text{if } \eta_i \leq 0 \\ 0 & \text{otherwise} \end{cases}$$

Both overachievement and underachievement of a goal cannot occur simultaneously. Hence, either one or both of these variable must have a zero value; that is,

$$\rho_i \times \eta_i = 0$$

Since, GP model is one in which all objectives are converted in to goals.

Based on those new auxiliary variables representation, the new objective function (Z) to minimize the unwanted auxiliary variables will be

$$\sum_{i=1}^K \sum_{j=1}^n C_{1[i,j]} X_{1[i,j]} + C_{2[i,j]} X_{2[i,j]} + C_{3[i,j]} X_{3[i,j]} + C_{4[i,j]} X_{4[i,j]} - T_{COST} = \rho_i - \eta_i$$

$$\sum_{i=1}^K \sum_{j=1}^n C_{5[i,j]} X_{1[i,j]} + C_{6[i,j]} X_{2[i,j]} + C_{7[i,j]} X_{3[i,j]} + C_{8[i,j]} X_{4[i,j]} - Q_{\text{VALUE}} = \rho_2 - \eta_2$$

The purpose of GP is to minimize the deviations between the achievement of goals and their aspiration levels. After identifying the unwanted deviation variables, ρ_1, η_2 the new *objective function* which is also known as an *achievement function* Z in an ordered vector of their priority levels

$$\text{Minimize } Z = \rho_1, \eta_2$$

To complete the conversion, the goal programming formulation, better to incorporate the above definitions of the ρ_i and η_i directly into the model.

❖ Goal Constraints

$$\rightarrow \sum_{i=1}^K \sum_{j=1}^n C_{1[i,j]} X_{1[i,j]} + C_{2[i,j]} X_{2[i,j]} + C_{3[i,j]} X_{3[i,j]} + C_{4[i,j]} X_{4[i,j]} - (\rho_1 - \eta_1) = \text{TCOST}$$

$$\rightarrow \sum_{i=1}^K \sum_{j=1}^n C_{5[i,j]} X_{1[i,j]} + C_{6[i,j]} X_{2[i,j]} + C_{7[i,j]} X_{3[i,j]} + C_{8[i,j]} X_{4[i,j]} - (\rho_2 - \eta_2) = Q_{\text{VALUE}}$$

❖ Hard (rigid) constraints

$$\rightarrow \sum_{i=1}^K \sum_{j=1}^n X_{2[i,j]} + X_{3[i,j]} \leq 2 \dots\dots\dots A \text{ check}$$

OR

$$\rightarrow \sum_{i=1}^K \sum_{j=1}^n X_{2[i,j]} + X_{3[i,j]} \leq 4 \dots\dots\dots C \text{ check}$$

$$\rightarrow \sum_{I=1}^K \sum_{j=1}^n X_{1[i,j]} + X_{4[i,j]} \geq 6 \dots\dots\dots A \text{ check}$$

OR

$$\rightarrow \sum_{I=1}^K \sum_{j=1}^n X_{1[i,j]} + X_{4[i,j]} \geq 12 \dots\dots\dots C \text{ check}$$

$$\rightarrow \sum_{i=1}^K \sum_{j=1}^n C_{1PMA [i,j]} X_{1[i,j]} + C_{2 [i,j]} X_{2[i,j]} + C_{3[i,j]} X_{3[i,j]} + C_{4[i,j]} X_{4[i,j]} \geq 65\% T_{COST}$$

$$\rightarrow \sum_{i=1}^K \sum_{j=1}^n C_{3 [i,j]} X_{3[i,j]} \leq 0.65 \sum_{i=1}^K \sum_{j=1}^n C_{1 [i,j]} X_{1[i,j]} \quad \forall(i, j)$$

$$\rightarrow X_{1[i,j]} + X_{2[i,j]} + X_{3[i,j]} + X_{4[i,j]} \geq 1$$

$$C_{1[i,j]}, C_{2[i,j]}, C_{3[i,j]}, C_{4[i,j]}, C_{5[i,j]}, C_{6[i,j]}, C_{7[i,j]}, C_{8[i,j]}, X_{1[i,j]}, X_{2[i,j]}, X_{3[i,j]}, X_{4[i,j]} \geq 0$$

3.5 Solution algorithm

As described in (Orumie, 2014) the main steps for managing goal programming are: -

- I. Observing the goals as a function of constraints and introducing their respective deviational variables.
- II. Analyzing the goals to decide which deviational variables ρ_1 , η_1 , ρ_2 , or η_2 or both to be minimized
- III. Goals are ranked in the order of their importance and/or preemptive priority factors p_i are assigned to each.
- IV. If there is any tie with priority, assign weights to each deviational variable.
- V. For each of the objectives, a target or goal is given (b_i), which is the required achievement.
- VI. Finally, the unwanted deviations (η or ρ) from the given set of goals (b_i) are minimized by using an achievement function (z).

The procedure considers goal constraints as both the objective function and constraints.

$$\text{Lexi min } Z = \rho_1, \eta_2$$

The solution algorithm can be managed as; first the objective function of the multi-objective problem is ranked according to their priority. Here I assume that the first objective function is in priority one and the second objective in priority two and the first objective function is minimized considering the original constraints. The second objective function is minimized subject to the original constraints plus one additional constraint from the above minimized value of first priority.

- 1) Set the first priority level, $K= 1$ known as INITIALIZATION. Get the initial simplex table without the *index row* ($Z_j - C_j$) also known as *Net evaluation row*.
- 2) Calculate the *index row for all the non-basic variables* of the initial table and *check for feasibility or optimality conditions*.
 - ✓ If all the indicator row, $Z_j - C_j \leq 0$ for all non-basic variables, then the current table is optimal.
 - ✓ If all the *right hand sides are equal to zero* solution is optimal
 - ✓ If all coefficients of the *priority row are less than or equal to zero*, then the first priority (P_k) is satisfied.

If either of the above optimality criteria is satisfied, then go to step 5. Otherwise go to step 3

- 3) *In order to determine the pivot element, identify: -*
 - Identify the *Entering variable*:
 - ✓ A non-basic variable with the *highest positive of* ($Z_j - C_j$) row; or
 - ✓ The variable with *highest positive coefficient in the priority row*
 - Identify the *leaving variable*:
 - ✓ The basic variable identified using the *minimum ratio test*.

The smallest value of the ratio of the RHS column with the corresponding entering variable column is known as the pivot element.

- 4) From the pivot element and pivot column, then Perform Gauss-Jordan Elimination Method to update the new iteration table. If P_k is still in the C_B column, go to step 3; if not go to the next step (step 5).
- 5) Increment processes: set the next immediate lower priority, $K=k + 1$.

The optimal solution is the value in the objective function as it appeared in the last iteration table.

CHAPTER FOUR: MODEL VERIFICATION USING CASE STUDY

The Ethiopian B737-700, ET-ALK next generation aircraft is planned to perform scheduled checks of A1 and 2A1 having MP and modification tasks, refer the data on table 4.1 for more. The package consists of ten inspection and modification job cards using an available ground time of 10hrs. The base maintenance manager in coordination with planning and record control, and PSCM section, wants to attain the following goals:

- I. Accomplishing the work package with maximum maintenance cost of 1,000,000 birr.
- II. Quality level of modification parts to the level of 4

Solution algorithm

Using the data on table 4.1 below,

C_2 = sum of all CEP = for the total number of 361 CEP components the case company have annual payment of 93,255,607.89 birr and on an average per component 256,903 birr.

1. Assessment of the Current Component Exchange Programs (CEP)

1.1. Initial and Supplemental spares investment cost reduction due to the effect of CEP

a. Flight Hour (Flat Rate) Payment Data for CEP 2015-16 Fiscal Year

CEP Program - Annual Price List for 2015/16 Fiscal Year					
Item	Type of program	Annual payment effected (F/C)	Annual payment effected (Birr)	No. of Aircraft covered in CEP	No. of Components covered in CEP
1	Q400 TCS with LHT	EUR 2,898,977.32	72,112,350.73	19	315
2	B737 ICS with SRT/ KLM	USD 4,161,339.04	93,255,607.89	26	291 with SRT (Previously) 363 with KLM (Current)
3	B777 CSP with Boeing	USD 5,153,241.62	115,484,144.7	16	917 (495 PAX & 422 Freighter)
4	B787 TCS with LHT	EUR 2,516,808.69	62,605,867.84	13	402
5	B787 DP 100 with Rockwell Collins	USD 353,808.00	7,928,837.28		46
	TOTAL		ETB 351,386,808.44	74	2043

Using the base line mathematical model, when i run from 1:2 and j runs from 1:10

$$\begin{matrix} K=2 & n=10 \\ \text{Minimize } Z_1 = \sum_{i=1} \sum_{j=1} C_1 X_{1[2,10]} + C_2 X_{2[2,10]} \end{matrix}$$

$$\begin{matrix} K=2 & n=10 \\ = \sum_{i=1} \sum_{j=1} 245,095 X_{1[2,10]} + 256,903 X_{2[2,10]} \geq 1,000,000 \end{matrix}$$

$$\begin{matrix} K=2 & n=10 \\ \text{Maximize } Z_2 = \sum_{i=1} \sum_{j=1} C_5 X_{1[2,10]} + C_6 X_{2[2,10]} \end{matrix}$$

$$\begin{matrix} K=2 & n=10 \\ = \sum_{i=1} \sum_{j=1} 5 X_{1[2,10]} + 4 X_{2[2,10]} \geq 4 \end{matrix}$$

The hard constraints of the model from equation will be

$$\rightarrow X_1 + \eta_1 - \rho_1 \geq 6$$

$$\rightarrow 35\% C_1 X_1 + C_2 X_2 \geq 65\% T_{\text{COST}} \gg 85783 X_1 + 256903 X_2 + \eta_2 - \rho_2 \geq 65\% * 1,167,232$$

$$\rightarrow X_2 + \eta_3 - \rho_3 \leq 2$$

Goal constraints are

$$\rightarrow 245,095 X_{1[2,10]} + 256,903 X_{2[2,10]} + \eta_4 - \rho_4 = 1,000,000$$

$$\rightarrow 5X_{1[2,10]} + 4X_{2[2,10]} + \eta_5 - \rho_5 = 4$$

$$\text{Lexi min } Z = [(\eta_1 + \eta_2 + \rho_3), \rho_4, \eta_5]$$

Let:-

$$\triangleright K_1 = \eta_1 + \eta_2 + \rho_3$$

$$\triangleright K_2 = \rho_4$$

$$\triangleright K_3 = \eta_5$$

Based on the solution algorithm and lexicographic order of the functional and goal constraints,

	Lexi Min $K_1 =$		$\eta_1 + \eta_2 + \rho_3$	
	$X_1 + \eta_1 - \rho_1 = 6$	}	Hard constraints	
	$X_1 + 3X_2 + \eta_2 - \rho_2 = 9$			
	$X_2 + \eta_3 - \rho_3 = 2$			

Initial table

	C NBV	0	0	1	1	0	0	0	1	
C BV	BV	X ₁	X ₂	η_1	η_2	η_3	ρ_1	ρ_2	ρ_3	RHS
1	η_1	1	0	1	0	0	-1	0	0	6
1	η_2	1	3	0	1	0	0	-1	0	9
0	η_3	0	1	0	0	1	0	0	-1	2
	Z _j	2	3	1	1	0	-1	-1	0	15
	CNBV - Z _j	-2	-3	0	0	0	1	1	1	15

→ The initial table is not optimal.
 → Performing gauss-Jordan elimination method , the new table-1 will be updated using $R_2 - 3R_3$
 → In a minimization problems a higher negative $C_{NBV} - Z_j$ will enter (X₂) and using minimum ratio test η_3 will leave the bases.

Table-1

	C NBV	0	0	1	1	0	0	0	1	
C BV	BV	X ₁	η_3	η_1	η_2	η_3	ρ_1	ρ_2	ρ_3	RHS
1	η_1	1	0	1	0	0	-1	0	0	6
1	η_2	1	0	0	1	-3	0	-1	3	3
0	X ₂	0	1	0	0	1	0	0	-1	2
	Z _j	2	0	1	1	-3	-1	-1	3	9
	CNBV - Z _j	-2	0	0	0	3	1	1	-2	9

→ Table-1 is not optimal.
 → In a minimization problems a higher negative $C_{NBV} - Z_j$ will enter (X₁) and using minimum ratio test ρ_2 will leave the bases. Due to the ties , choosing X₁.
 → Performing gauss-Jordan elimination method , the new table-2 will be updated using $R_1 - R_2$

Table-2

	C NBV	1	0	1	1	0	0	0	1	
C BV	BV	η_2	η_3	η_1	η_2	η_3	ρ_1	ρ_2	ρ_3	RHS
1	η_1	0	0	1	-1	3	-1	1	-3	3
0	X ₁	1	0	0	1	-3	0	-1	3	3
0	X ₂	0	1	0	0	1	0	0	-1	2
	Z _j	0	0	1	-1	3	-1	1	-3	3
	CNBV - Z _j	1	0	0	2	-3	1	-1	4	3

Table-3

	C NBV	1	0	1	1	1	0	0	1	
C BV	BV	η_2	η_3	η_1	η_2	η_1	ρ_1	ρ_2	ρ_3	RHS
0	η_3	0	0	1/3	-1/3	1	-1/3	1/3	-1	1
0	X ₁	1	0	1	0	0	-1	0	0	6
0	X ₂	0	1	-1/3	1/3	0	1/3	-1/3	0	1
	Z _j	0	0	0	0	0	0	0	0	0
	CNBV - Z _j	1	0	1	1	1	0	0	1	0

Table-3 is optimal and all η_1 , η_2 , and ρ_3 will be dropped. The presence of zero (0), the optimal value of the objective function being zero, indicates there is a feasible region associated with the hard constraints. The existence of zero shows it is good and there is a feasible region symbolized by $K_1 = \eta_1 + \eta_2 + \rho_3 = 0$.

Lexi Min K 2 = ρ_4	
$245095X_1 + 256903X_2 + \eta_4 - \rho_4 = 9$	} The fourth goal constraint

Expressing X₁ and X₂ as a function of η_3 , ρ_1 , ρ_2 , and using the above optimal table;

$$X_1 - \rho_1 = 6$$

$$X_2 + \eta_3 + \rho_1/3 - \rho_2/3 = 1$$

Substituting all those in the fourth constraint it will be;

$$(-478382 \rho_1/3) - (256903 \rho_2/3) + 256903 \eta_3 - \eta_4 + \rho_4 = 727473$$

Table-4

	C NBV	0	0	0	0	1	
C BV	BV	η_3	ρ_1	ρ_2	η_4	ρ_4	RHS
0	η_3	0	- 1/3	1/3	0	0	1
0	X1	0	-1	0	0	0	6
0	X2	1	1/3	- 1/3	0	0	1
1	ρ_4	256903	- 478382/3	- 256903/3	-1	1	727473
	Z_j	256903	- 478382/3	- 256903/3	-1	1	727473
	CNBV - Z_j	- 256903	478382/3	256903/3	1	0	727473

→ Table-4 is not optimal.
 → In a minimization problems a higher negative $C_{NBV} - Z_j$ will enter (η_3) and using minimum ratio test X 2 will leave the bases.
 → Performing gauss-Jordan elimination method , the new table-5 will be updated using **R4 - 256903R3**

Table-5

	C NBV	0	0	0	0	1	
C BV	BV	X2	ρ_1	ρ_2	η_4	ρ_4	RHS
0	η_3	0	- 1/3	1/3	0	0	1
0	X1	0	-1	0	0	0	6
0	η_3	1	1/3	- 1/3	0	0	1
1	ρ_4	0	- 735285/3	0	1	1	470570
	Z_j	0	- 735285/3	0	1	1	470570
	CNBV - Z_j	0	735285/3	0	0	0	470570

Table-5 is optimal.

From the above optimal table-5, I observed that the objective function value is not zero(470570). It is not possible to get ρ_4 equal to zero. It is not required to include the fifth objective function and constraints further. Better to observe the effect of the solution on the fifth objective function and constraints.

$$X_1 = 6, X_2 = 1, \eta_3 = 1$$

$$5X_{1[2,10]} + 4X_{2[2,10]} + \eta_5 - \rho_5 = 4 \quad \gg \quad 5(6) + 4(1) + \eta_5 - \rho_5 = 4$$

$$\gg \quad \eta_5 - \rho_5 = -30 \text{ since } \eta_5, \rho_5 \geq 0$$

$$\gg \quad \eta_5 = 0 \text{ and } \rho_5 = 30$$

From the overall verification process defining my aspiration level of total maintenance cost to 1,000,000birr per A1,A2 checks and compared with the actual maintenance cost of 1,167.232birr and it will be 14.33% which will be under the aviation industry average.

CHAPTER FIVE: CONCLUSION, RECOMMENDATION AND FUTURE RESEARCH

5.1 Conclusion

It is very well understood that performing aircraft preventive maintenance has cost, and adjusting the frequency of such type of preventive maintenance could be attained through customization of the OEM maintenance program(MP) without compromising on safety and quality of maintenance activity. Carefully Optimizing maintenance planning and scheduling, maximizing aircraft utilization, and straggling to minimize aircraft maintenance costs through conscious approach of resource management, especially the major maintenance cost drivers, will increase Ethiopian airline's profitability. Aircraft component maintenance and management is the major maintenance cost drivers for the case company MRO. The case company management observing only to minimize flight delay and/or cancellation in the line maintenance area by using component pool agreement as a function of lead time minimization. Compared to the impact of other airline's maintenance activities, negligible effort has been made so far in building in-house capability development instead of component pooling, and of foreign repair option. Because those options might have a higher initial investment, but it will have a good investment return and in the long range will become one means of income generation. Using regulatory authority approved PMA components /parts have a good cost saving without compromising safety and quality, but this requires higher management involvement to prepare the plate form such as preparing policy and procedure, communicating the aircraft OEM to include the parts in the illustrated parts catalogue (IPC). Current practices and problem areas, common in the Ethiopian airlines, compared to the industry standard IATA's report are cases to manage the none-routine maintenance strategy, and aircraft part management. In general, the case company requires

integrating the planning and scheduling the aircraft for heavy maintenance with the associated parts with in-depth communication with the maintenance manager for decision making targeting to minimize the total maintenance cost instead of planned part purchase based upon the historic data. The developed mathematical model can be used as a decision making tool.

5.2 Recommendations

The research aimed at analyzing and identifying the major cost drivers during Ethiopian MRO preventive maintenance activities. It is identified that aircraft part management is the major one. The case company component management principle totally lies accepting aircraft part through component pool agreement instead of developing in-house capability and using regulatory authorities approved PMA component/parts. Majority of airlines use the component pool agreement in order to manage line maintenance activities to minimize surprise flight disruptions resulting aircraft delay and/or cancelation. Using component pool agreement for base maintenance activities is not a cost effective approach due to the existence of aircraft ground time in the hangar relative to line maintenance. Using the mathematical model as a maintenance planning decision support tool in order to prepare the aircraft parts for base maintenance letter checks in associations with a detailed utilization of aircraft maintenance program will be effective. The model can be used in order to tradeoff between CSP pool access, PMA part purchased instead of OEM parts and without compromising quality and aviation safety.

At the Ethiopian Airline the following sections shall take responsibility to implement PMA procedures: –

- I. The Purchasing or Finance or PSCM section shall identify an opportunity to use a specific PMA part, perform the analysis necessary to show a “business case” and assemble a “Standard Data Package” using documentation from the prospective PMA part supplier.

II. Aircraft systems engineering department shall review the standard data package for applicability to the Ethiopian fleet and verify that local regulatory standard and the airline's technical requirements have been satisfied. If the review shows that the PMA part is acceptable, the engineering department issues an engineering authorization to use the PMA part and initiates the necessary documentation changes for use by Maintenance. If the review identifies any issues, the candidate PMA part may be rejected or the PMA supplier may be requested to provide additional documentation.

5.3 Future research

The developed mathematical model provides an insight of what are the major maintenance cost drivers and how they can be linked to the total maintenance cost and aircraft part quality concepts irrespective of using OEMs part purchase. For further analysis, it is recommended to develop software using the solution algorithm that easily shows as a priori technique for the decision maker or maintenance manager and also an easy mechanism of for validation or verification for the model.

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APPENDIX

case company aviation expert's profile

<i>EAL department/division</i>	<i>Position</i>	<i>Experience</i>
EAL AEP	Director	15/10 years
EAL PSCM	Director	20 years
EAL Line maintenance	Director	17 years
EAL base maintenance	Director	16 years
EAL TSM	Director	18 years
AOG support(Spares)	Manager	12 years
Aircraft Systems Engineering	Manager	10 years
PSCM supervisors/staffs	Procurement officers/supervisors	5-13 years