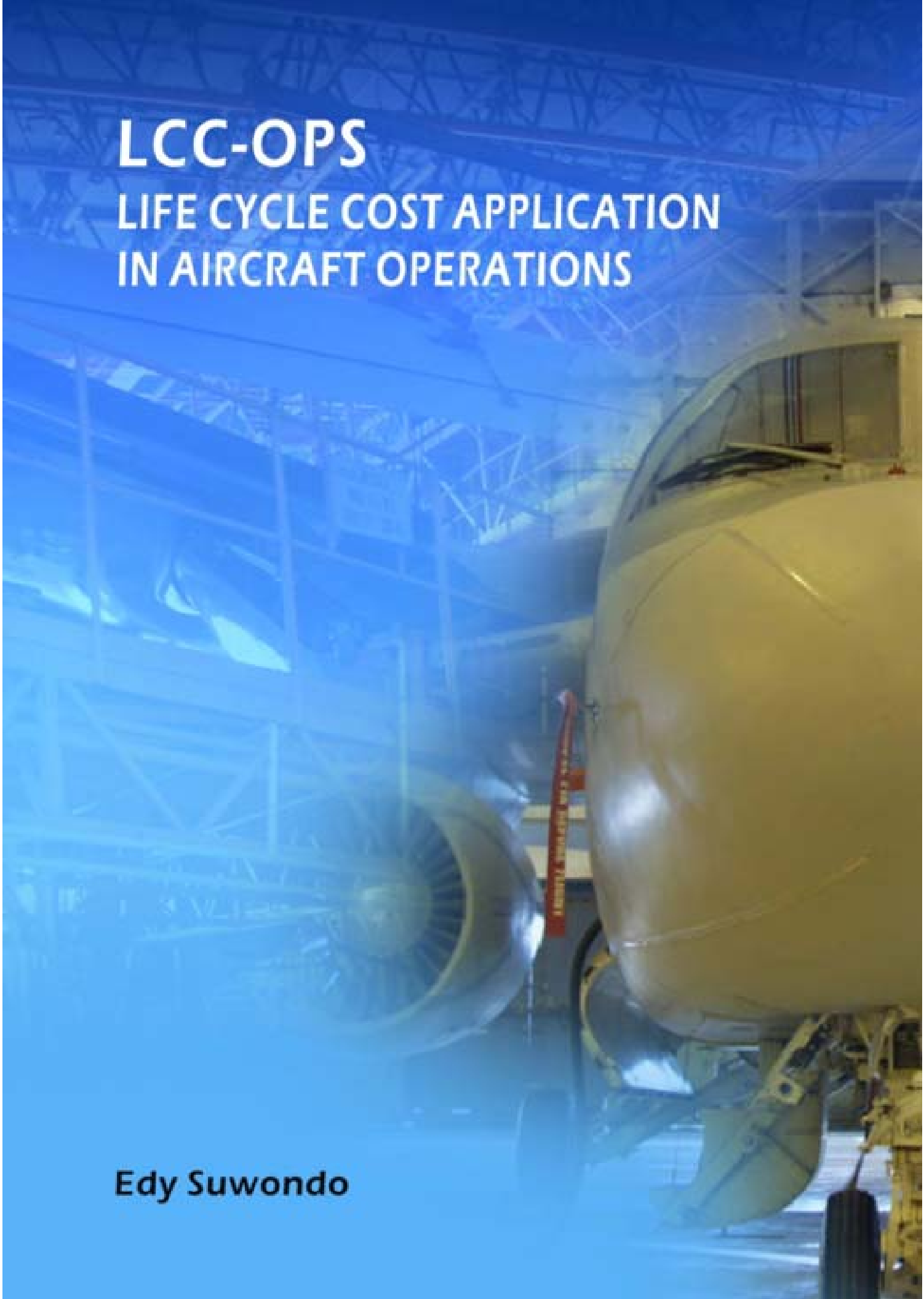
LCC-OPS

LIFE CYCLE COST APPLICATION IN AIRCRAFT OPERATIONS



Edy Suwondo

LCC-OPS

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Observation of current practices in aircraft operations and maintenance shows limited consideration of cost savings applied by aircraft modifications, maintenance program optimisation and aircraft selection. This is due to hidden (maintenance dependent) costs and difficulties in quantifying the utilisation of a higher availability or reduction of revenue losses. Hidden costs can be a significant portion of operating costs and could be reduced by a better aircraft reliability. Most of the decisions for aircraft modification and maintenance program optimisation are made only to fulfil airworthiness or operational (technical delays and cancellations) requirements. The considerations for the impact of aircraft reliability and maintenance dependent costs on life cycle cost are limited during aircraft selection, because operational data is very limited and the methods to quantify technical delays and cancellations are not available.

This situation can be improved by a better quantification of the required investment and the savings achieved by a proper evaluation of the implemented modifications and maintenance program optimisations. In this thesis a Life Cycle Cost model is developed, called LCC-OPS, which visualises the hidden costs and quantifies opportunity revenues or losses. This model will provide an objective calculation and evaluation of the current and projected alternatives.

PENERBIT ITB

Jl. Ganesa 10, Bandung 40132,Indonesia
Telp. +62-22-2504257, Fax. +62-22-2534155
E-mail: itbpress@bdg.centrin.net.id

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Proefschrift

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Dit proefschrift is goedgekeurd door de promotoren:
Prof. ir. K. Smit
Prof. ir. O. Diran, MSAE.

Samenstelling promotiecommissie:

Rector Magnificus, voorzitter	
Prof. ir. K. Smit	Technische Universiteit Delft, promotor
Prof. ir. O. Diran, MSAE.	Institut Teknologi Bandung, tweede promotor
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Prof. dr. ir. Th. van Holten	Technische Universiteit Delft, reserve

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Printed in Indonesia

To my wife Suci Resmiwati,
my daughters Yusrina Nur Dini,
Hasna Nur Karimah and Marha Nur Amalina

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Abbreviations

AD Airworthiness Directive

AFL Aircraft Flight Log

ALI Airworthiness Limitation Items

AMOC Alternative Means Of Compliance

AML Aircraft Maintenance Log

AMM Aircraft Maintenance Manual

AOL All Operators Letter

ASK Available Seat Kilometre

ATA Air Transport Association

ATC Air Traffic Control

ATK Available Ton Kilometre

BEP Break Even Point

BPP Basic Production Planning

CASR Civil Aviation Safety Regulation

CBA Cost Benefit Analysis

CBS Cost Breakdown Structure

CCM Configuration and Change Management

CEM Cost Estimation Method

CML Cabin Maintenance Log

CMMIS Computerised Maintenance Management Information System

CMR Certification Maintenance Requirements

CPCP Corrosion Prevention and Control Program

DGAC Directorate General Air Communications

DMC Direct Maintenance Cost

DOC Direct Operating Cost

ECR Engineering Change Request

EES Engineering Evaluation Sheet

E&M Engineering and Maintenance

EO Engineering Order

EI Engineering Information

IFSD In- Flight Shut Down

FAA Federal Aviation Administration

FH Flight Hours

FISR Fleet Issues Summary Report

FQIS Fuel Quantity Indicating System

FSR Flight Summary Report

GIA Garuda Indonesia Airlines

GMF Garuda Maintenance Facility

GNP Gross National Product

GVC General Visual Check

HLA How Long Ago

HML How Much Longer

IATA International Air Transport Association

IOC Indirect Operating Cost

IRR Internal Rate of Return

ITEL Illustrated Tools Equipment List

LCC Life Cycle Cost

LCCA Life Cycle Cost Analysis

LCP Life Cycle Profit

LRU Line Replacable Unit

MAREP Maintenance Report

MB Manufacturer's Bulletin

MCRM Maintenance Control by Reliability Methods

MDC Maintenance Dependent Cost

MDR Maintenance Discrepancy Report

MFG Manufacturer

MPD Maintenance Planning Data

MPP Maintenance Program Proposal

MR Maintenance Requirements

MRB Maintenance Review Board

MRC Maintenance Review Committee

MRI Maintenance Requirement Item

MRO Maintenance and Repair Organisation

MSC Maintenance Steering Committee

MSG Maintenance Steering Group

MSI Maintenance Significant Item

MTBF Mean Time Between Failure

MTOW Maximum Take Off Weight

MWG Maintenance Working Group

NDT Non-Destructive Test

NPV Net Present Value

O&S Operation and Support

O&M Operation and Maintenance

PERT Program Evaluation and Review Technique

PIREP Pilot Report

RCP Reliability Control Program

RDT&E Research Development Test and Evaluation

RMR Reliability Monitoring Report

ROI Return On Investment

SADT Structured Analysis and Design Technique

SB Service Bulletin

SDR Service Difficulty Report

SID Structural Integration Design

SL Service Letter

SPC Special Check

SRM Structural Repair Manual

TCDS Type Certificate Data Sheet

TDR Technical Delay Report

TOC Total Opearting Cost

TSI Time Since Install

TSN Time Since New

TSO Time Since Overhaul

TPM Technical Procedure Manual

UCL Upper Control Limit

WFA World Fleet Average

WI Work Instruction

PART I
INTRODUCTION

Chapter 1

The Areas of the LCC Concept Application

This chapter gives an overview of the Life Cycle Cost (LCC) concept application in aircraft maintenance by describing the motives to apply the LCC concept in the operational phase of aircraft. A literature survey on aircraft maintenance is given as well, to identify how far costs are considered. Description of the research subject, the approach of the research and the structure of the thesis close this chapter.

1.1 Motives to Apply the LCC Concept

This section presents the motives to apply the Life Cycle Cost (LCC) concept, instead of the standard Cost Benefit Analysis (CBA) methods[1], for evaluation of alternatives in the area of aircraft modifications, maintenance program optimisation and aircraft selection within Fleet Management of an airline. The research is focused on aircraft engineering and maintenance, as the main subject.

The motives to apply the LCC concept, as mostly described in literature, are that the exploitation cost have a higher proportion within LCC as compared to the investment cost, and that the exploitation cost is in some cases not clearly visible (hidden[2]). The major applications of the LCC concept are in the early stages of the aircraft development phase, due to the impact of the selected design alternatives to the LCC committed. However, the following will show that application of the LCC concept in the exploitation phase is of importance as well.

1.1.1 Composition of Life Cycle Cost

A general definition of Life Cycle Cost (LCC) is "the total cost incurred by an item along its entire life (life cycle)" [Suwondo, 1999]. This total cost consists of the initial investment

[1] Appendix E specifically provides a comparison between various methods or criteria of economic analysis.
[2] This 'hidden' costs are normally consequences of failures, including loss of revenues due to flight delays and cancellations.

(acquisition) and exploitation (Operation and Support, O&S) costs, which indicates also the two major phases of the life cycle. Investment costs are normally divided into Research and Development, Test and Evaluation (RDT&E), and production cost. While the exploitation costs includes the operation, maintenance and retirement (disposal) cost.

In the exploitation phase of aircraft, the Total Operating Cost (TOC) is normally divided into categories as shown in Table 1.1. This data is from aircraft of IATA members, a mix of passenger and cargo with various models, size, utilisation and age. TOC is also divided into two major categories, i.e. the Direct Operating Cost (DOC) and the Indirect Operating Cost (IOC). Table 1.1 shows that IOC is 57.6% of TOC, while DOC is 42.4%. Typical characteristic of DOC is that it can be influenced during the design and also in the exploitation phase. Therefore, DOC, and in this research specifically Maintenance and Overhaul costs, is the point of consideration for cost reduction efforts.

DOC is per definition operating costs which are directly attributable to the aircraft being operated. The rests are IOC. DOC normally consists of four major cost categories, i.e. crew cost, fuel and oil cost, depreciation cost and maintenance cost. The depreciation cost includes also insurance cost. The annual insurance cost is about 1.5% to 3% of the full purchase price and depends on the number of aircraft to be insured and geographical area of operation [Doganis, 1992, p.112].

From LCC point of view, all cost categories resulting from aircraft acquisition and exploitation are included in the LCC. Therefore, only two cost categories of Table 1.1 are *excluded* from LCC, namely Ticketing, Sales and Promotion, and General and Administration cost. These cost categories are more appropriate to be attributed to the company operation than to the aircraft. Assuming that the operating costs composition is constant along the aircraft life cycle, then the acquisition cost (represented by the depreciation cost) is only 16.3% of LCC. In other words, exploitation cost over the whole economic life is about 5 times of the acquisition cost.

It is clear that for a long range operation the DOC is very much dominated by fuel cost, while for short range the contribution of fuel cost on DOC is lower. However, it depends

Table 1.1 Distribution of operating cost per ATK [IATA, 1999]

Cost component	% to TOC	% to DOC	% to LCC
DOC:			
Cockpit Crew	7.2	17.0	9.2
Fuel and Oil	12.5	29.4	16.0
Depreciation, Rentals and Insurance	12.7	30.0	16.3
Maintenance and Overhaul	10.0	23.6	12.8
TOTAL:	42.4	100.0	54.4
IOC:			
Landing Charges	5.4		6.9
En-Route Charges	4.6		5.9
Station and Ground Costs	12.0		15.4
Cabin Crew and Passenger Service	13.6		17.4
Ticketing, Sales and Promotion	16.4		
General and Administration	5.6		
TOTAL	57.6		45.6

significantly on the technology applied on the aircraft, type of operation and the fuel price. As indicated by Friend, for the B747 the depreciation and rental cost is only 15% of DOC, while for B757-200 depreciation and rental cost is 29.3% [Friend, 1992]. More advanced technology is applied for the later aircraft which resulted in a lower fuel consumption. Assuming that proportion of DOC and IOC is the same as in the earlier discussion, the contribution of acquisition (depreciation and rental) cost to LCC for those aircraft is 8.2% for B747 and 16% for B757. In other words, the exploitation cost is 11.2 times of the acquisition cost for B747 and 5.25 times of the acquisition cost for B757 (Ticketing, Sales and Promotion cost and General and Administration cost excluded).

Due to the significance of exploitation cost in LCC, high attention to exploitation cost is necessary. This is done especially during acquiring new aircraft to compare the LCC of the aircraft options. Continuous evaluation of potential exploitation cost saving need to be conducted as well during the operating phase. Efforts to reduce DOC can be applied to the cost of fuel & oil consumption, maintenance and depreciation. Reduction of fuel cost can be made through weight and drag reduction by aircraft modifications. Reduction of maintenance cost is conducted through maintenance program optimisation and/or aircraft modifications. While reduction of the depreciation cost can be obtained by increasing the resale value of the aircraft through modifications and proper maintenance.

1.1.2 Total Cost Visibility

The exploitation cost is not clearly visible at the time of acquisition, even though its portion is dominant as compared to the acquisition cost. This is because the exploitation cost incurs in the future. The invisibility of exploitation cost is typically illustrated as an "iceberg", where almost all cost components of exploitation are hidden or overlooked, as shown in Fig. 1.1. Figure 1.1 shows also more detailed components of LCC, i.e.:

i. *acquisition costs*: research and development, design, test and production.
ii. *exploitation costs*: delivery, operation, supporting software, maintenance, test and support equipment, training, spares, documentation, *down time* and retirement.

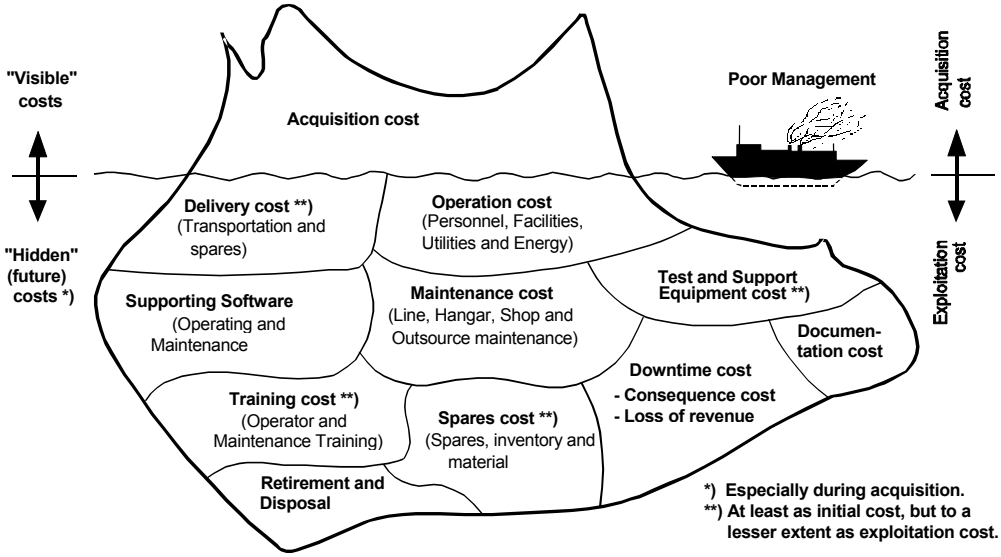


Fig. 1.1. The 'iceberg' phenomena analogy for the invisibility of exploitation cost [Blanchard, 1991, modified]

The fact that the exploitation cost is often overlooked or badly estimated can be reflected, principally in two processes, i.e.:

a. *evaluation of (sub-)systems/engines during aircraft acquisition*
   During the evaluation of a (sub-)system to be acquired, the greatest attention is paid to the conformance of functional performance specifications and the initial purchase price. The exploitation cost has limited attention, shown by the absence of contract clauses on exploitation cost.

b. *design of a new system or modifying existing system*
   During the design of a new aircraft or major modification of an existing system, attention is much more paid at the functional performance requirements. The reliability, maintainability, supportability and the cost consequences are minor considerations or not considered at all. This is shown by the absence of penalties for performance targets (agreed initial specifications) which are not reached in the initial exploitation phase.

The followings discuss some areas where potential cost savings could be gained.

1) Delay and cancellation costs:

A special category of exploitation costs is the *downtime cost* which consists of the cost of delays and cancellations, and *loss of revenue* due to lower aircraft availability. Loss of revenue, or opportunity revenue if it is an improvement, is a method to translate the changes of aircraft availability in financial terms. The assumption is that any changes of aircraft availability will have *the same probability to gain revenue*. The following discusses the contribution of the delay and cancellation cost to exploitation cost.

American Airlines divides delays into ten categories [NASA CR-145190, 1977], i.e.:

- Late arrival from another station
- Maintenance
- Passenger service
- Cabin/cargo service
- Ground equipment, includes also unavailability of terminal facilities.
- Stores, due to shortages of parts or defective parts from the stores.
- Flight crew (and/or cabin crews)
- Weather, includes also aircraft de-icing.
- Late equipment, includes also aircraft late from hangar.
- Others, includes ground based air traffic control (ATC), unscheduled work stoppages and other gate hold causes.

Based on comparison with recent delay cause codes of other airlines, above delay causes are still relevant. Amongst the factors above, maintenance, ground equipment and stores can be influenced during design or operation phase. The required maintenance elapsed time is an indication of aircraft maintainability and this can be reduced through a good design or by modifications during exploitation phase. During design, the use of commonality concept for equipment and parts will reduce cost to provide equipment and spare parts and rotables. Number of delays and cancellations will decrease with applying components with high reliability or the use of redundancy and by an optimum maintenance schedule.

In the year 1976, for American Airlines, delay and cancellation costs is 4.26% of the Direct Maintenance Cost (DMC), excluding engine maintenance [NASA CR-145190, 1977]. For the 727's fleet, the delay cost due to maintenance (mechanical delay) is USD 596 (1976 USD) per delay, while the others is USD 166 per delay. The contribution of maintenance to cancellation cost is about 30% and to the total delay cost is 21.0%. Late of arrival has the highest contribution to delay cost, i.e. 23.2%. From these figures, it is clear that maintenance had a significant contribution to the delay and cancellation cost. However, comparison of delay cost from one airlines to another must be based on the same definition of delay. American Airlines uses criteria that over one minute is considered as a delay.

The Air Transport Association (ATA) reported that the costs of delay resulted by 28 major US airlines in 1999 is USD 4.3 billion, which consists of USD 2.2 billion attributed to airlines and USD 2.1 billion as the value of passenger time [ATA; Aviation Week, 25 Oct., 1999]. Another USD 850 millions must be added to handle passengers grounded by delays. The distribution of delay cost for ATA member airlines is shown in Table 1.2. However, ATA does not provide information on the contribution of aircraft maintenance to this delay cost in 1999.

Table 1.2. The distribution of delay cost of ATA members [ATA, 2000]

Phase of flight	% of delay cost
Taxi out	47.2
Airborne	34.3
Taxi in	12.9
Gate	5.6

2) Maintenance interval escalation:

Scheduled maintenance cost, generally, can be considered as visible costs. This is because it can be estimated before it incurs. It can be estimated based on the required man-hours for each maintenance package and the intervals. Significant maintenance cost savings can be gained by escalating maintenance intervals. Furthermore, escalation of maintenance intervals increases aircraft availability (opportunity revenue). However, escalation must consider its impact on non-routine maintenance (repairs) and corrective maintenance. The following gives an example of maintenance cost savings due to escalation of maintenance package interval.

Example of maintenance interval escalation:

The existing interval of an A-check for a B747-400 is 500 flight hours (FH), based on the Maintenance Review Board (MRB) document. If this interval is escalated for 10%, the resulting cost savings are as follows.

Assumptions:
Annual operating flight hours of B747-400 is 5500 FH, or average daily utilisation of about 15 FH.
Maintenance cost per A-check is USD 45,000.- [www.air-transport.org]
Ground time per A-check is 55 hours [www.air-transport.org]

Aircraft operating life is 25 years.
The first year of A-check data with the original interval (500 FH) will be used for analysis of the in-service experience, thus the evaluation period of escalation is 24 years.

By escalating the A-check interval by 10%, reduction of the number of A-checks for 24 years is: 24 * (5500/500 – 5500/550) = 24 A-checks.
This value equals to a maintenance cost reduction of USD 1,080,000.- (=24 * 45,000.-).
The increase of aircraft availability (opportunity revenue) is 1320 hours (=24 * 55 hours), where time for maintenance has been taken into account. By assuming that the opportunity can be commercially utilised, the opportunity revenue is:
1320 * 850 * 0.13 * 440 * 0.70= USD 44.9 Millions, where

1320 = increase of aircraft availability (hours)
850 = estimated block speed of B747-400 (km/h).
0.13 = revenue passenger kilometre (RPK) [Airline Business, 1999]
440 = number of seats
0.70 = assumed load factor

The profit margin is 6.5% [Airline Business, 1999], therefore the increased profit can be expected is: 0.065 * 44.9 = USD 2.92 Millions.

The total cost savings per aircraft for the evaluation period (24 years), including opportunity profit, could be USD 4.0 Millions (=1.08 + 2.92), assuming that the number of non-routine maintenance does not increase due to the increased interval.

3) Aircraft modifications:

It is clear that the number of Service Bulletins (SB's) and Service Letters (SL's) introduced by the aircraft manufacturer differs from aircraft type to type. For the relatively new A330, in 1997 there were 408 SB's and 247 SL's issued. While for DC10-30, for the same period, only 112 SB's and 42 SL's were issued. With seven types of aircraft, Garuda Indonesia Airlines in 1997 received nearly two thousand SB's and about nine hundred SL's. The number of Airworthiness Directives (AD Notes) issued in that period was only 67 for those seven types of aircraft. The many SB's/SL's and AD Notes being issued in a particular period indicates that the aircraft had problems in that period. A very limited number of the SB/SL's resulted by cost reduction or performance improvement solely.

The number of issued SB's varies also from system to system (ATA two digits). For Aircraft Systems of A330, for instance, 154 SB's were issued in 1997. Available engineers for Aircraft Systems of A330 at Garuda Indonesia Engineering is only two. Their tasks includes also providing engineering services for problems coming from line and hangar maintenance. Engineers have to analyse problems indicated by the reliability monitoring program as well. Due to shortage of personnel, only SB's free of charge or SB's as solution for reliability problems were implemented. Furthermore, SB's do not provide estimates on the projected reliability improvement and the information required to judge the SB's is hardly available. For the time being, evaluation of SB's requires a significant effort and the projected advantages of implementation is still questionable. As an illustration, the average elapse time to develop an Engineering Order (EO) from a SB is three weeks, while the average elapse time to develop EO initiated by intern reliability problems is about two months.

As shown in Appendix I, an analysis on an SB (as an Alternative Means Of Compliance, AMOC) is conducted to comply with AD Notes. Implementation of this SB will result in cost savings of more than a half million USD for 5 years period of operation and fulfil also the AD Notes. This example shows that some of the in-coming SB's have a considerable potential for cost savings. The engineering function must be able to identify quickly which SB's have realistic potential cost savings or will improve *aircraft performance*[3] and availability (opportunity revenue).

1.1.3 Approach to Visualise Hidden Cost

Application of the LCC concept during *the operating phase*, due to the invisibility of the exploitation cost, is aim at evaluating the LCC reduction by any *proposal*[4], e.g. modification to improve performance, changes of maintenance program and selection of new aircraft. In most cases, operators have sufficient experience and data of their operation, therefore the hidden parts of operating cost can be visualised by using a structured process of evaluation which include LCC consideration. This structured process will be used during the application of the LCC concept for the three areas above. The process is derived from a point of view of the author on the Systems Engineering[5] process. Explanations of the process are following.

The structured evaluation process of Systems Engineering consists of three major sub-processes[6], i.e.:

a. evaluation of proposals by the engineering function with cost orientation to establish LCC saving targets
b. technical verification of LCC saving targets by the engineering function
c. demonstration of LCC saving targets after implementation.

Table 1.3 shows these three major evaluation sub-processes, their products and the required activities. The following explains Table 1.3.

Ad a. Evaluation of proposals:

This is a preliminary evaluation on the LCC savings which could be gained by a proposal. The objective of this activity is to identify realistic LCC savings, including the opportunity revenues (performance). Non-economical quantifiable performance improvements (e.g. passenger satisfaction) can be included as well, as far as relevant and quantifiable. For aircraft modifications, the target is based on the projected improvement dedicated by the SB/SL and own experience (reliability records and inspection findings). For maintenance interval escalation, the target is based on bench marking with other airlines and own experience. While for selection of a new aircraft, the target is based on information from the manufacturer, bench marking with other airlines and own experience with previous

[3] If it is not mentioned specifically, aircraft performance means aircraft reliability performance.
[4] **Proposal** is any initiative to reduce aircraft operating cost or to increase aircraft availability. For aircraft selection, proposal is the aircraft alternative/selection.
[5] **Systems Engineering** is an interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and life-cycle balanced set of system product and process solutions that satisfy customer needs [MIL-STD-499B, 1993].
[6] LCC is part of the System Engineering, see also Appendix B: LCC in Systems Engineering.

Table 1.3 The structured evaluation process of modifications, maintenance program optimisation and (sub)system selection

Sub-process	Product	Activities
Evaluation	LCC savings and performance improvement target	Evaluate cost savings gained by implementing modification, maintenance interval escalation or aircraft selection. Conducted by an engineering unit with cost orientation (Cost Engineering).
Verification	Verified target	Technical analysis of the identified LCC savings and performance improvement targets. Conducted by aircraft engineering unit with technical orientation.
Demonstration	Demonstrated target	Implement the proposed changes and record the realised cost and performances, during maintenance production and operation. Data recording by hangar, line maintenance and operation. Data analysis by engineering unit with cost orientation (Cost Engineering).

generation aircraft, as far as available. This activity must be carried out by an engineering function with cost orientation, where cost data is collected and managed. The proposed name for this function is 'Cost Engineering'. Section 2.6 will discuss this function into more detail.

Ad b. Technical verification:

The activities of technical verification consists of allocation of the LCC savings target into lower levels of hardware or into a more detailed 'work package' and technical analysis of the allocated target. The objective of the technical analysis is to investigate whether the LCC saving targets can be realised from a technical point of view. If it cannot be reached (target is not realistic), then back to sub-process of evaluation.

Ad c. Demonstration of LCC:

The objective of demonstration is to evaluate whether the proposal (aircraft modification, maintenance interval escalation or aircraft selection) conforms the implementation results. This activity requires data from hangar maintenance production and aircraft operation. The Cost Engineering function will conduct this activity. The evaluation includes:

i. calculated cost versus real cost of implementation
ii. estimated cost savings versus real cost savings
iii. estimated opportunity/revenues versus realised.

1.1.4 Cost-Effectiveness and the LCC-OPS Model

Discussions on cost-effectiveness are considered important because this subject has a significant contribution for the development of the proposed model. Cost-effectiveness is normally applied for non-commercial systems where the output of the system is not financially quantifiable. Adjustment for application in commercial aviation is made after discussing the original concept of cost-effectiveness.

The effectiveness of a system is defined as the actual output produced (performed) by the system divided by the specified output. Parameters which determine the output of a system are for instance system capacity, speed, range, availability, reliability, maintainability, etc. In order to produce output, inputs are required. By referring to the definition of LCC in sub-section 1.1.1, the total cost to provide the required input (including the acquisition cost of the system) along the life cycle of the system is called LCC. Therefore, Blanchard defines cost-effectiveness as a characteristic of a system in terms of system effectiveness and total life cycle cost [Blanchard, 1992], where their relationships are shown in Fig. 1.2. Parameters which determine system effectiveness influence also LCC. In the left down side of Fig. 1.2, it is shown that reliability and maintainability are factors which determine LCC implicitly (e.g. as factors of maintenance cost), but they are *intrinsic* factors of system effectiveness, i.e. availability. In the right down side of the figure, it can be seen that the factors which influence *extrinsic availability* (user induced availability), e.g. facilities, supply support, personnel and training, etc., are actually also factors of LCC.

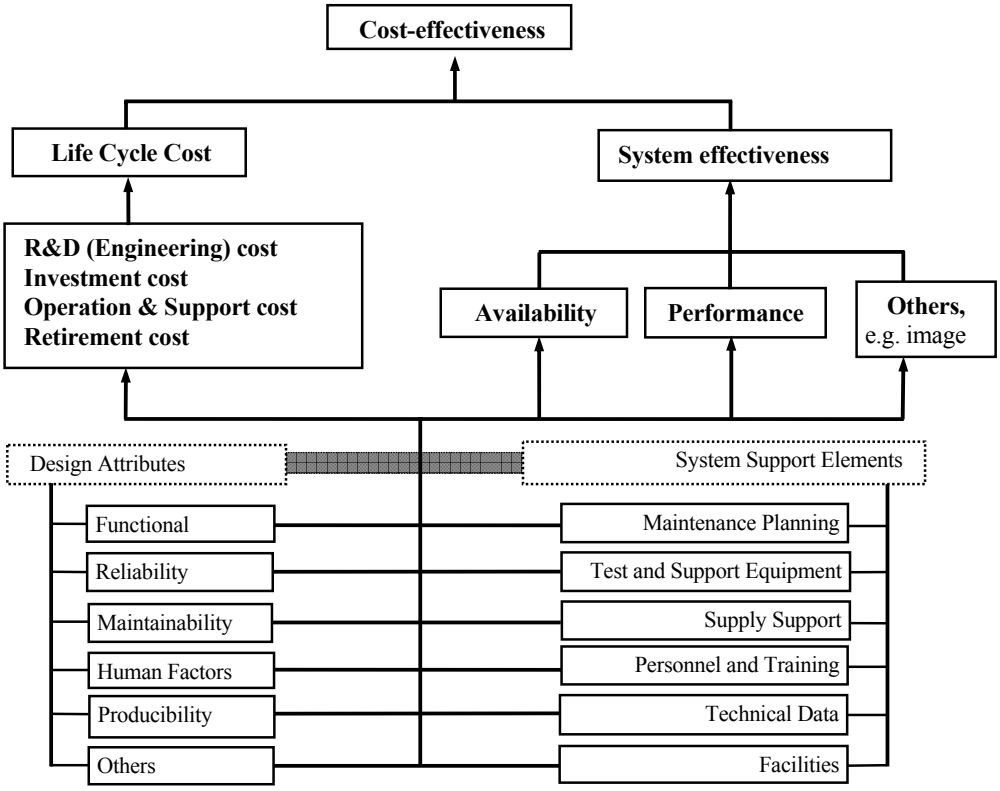


Fig. 1.2 The factors of cost-effectiveness [Blanchard, 1992]

LCC-OPS Model:

Adjustment of the cost-effectiveness relationships for commercial aircraft is done in this thesis, the relationships is called the LCC-OPS Model. Therefore, LCC-OPS is an LCC model which takes into account the impact of performance improvement as an opportunity revenue. The opportunity revenue is added to the LCC savings. Figure 1.3 shows the top level structure of the LCC-OPS model. The OPS term is used to indicate that the application of the model is to support decision or problem evaluations typically occurring in the

operating (exploitation) phase. The typical characteristics of the operating phase is that major aircraft functional parameters (e.g. capacity, speed, range) are fixed, and improvements are more aimed to improve aircraft availability and reduce operating costs. For design or development phase, the Life Cycle Profit (LCP) model developed by Bazovsky (1974), and later by Ahlmann (1984), is more relevant. LCP is beyond the discussion of the thesis, because its attention is more on the modelling of the demand or market.

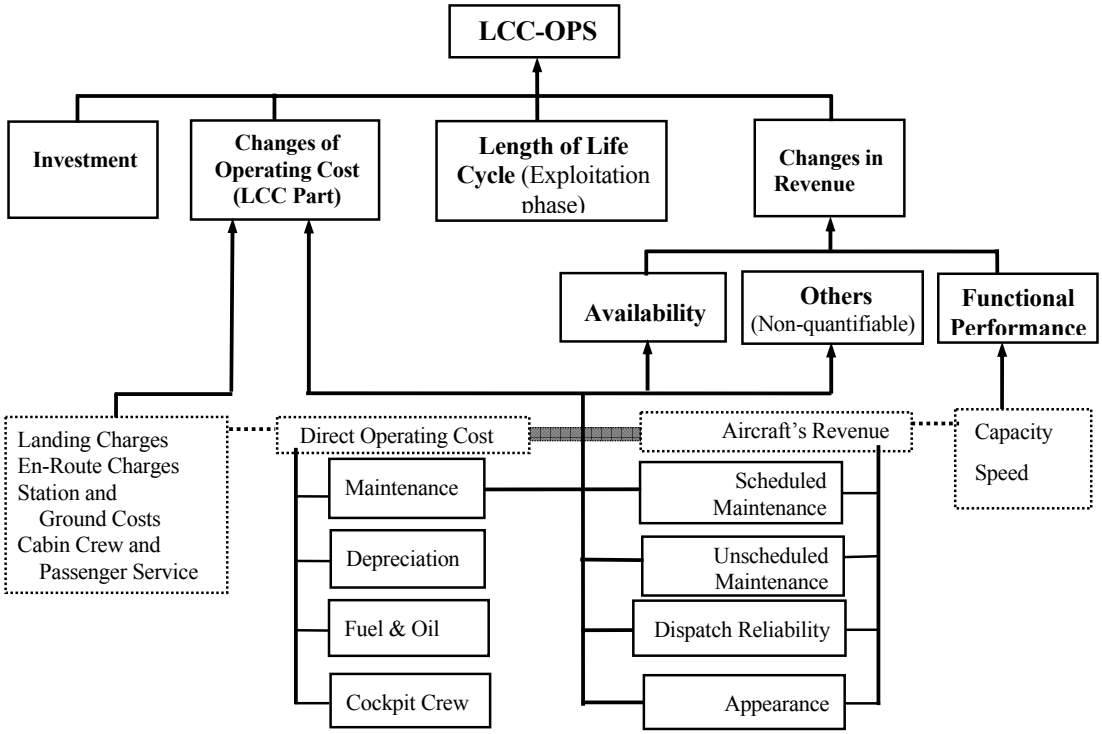


Fig. 1.3 The Top Level Structure of the LCC-OPS Model

As shown in Fig. 1.3, the major factors of LCC-OPS are:
a. Investment required for improvement/change (Invest)
b. Reduction of the LCC part of Operating Cost (ROC) (see Table 1.1)
c. increase of aircraft (opportunity) operating Revenue (Rev)
d. the length of Life Cycle (exploitation phase) (LC)

Therefore, $LCC\text{-}OPS = (ROC + Rev) * LC - Invest$ (1.1)

Ad a. Investment:

An investment is required to realised the changes of operating cost and revenue. In aircraft modifications, it consists of the cost of material, labour, engineering hours, aircraft downtime and special tools, when required. For maintenance program optimisation, investment means the efforts required to collect and analyse maintenance data, and modification cost when required. For aircraft selection, investment is the aircraft purchase price, including the required initial spares, training costs, documentation, tooling and test equipments.

Ad b. Changes of operating cost:

As described earlier, aircraft operating costs are classified into Total Operating Cost (TOC) which consists of the Direct Operating Cost (DOC) and Indirect Operating Cost (IOC) and the category of LCC (see Table 1.1). DOC is part of LCC with four major cost components of Maintenance, Depreciation, Fuel & Oil and Cockpit Crew. Generally, only the first three cost components of DOC can be influenced during the exploitation phase. How these cost components are influenced will be discussed later in relevant chapters.

Ad c. Changes in aircraft operating revenue:

Aircraft operating revenue depends on the aircraft functional parameters (capacity, speed, range). The emphasise of LCC-OPS is on the changes or variations of the aircraft availability and maintenance cost due to aircraft modifications, maintenance interval optimisation and aircraft selection. Parameters taken into account are the required scheduled and unscheduled maintenance down time and the dispatch reliability. Dispatch reliability is an indication for aircraft reliability and maintainability. Other parameters are non-quantifiable and may have impact to revenue as well, e.g. appearance, passenger satisfaction, company image, etc. These non-quantifiable parameters are beyond the discussion of the thesis.

Ad d. Aircraft life cycle (exploitation phase):

Per definition, aircraft life cycle is the time period from the initial design of an aircraft until the aircraft is retired. Normally, the life cycle is ended by the design life of the aircraft which is usually determined by the structural life of the aircraft, e.g. 25 years or more. In order to apply the LCC concept in *the operating phase* a 'life cycle' must be defined. In this thesis, the life cycle is defined as the evaluation period since the proposal is implemented until the end of the intended use by the operator. At the beginning of the evaluation period, the aircraft is not necessarily new, as we can buy a second hand aircraft. At the and of the evaluation period the aircraft is not necessarily to be retired, as some airlines sell relatively new aircraft. The concerns are on the acquisition cost, the resale value and the operating costs of the aircraft.

Aircraft replacement:

This paragraph describes the problems encountered in aircraft replacement and initial identification on the need to apply the LCC-OPS model for this subject.

By increasing aircraft age, the number of maintenance activities are increasing. For the D-check of 727, the ratio between unscheduled and scheduled maintenance labour at the first D-check (five years old) is 1:1, while at the fifth D-check (twenty five years old) is 2.7:1 [de Decker, 2000]. The increase of unscheduled maintenance will increase also the required downtime for maintenance. As a result the availability of the aircraft decreases, which means decreases of revenue as well. De Decker mentioned that availability will drop to 95% at age about 15 years, to 70% at age 20 years and to 55% at age 30 years. ATA provided the ratio of unscheduled and scheduled maintenance cost as a function of aircraft age, as shown in Fig. 1.4. Figure 1.4 is only valid for aircraft maintenance incorporating aircraft ageing program. For aircraft maintenance without ageing program, the trend of the ratio will be higher [comparison with ATA Report 51-93-01, 1993, p.7]. This figure indicates that the

unscheduled maintenance activities increase more than 100% at the end of the exploitation phase, as compared to the initial exploitation phase.

From an aircraft maintenance point of view, the following factors must be taken into account during evaluation of the cost-effectiveness (profitability) of aircraft candidates, [Aircraft Economics, issue 49], i.e.

a. maintenance cost per flight hour and flight cycle
b. duration of each maintenance activity (inspection or check)
c. scheduled maintenance interval

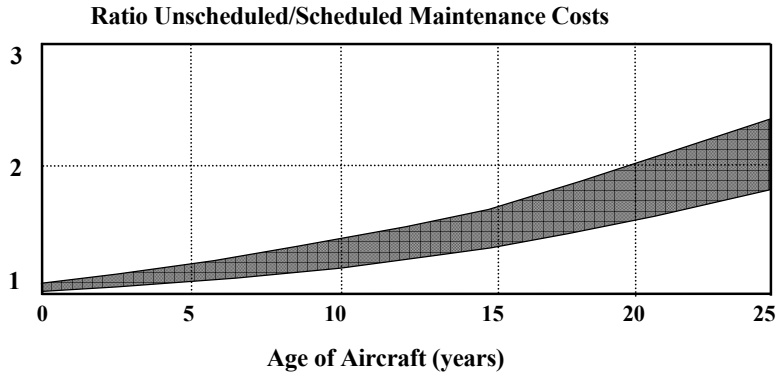


Fig. 1.4 Development of the ratio of unscheduled/scheduled maintenance cost as a function of aircraft age [ATA, 1998]

Maintenance cost contribute to the total operating cost, while the duration and interval of scheduled and unscheduled maintenance determine the availability of the aircraft. However, the total cost of operation, especially the Direct Operating Costs (DOC), is normally the central point of evaluation. Further detailed discussion on those subjects will be given in Chapter 8: Aircraft Selection.

Aircraft replacement includes evaluation of the performance and operating costs of the existing aircraft in the fleet, as well as the resale value of the aircraft. Maintenance has a contribution to maintain the aircraft physical condition and documentation, so that it remains high resale value. From aircraft maintenance point of view, factors determining aircraft resale value are following [Groeneveld, 1992]:

a. number of total cycle and flight hours.
b. maintenance status, which indicates the duration before the next inspection.
c. conversion potential
d. physical condition (implemented SB's/SL's) and maintenance documentation
e. type of previous utilisation and climatic environment.

From the explanations above, two aspects need to be considered during evaluating aircraft for replacement, i.e. the projected behaviour of **maintenance cost and aircraft availability** as a function of aircraft age. Therefore, application of the LCC-OPS model is necessary for this subject. For the subject of aircraft replacement/selection, the following questions need to be answered.

a. Optimum aircraft replacement time, which refer to at which aircraft age, for the existing fleet, an aircraft (type) needs to be replaced. Considerations will concentrate on the trend of aircraft unavailability and maintenance cost due to unscheduled maintenance as a function of aircraft age.
b. Selection of which aircraft model/type, is the most appropriate to replace or to be added to the existing fleet (fleet composition) as a function of the operating requirements (schedule), e.g. FH/cycle ratio.

1.1.5 LCC versus Standard Economic Evaluation Criteria

This sub-section provides a summary of the comparison between LCC and the 'standard' economic evaluation criteria, i.e. Payback Period, Return On Investment (ROI), Net Present Value (NPV) and Internal Rate of Return (IRR). Other terms 'popularly' used to name economic evaluation are the Cost Benefit Analysis (CBA) and the Profitability Analysis. Appendix E (Economic Analysis) discusses this subject in more detail.

Jelen [1983] and Humphreys [1993] provide the most complete and clear classification of the economic evaluation criteria in literature, which are divided into four categories. Table 1.4 shows these categories, their definition and characteristics. As an economic evaluation criterion, LCC is part of the Net Present Value (NPV). LCC only takes into account the costs of investment and operation, while NPV generally includes also revenues (incomes) on top of the costs. Therefore, the objective of application of LCC and general NPV is different. LCC is applied to seek the minimum total costs (LCC), but NPV is applied to find alternatives which provides the highest profit (revenue minus costs).

As discussed earlier, adjustment of the LCC concept is made in the thesis to take into account the changes in revenue. The result of this adjustment is the LCC-OPS conceptual model.

In order to make a fair comparison, application of the LCC concept for evaluating alternatives with different lengths of life cycle will require adjustment of the method, which becomes the uniform annualised cost (unacost). Unacost uses an assumption that at the end of system life cycle, the investment can be reinvested with the same rate of return. However, the application of the LCC concept in the thesis is limited for alternatives with (defined) equal length of life cycle, as mentioned in the discussion of LCC-OPS model earlier.

Based on Table 1.4, LCC is superior to the payback period and return on investment because LCC takes into account the cash flow after the payback period and the timing of cash flow. But, Internal Rate of Return (IRR) is superior to LCC, as indicated by the characteristics on the IRR in Table 1.4. For the cases of equal length of life cycle, the superiority of IRR is diminished. LCC is theoretically still inferior to IRR by taking into account the size of the investment (profit relative to the total investment). However, in practice (aviation) the size of investments to be compared are about the same, for the same type of aircraft. But, due to the high capital characteristic of airline business (including leasing), a low IRR (in percent) can mean a big amount of money. Therefore, the author recommend to use LCC-OPS, as an improvement of LCC, during aircraft exploitation phase.

The main role of the LCC-OPS model application in the thesis is to identify all cost components and revenues in the period of evaluation (life cycle) which are influenced by aircraft modifications, maintenance program optimisation or aircraft selection. In other words, the objective of the LCC-OPS model application is *to visualise hidden costs and revenues*. After these cost components and revenues are identified, an economic evaluation by using the adjusted LCC model will be conducted.

Table 1.4 Categories of the profitability criteria, their definition and characteristics

Criterion	Definition	Characteristics
a. Payback Period	The time elapsed before the net revenues return the cost incurred.	Ignores the cash flow beyond the payback period.
b. Return On Investment (ROI)	The margin of the profit to the balance (when no profit).	Timing of cash-flow is not considered.
c. Present Value (LCC included)	The total cost in present time obtained by discounting all cost components using a reference rate of return.	Requires adjustment for alternatives with different life cycle.
d. Internal Rate of Return (IRR)	The rate of return which makes the Net Present Value (NPV) equal to zero.	Recognises the life cycle of the system, the timing of cash-flow and the size of the investment.

1.2 Cost Considerations in Maintenance

This section discusses cost considerations in maintenance based on available open literature, from the early ones until the most recent one. The main objective of the description is to find guidelines for the application of maintenance cost consideration in the operating phase. Another objective is to identify the parameters taken into account in maintenance cost considerations. However, the parameters to be taken into account depend on the area of application. Therefore, the detail of parameters is not really important in this stage (Introduction). The survey is not limited to aviation, because apparently very limited sources can be discovered in aircraft maintenance. Attention is especially given to literature which takes into account maintenance dependent cost[7] (e.g. delay and cancellation cost), because this cost is usually not clearly visible.

The literature survey concerns five areas of attention, namely:
a. the need of maintenance cost recording and reporting
b. the roles of maintenance cost in maintenance management

[7] **Maintenance dependent cost** is cost resulting or income not generated from in-operability of the system (aircraft) due to maintenance.

c. the specification of maintenance cost reporting
d. the areas of application of maintenance cost recording
e. the factors which determine maintenance cost.

Ad a. The need of maintenance cost recording and reporting.

In 1971, about thirty five years ago, Wilkinson and Lowe reported that by using a Computerised Maintenance Information System (currently called the Computerised Maintenance Management Information System, CMMIS), maintenance performance and costs can be made visible. In other words, hidden maintenance costs can be made visible [Wilkinson, John J. et al, 1971, three series]. For this purpose, a cost centre is introduced to identify excessive (unnecessary) maintenance costs, to depict cost trends related to specific sub-systems, to relate to maintenance budget and to highlights the problems of the system for major overhaul or replacement considerations [Wilkinson, John J. et al, March 18, 1971, pp.69]. These publications do not mention any specification of the cost data base structure. However, the mentioned major functions of cost centre remain the same up to now.

Shalih O. Duffuaa, A. Raouf and J.D. Campbell recommend a summary of maintenance costs by work (activities) to be issued monthly to control maintenance cost and develop the costs of manufactured products. The cost report will indicate the most needed cost reduction programs [Shalih O. Duffuaa, 1999, pp. 36]. According to Shalih et al, modification is an area for maintenance cost reduction, including change of material and maintenance procedure.

In aviation, current status of maintenance systems can be seen by the various computer software packages available in the market. 27 software programs for automating aviation are reviewed in the Aviation Maintenance magazine edition October 1999. All of them aim to record all data related to maintenance planning and execution. The following software specifically mention maintenance cost recording, i.e. the OASES product of the Communications Software, the Ultramain product of the Software Solutions Unlimited, the BART Pro-maintenance product of the SeaGil Software Company, the Shopfloor 2000 product of the iBASEt and SAP. However, from these software only Ultramain provides detailed descriptions on the cost of maintenance.

Ultramain provides the LCC of an item (called asset) being considered. The LCC consists of the cost of acquisition, depreciation, modification, maintenance and operation (fuel and oil). The application of LCC here is **not** aimed for evaluation or analysis of maintenance. Maintenance cost is calculated based on the maintenance schedule, work order activity, and parts and labour charges, as well as the unscheduled maintenance activities. Ultramain supports also the determination of the appropriate corrective actions of component failures or defects. Analysis of downtime can be conducted as well by using the module of Ultramian Downtime Analysis (UDA). What missing in Ultramain are the maintenance dependent costs, covering the schedule interruption cost (delay and cancellation costs) and the opportunity revenue (availability). However, the author of this thesis considers Ultramain as a good *maintenance information system* to support the model being developed, i.e. the LCC-OPS. Further discussion will be given in the next relevant chapters.

Ad b. The role of maintenance cost in maintenance management.

Dekker conducted a literature review of 132 publications on maintenance optimisation which resulted in **no** specific LCC application in maintenance optimisation [Dekker, R., 1996]. However, De Jong in her MSc. thesis uses maintenance cost to control maintenance management extensively [De Jong, J.J., 1990]. The mathematical models of maintenance she used are too theoretical for application in aviation. However, she mentioned important roles of maintenance cost in maintenance management as follow.

i. The whole process of maintenance management begins with *cost specification*, where total maintenance costs are broken down into various categories. The breakdown of cost can be based on activity type (inspection, repair, failure) or cost type (labour, material, third party). The breakdown of total maintenance cost will depend on the objective of analysis and the model to be applied.
ii. The result of cost specification will be used as a reference *to evaluate* the financial report, after execution of the maintenance.
iii. The result of cost specification will be used to control and analyse the clustering of maintenance items, inspection procedure and repair procedure.

Ad c. The objectives of maintenance cost reporting.

A guideline of cost reporting for maintenance costs systems is described by Wireman [Wireman, 1986, pp.18], i.e. :

i. provide a measure of the effectiveness of manpower and material utilisation.
ii. provide an indication of the cost trends, so areas needing attention can be spotted early.
iii. provide information so that equipment having unusual maintenance costs can be identified.
iv. allow production to identify all maintenance costs by product or equipment.

Even though Wireman did not provide the detail of maintenance cost reporting, the guidelines he gave is very useful in determining or selecting the form of cost reporting. In evaluating software package, as described earlier, these guidelines can be applied.

Ad d. The areas of application of maintenance cost recording

The areas which can be improved by introducing maintenance cost recording and reporting are indicated by the following authors:

a. together with reliability performance reporting, it is applied to establish, escalate or de-escalate inspection interval, as stated by Mann [Mann, 1976, pp. 221] and Duffuaa [Shalih O. Duffuaa, 1999, pp. 36].
b. modifications to reduce LCC which should be done in the early time of operation [File, 1991, pp. 87].
c. decision to repair, upgrade or replace (sub-)system or repairable spares is recommended to use the LCC concept [Shalih O. Duffuaa, 1999, pp.53].
d. improvement of profit or performance, as mentioned by File [File, 1991, pp. 2, 100].
e. increased maintenance costs is a factor which will affect the disposal decision [File, 1991, pp.87].

The authors above do not mention the detail of maintenance cost for those various applications. Therefore, this detail becomes the subject of this thesis.

Ad e. The factors which determine maintenance cost.

The major factors which determine the maintenance cost are indicated by Duffuaa [Shalih O. Duffuaa, 1999, pp. 36] and Beekelaar [Beekelaar, 1995, pp.9.2] as follow:

a. direct maintenance: labor, spares, material, equipment and tools
b. operation shutdown cost due to failure
c. modifications (for safety, reliability, economy, passenger comfort).
d. redundancy cost due to system backups
e. equipment deterioration cost due to lack of proper maintenance
f. cost of over-maintaining.

Conclusions (problem statements):

a. Maintenance cost is an important criterion for evaluation of maintenance performance.
b. There is no application of LCC for evaluation or analysis of maintenance problems.
c. The process of target establishment, verification and demonstration (see section 1.1.2) is applicable for the subject of maintenance (operating phase).
d. Guidelines for cost classification and reporting are available.
e. Application of LCC is recommended for evaluating modification proposals.
f. Identification of the parameters which determine maintenance cost is required.

1.3 Overview of the Research Subjects

The main goal of the research is to develop a model to evaluate alternatives (proposals) for aircraft modifications, maintenance interval escalation and aircraft selection, in order to reduce aircraft LCC during the exploitation phase. The other goal is to identify the required performance and cost data base contents and structure to support the evaluation. Finally, the required adjustment of the evaluation process and organisation to support the model application will be identified.

Information resulting from any effort to reduce exploitation cost is, ideally, reported by the users to the manufacturer or vendor, to reduce the LCC of the next series of aircraft during the development stage. As a matter of fact, the information link between aircraft operators and manufacturers is only in the area of aircraft safety and performance, almost no cost information is reported. Therefore, it will give maximum results when the research is also conducted at aircraft operators (airlines), as the main source of information. Garuda Indonesia Airlines (GIA) is selected for the research, as the largest airline in the homeland of the author.

Application of the LCC concept, for evaluating alternatives for aircraft modifications, optimisation of maintenance programs or aircraft selection is to see the advantages of each alternative as compared to the existing situation. The LCC-OPS model, described earlier, is

the core of the LCC concept application. By applying the LCC-OPS model for each alternative and compare it with the existing situation, then the advantages of the alternatives can be quantified in term of LCC savings. A general procedure to implement the LCC concept, so called the Life Cycle Cost Analysis (LCCA) procedure (see Appendix F), is applied for the three subjects of the thesis (see Appendices J, K and L). The LCCA procedure described in Appendix F, is a result of research by the author of the thesis.

The following provide an overview of aircraft modifications, maintenance program optimisation and aircraft selection, to be discussed in the thesis. The objectives of the description are to show the *relevance* of the LCC concept application and to give the framework of the thesis structure.

1.3.1 Aircraft Modifications

Chapter 2 discusses this subject in detail, which covers the processes, information and organisation required. There are four categories of initiatives for aircraft modification i.e.:

a. Internal Engineering of an airline
b. Manufacturer/vendor bulletins
c. Airworthiness Directives (AD Notes) issued by Authorities
d. Engineering Change Requests (ECR) from Operations or Marketing function in an airline.

Ad a. Internal Engineering

The operational and maintenance data of aircraft is collected and evaluated. When anomalies from performance standards are identified, investigations and analyses are conducted by the relevant engineers of the airline to find out appropriate corrective actions. These corrective actions *frequently* lead to aircraft modifications which consist of hardware/software modifications and/or change or add of individual maintenance program or operating or maintenance procedure. In this case, the changes of maintenance program is driven by problems being faced, not an attempt to *escalate maintenance program interval* (see also sub-section 1.3.2). Information from the manufacturer or vendor is utilised in searching and developing corrective actions. Application of the LCC-OPS model has to include the maintenance dependent costs prevented by implementing the modifications.

Ad b. Manufacturer/Vendor Bulletins (SB/SL)

Manufacturer/vendor bulletins are issued to improve the performance of aircraft, engines or components, as corrective actions to the reported problems by the operators. However, the operators have to check the *effectivity*[8] of the bulletins for their fleet. Effective bulletins will be further evaluated for economy. It must be emphasised that aircraft modifications due to manufacturer/vendor bulletins means that the driver/initiator of the modification is the bulletin itself, not the problems faced by the operator. An individual operator is probably not facing the same problem as mentioned in the bulletins. But, the bulletin sometimes offers an improvement in reliability or a reduction of maintenance cost. Aircraft modifications due to

[8] **Effectivity** means the bulletin is applicable for the aircraft or engine types and series operated by the airlines. List of these aircraft and/or engine types and serial numbers are mentioned in the beginning of the bulletin.

manufacturer/vendor bulletins can increase also the resale value of the aircraft. Application of the LCC-OPS model will quantify the advantages of the modification proposals in term of LCC savings.

Ad c. Airworthiness Directives (AD Notes)

An Airworthiness Directive is an instruction letter from the Regulatory Authority to inspect or modify an item which must be carried out before a specified due date as a correction on **unsafe conditions** of the aircraft, and it is applicable for aircraft, engines or components. Due to its mandatory character, economic consideration is not relevant, including LCC.

Ad d. Engineering Change Request (ECR) from the Operation or Marketing Function

The Operation or Marketing function can request modifications to increase revenue, to reduce cost, to improve passenger satisfaction, to improve airline image or to comply with operational standards/regulations. When the reason for the modification is to increase passenger satisfaction or to improve airline image, the proposed modification is evaluated on the basis of the required modification cost and the expected customer reaction (mostly qualitative). If the objective is to comply with operational standards/regulations, then no economical analysis is relevant. LCC-OPS is applied **only** when the objective is to increase revenue or to reduce cost.

1.3.2 Maintenance Program Optimisation

In this thesis, optimisation of maintenance program is addressed to *interval escalation of the maintenance package*, i.e. the letter checks. During the evaluation process of the existing program, the performance of each individual maintenance task in the package will be evaluated. The driver of maintenance task evaluation is the attempt to escalate the interval of the whole package, not as a solution of problems being faced by the internal engineering (see ad a of sub-section 1.3.1). One of the reasons of the attempt to escalate the intervals is reduction of scheduled maintenance cost. However, aircraft airworthiness and reliability performance should not be jeopardised, as well as the related maintenance dependent cost.

So far there is no international regulation concerning the maximum limit of interval escalation [Boeing correspondence]. Maximum limits for interval escalation are determined by the Local Regulatory Authority, *based on the approved Reliability Program*. In most cases escalation up to 20% of the original interval in one step, as long as the airline can 'convince' the Regulatory Authority, is accepted [Garuda, 1997]. Co-ordination with the Reliability Engineering function, who records and evaluates the aircraft reliability performance, is necessary to investigate the feasibility of the escalation. This is especially relevant when there are a lot of findings in the previous scheduled maintenance. When the reliability performance does not satisfy the required level for escalation then modifications of relevant items are frequently required in order to justify the escalation. Application of the LCC-OPS model will support the feasibility evaluation, by taking into account also the required improvement of aircraft performance.

1.3.3 Aircraft Replacement and Selection

Decisions on aircraft selection are rarely based on long term cost considerations. Most decisions are made due to specifications, the purchase price or financing method (leasing).

The process of aircraft selection (fleet planning) include market and commercial analysis, operational, technical, economical and financial analysis. These analysis are interrelated to each other, with the end-goal of (generally) maximising profit. It means economic analysis plays the most important role, while other analysis are providing information. Assuming that revenues are independent of the model (manufacturer) and type of aircraft being operated, maximum profit is achieved through minimising the LCC.

The cost of maintenance in the course of aircraft life is normally increasing, as shown in Fig. 1.4. By knowing the total maintenance cost as a function of aircraft age and the number of aircraft operated, solving of the following problems can be supported by application of the LCC-OPS model, i.e.:
a. optimum aircraft replacement time
b. selection of model/type
c. fleet composition.

The LCC-OPS model should include the parameters relevant for maintenance cost and performance (e.g. family concept, number of aircraft, aircraft age). The increase of resale value due to implementation of particular modifications will also be included.

1.4 Approach for the Research

The PhD. research aims to develop LCC-OPS, i.e. an application of the Life Cycle Cost concept in aircraft operation, including the required information, supporting processes and organisation. The subjects of application are aircraft modifications, maintenance program optimisation and aircraft selection. The end results of the research are:
a. LCC-OPS model specifications, i.e. LCC model for the three subjects of application
b. the required information database contents (cost and performance), structure and definitions
c. recommendations on process adjustment of the three research subjects.
d. organisational requirements.

Figure 1.5 shows the approach of the research for these three subjects. The activities to develop LCC-OPS specifications begins with describing and judging the AS-IS situations. The AS-IS situations are made as general as possible, based on the available sources and experience of the author. Judgement of the AS-IS situations are based on the results of literature study. The inputs of this activity are the existing procedures and manuals, interviews of relevant persons of Garuda Indonesia Airlines and the implementation of those procedures and manuals (‘real world’). This activity results in problem statements for the AS-IS situation, including the discrepancy between the procedure and the real world, as far as relevant. These problem statements will be solved by introducing the LCC model for each research subject.

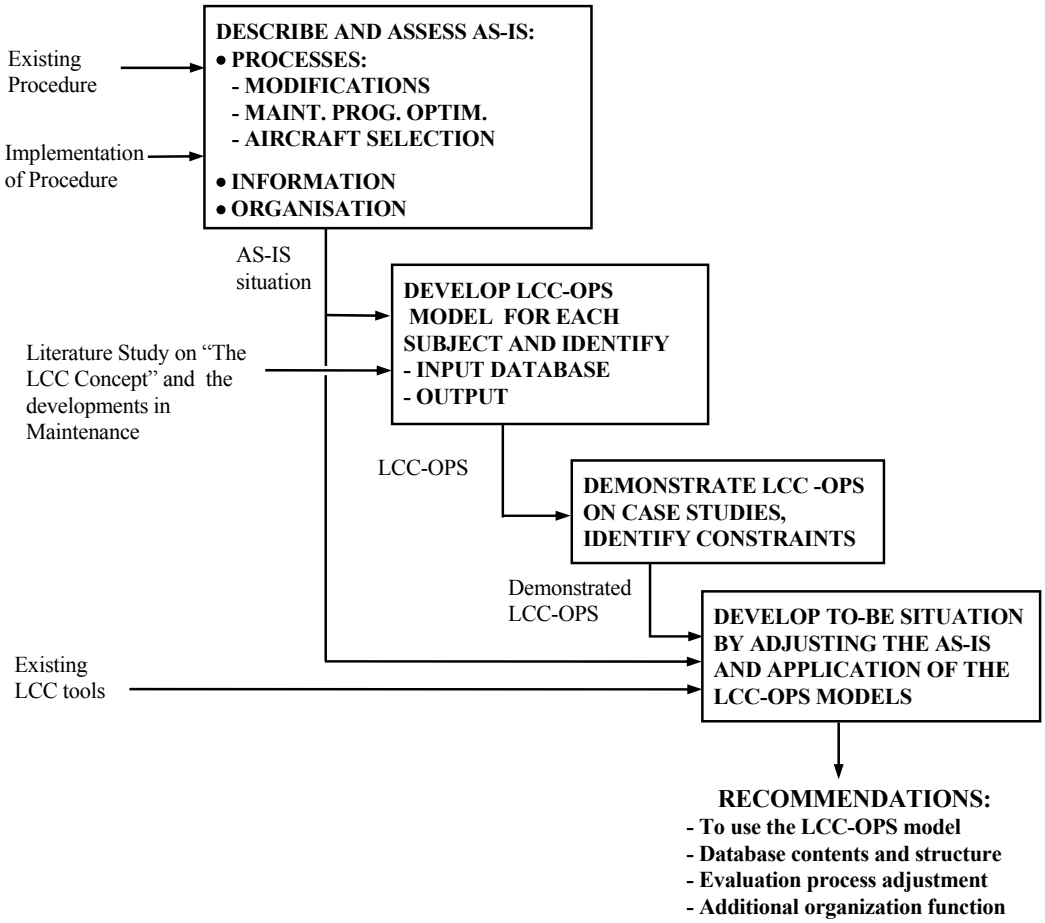


Fig. 1.5. Approach for the research

The LCC models are applied in case studies derived from Garuda practices (to demonstrate the model) and will be improved if necessary. Adjustment of the performance and cost data base content and structure, as well as the process and organisation, will be made to support the application of the LCC model (TO-BE situation).

Table 1.3 describes the approach for each subject of the research, as detailing of Fig. 1.5. It is considered as self-explaining, by referring to earlier descriptions. The introduced LCC model is based on the described AS-IS situation, the LCC concept and interviews with relevant persons of Garuda. Study of relevant literature and an evaluation of the existing economic evaluation tools in aircraft maintenance are conducted to arrive at the specifications for the LCC-OPS model. Finally, the LCC-OPS model for each subject of the research, in a simple way, is developed by the author as one of the results of the research.

The objectives to implement the LCC-OPS model on case studies are to evaluate whether the LCC model works and to identify the constraints during the implementation. In other words, this activity is to demonstrate that the LCC-OPS model answers the research questions.

1.5 Structure of the Thesis

There are three subjects of investigation in this research, i.e. LCC consideration of modifications, maintenance program optimisation and aircraft selection, which are discussed in Part II, III and IV, respectively. In each part, the AS-IS situation, developed LCC model, case study and the TO-BE situation will be described. The AS-IS and TO-BE situation include the evaluation processes, information required and the organisational aspects. Eleven appendices are added at the end of the thesis to support the understanding and the required detailed information of the thesis.

The Structured Analysis and Design Technique (SADT), developed by D.A. Marca [Marca, 1988], is selected to described the processes in this research. This is because SADT is relatively simple and includes the components of a process completely. It is not the intention of the research to conduct a study on the process description methods. Appendix A describes SADT into more detail.

Part I contains Chapter 1 which discusses the relevance and motives of the LCC concept application. It describes the AS-IS situation how the aircraft operating costs are seen. The AS-IS situation is then analysed and the LCC-OPS, i.e. a model to evaluate aircraft operating costs based on the LCC concept, is introduced. LCC-OPS covers activities within the Engineering and Maintenance function which influence aircraft LCC. The general (top level) specifications of the LCC-OPS are the identified demands of operators and manufacturers to quantify the cost of aircraft operations, literature survey on cost consideration in maintenance and of course the LCC concept itself. Examples on the application of LCC-OPS are given to illustrate the contribution of LCC-OPS. These discussions lead to an initial identification of the required evaluation process, organisation and information data base. Chapter 1 can be considered as the top level of the research subject where the approach of the research, as discussed in section 1.4, becomes the outline of the chapter. Chapter 1 contains also an overview of the research subjects and description of the approach of the research.

Part II: Aircraft Modifications, is a result of four types of modification initiatives, i.e.:
a. Reliability Engineering Request, which is based on aircraft reliability performance monitoring and evaluation
b. Airworthiness Directives (AD Notes)
c. Manufacturer's bulletins (SB/SL), and
d. Engineering Change Request (ECR).

The operation and maintenance cost information is recommended to be another source of modification initiatives (maintenance cost driven modifications).
Part II is divided into three chapters, following the approach shown in Fig. 1.5, i.e.:

i. Chapter 2 describes the AS-IS situation of Aircraft Modifications, containing the evaluation process (including the form used), information used by the process, and the organisation.

ii. Chapter 3 presents the development of LCC-OPS for aircraft modifications, application of the LCC-OPS on a case study and identification of the required information data base contents (cost and performance), structure and definitions.

iii. Chapter 4 discusses the development of the TO-BE situation, covering the adjustment of the AS-IS process and the organisation.

Each chapter of Part II covers all of the four types of aircraft modification initiatives mentioned earlier. Aircraft modification due to cost and performance monitoring is included in the TO-BE situation.

Part III: Maintenance Program Optimisation is divided into three chapters, i.e.:

a. Chapter 5 presents the general introduction of 'Customised Maintenance Program" development and the AS-IS situation at Garuda Indonesia Airlines (GIA).
b. Chapter 6 discusses:
   - the application of the Delay Time model to determine the optimum interval of individual maintenance task
   - the development of LCC-OPS for maintenance program optimisation
   - application of the LCC-OPS on a case study, and
   - identification of information database contents, structure and definitions.
c. Chapter 7 contains the development of TO-BE situation of letter checks interval escalation, covering the required process and organisation.

Part IV: Aircraft Selection, contains Chapter 8. The scope of Part IV is not as wide as the earlier chapters, therefore the discussion is combined in one chapter. However, the approach is still the same. Chapter 8 discusses the AS-IS process of aircraft selection based on open sources and relevant information from GIA. Chapter 8 contains also the development of LCC-OPS for aircraft selection, application of LCC-OPS on a case study and identification of the required information database. Recommendations to improve the AS-IS process and organisation are discussed as well.

Part V: Conclusions and Recommendations, contains Chapter 9. Part V provides a summary on the aspects which need to be improved with respect to Life Cycle Cost application in civil aviation. These conclusions and recommendations are derived from the observations of the current practices of aviation maintenance at Garuda Indonesia Airlines and the case studies described in this thesis. It covers the decision criteria, analysis process, the cost data recording and information systems, the organisational aspect and recommendations for future research.

Part VI: Appendices, contains the following appendices.
Appendix A: Structured Analysis and Design Technique (SADT), applicable for all chapters.
Appendix B: LCC in Systems Engineering, applicable for all chapters
Appendix C: Maintenance Control by Reliability Methods, applicable for Part I to V.
Appendix D: MSG-3, applicable for Chapter 1 to 8.
Appendix E: Economic Analysis, for Chapter 1
Appendix F: Life Cycle Cost Analysis Procedure, applicable for Chapter 1 to 8.
Appendix G: Cost Component Estimation Methods, especially applicable for Appendix F.
Appendix H: Inspection Intervals and Delay Time Models
Appendix I: LCC-OPS case: Aircraft Modifications
Appendix J: LCC-OPS case: Maintenance Program Optimisation
Appendix K: LCC-OPS case: Aircraft Selection

Table 1.3. The approach of the research for each part (subject)

<table>
<tr><th>Part and SUBJECT</th><th>Description of AS-IS Situations</th><th>Development of LCC-OPS</th><th>Case Study (Implement LCC-OPS)</th><th>Development of TO-BE Situation</th></tr>
<tr><td>Part I: Introduction</td><td>Basically based on open sources of aircraft operating costs</td><td rowspan="4">Identification of LCC-OPS spec's for each subject.

Development of LCC-OPS for each subject.</td><td>Examples (hypothetical) in three research subjects</td><td rowspan="4">Adjustment of the AS-IS situation to accommodate the LCC model application by improvements on:
a. Process
b. Organisation
c. Information data base contents and structure.

Information data base covers area of aircraft performance and costs.

The TO-BE Situations will indicate in structured manner the impact of any changes by modification, maintenance program or aircraft replacement to:
a. Operating performance
b. Aircraft LCC</td></tr>
<tr><td>Part II: Aircraft modifications</td><td>Based on:
a. Open literature
b. Internal GIA procedure, evaluation forms and interviews
c. Intern GIA record/ documentation on modification</td><td>Application of LCC-OPS on retrofit of Fuel Quantity Indication System of B747-200</td></tr>
<tr><td>Part III: Maintenance Program Optimisation</td><td>Based on:
a. Open literature
b. Intern GIA procedure and interviews
c. Intern GIA documentation on letter check escalation</td><td>Application of LCC-OPS on escalation of A-check interval B737'</td></tr>
<tr><td>Part IV: Aircraft Selection</td><td>Based on:
a. Open literature
b. Interviews at GIA
c. Manufacturer's analysis for intern GIA fleet</td><td>Application of the LCC-OPS on replacement of B742</td></tr>
<tr><td>Part V: Conclusiona and Recommen-dations</td><td colspan="4">Summary of the description of the AS-IS situation, application of the LCC-OPS models and the TO-BE situations.</td></tr>
</table>

PART II
AIRCRAFT MODIFICATIONS

Chapter 2

AS-IS Situation of Aircraft Modifications

This chapter describes the AS-IS situation of aircraft modification decisions in the operating phase. Major information of this description comes from Garuda Engineering and Maintenance. However, the description is made as general as possible by using literature available. Description begins with the objectives of aircraft modification presenting the modification policy. It is continued by discussion on the organisations involved in aircraft modification, the processes of modification, information used for economic evaluation of modification initiatives, the process for each type of modification and the logic of analysis to find appropriate problem solutions. Observations are gathered from description of these subjects. These observations are to be analysed in Chapter 3 and 4, in order to develop the LCC-OPS model for aircraft modifications and the TO-BE situation for modification decisions.

2.1 The Objectives of Aircraft Modifications

Generally speaking, aircraft modifications are aimed to ensure and maintain the airworthiness of the aircraft, to improve reliability and consequently profitability, to increase the quality of the services, to improve the asset value and marketability of the aircraft. Therefore, any request for modification has to be evaluated on the aspects of safety, technical feasibility, operation and economics.

As described in sub-section 1.3.1, there are four sources of aircraft modifications. In the AS-IS situations, actions taken for each category of modification proposal are followings [GIA Technical Procedure Manual, 1997].

a. Mandatory modifications not only have to be evaluated by the Engineering Department, but their schedule for implementation has to be prioritised. Mandatory modifications come from AD Notes. Modifications due to Service Bulletins (SB's) or other sources with the category of 'effect to safety of aircraft' or similar are handled in the same

manner as AD Notes. Economic evaluation is conducted in case several alternatives are available (Alternative Means Of Compliance, AMOC).

b. Modification initiatives coming from own experience (Internal Initiatives) have to be evaluated for the technical feasibility, economical aspects and authorised.

c. If required, support from relevant units (Shop Engineers or Production Engineers) can be requested to evaluate modification initiatives, under co-ordination of the Aircraft Engineering unit.

d. Any initiative for modification from the manufacturer/vendor or other sources (e.g. Engineering Change Request, ECR) which does not effect to safety will be evaluated in economical basis. This type of modification initiatives can provide potential operating cost savings or opportunity revenue.

Based on the descriptions of the AS-IS situations above, observations (not necessarily deficiencies) can be formulated as follows.

Observation 1:

Aircraft modifications are carried out when:
a. it is mandatory and close to the due date
b. it may have a safety impact
c. it is an alert item (Internal Initiatives)
d. it is a request from the Operation or Commercial function
e. it is a free of charge SB (the modification kit is free of charge).

2.2 Organisation

Before discussing the process of aircraft modifications, it is important to present the organisation elements involved in the modifications and to know the actor (mechanism) of the activities. In the **AS-IS** situations, there are two organisation elements directly involved in aircraft modifications [GIA Technical Procedure Manual, 1997], i.e.:

a. the Maintenance Engineering which make initial evaluation, detailed engineering analysis and monitor the implementation and operating performance after implementation the modification. The position of the Maintenance Engineering in the organisation structure of Garuda Indonesia Airlines, especially the Engineering and Maintenance (E&M) function, is shown in Fig. 2.1.

b. the Modification Committee (ModCom) which evaluate and approve (authorises) modification proposals.

Each of the organisation elements above is discussed further below.

2.2.1 Maintenance Engineering

Most of the analysis for modification are carried out by the Maintenance Engineering organisation. The AS-IS situation of Maintenance Engineering organisation is shown in Fig. 2.1. The function of the Maintenance Engineering is to develop, establish and maintain standards and specifications and to provide engineering services to support the achievement of the goal of the Engineering and Maintenance function. Another function is to assure that the airline complies to the Regulatory Authority requirements, the manufacturer/vendor recommendations and the company policies [Job descriptions of the Garuda Maintenance Engineering function, 1999]. The Maintenance Engineering organisation is divided into two units, i.e. Aircraft Reliability Engineering and Aircraft Engineering. The functions of each unit are following.

a. Aircraft Reliability Engineering:

The function of the Aircraft Reliability Engineering unit is to manage all sections under this unit in order to achieve the Maintenance Engineering objectives/functions. As shown in Fig. 2.1, the Aircraft Reliability Engineering unit consists of the sections of Reliability Management, Maintenance Program Management, Configuration & Change Management, Flight Data Services and Technical Publication Services. By the names used, it is clear that the core section of this unit is Reliability Management. The Configuration & Change Management is introduced later, for managing incoming manufacturer/vendors bulletins, AD Notes, Engineering Change Request (ECR). Other sections have a supporting function.

The function of each section within Aircraft Reliability Engineering is following.

- Reliability Management: to monitor and evaluate the performance of aircraft, systems, engines and components (LRU's).
- Maintenance Program Management: to develop maintenance programs, to monitor and evaluate the implementation of maintenance programs, and adjust them when necessary (escalation, drop-out).
- Configuration & Change Management: to record and monitor the configuration of the aircraft fleet, including any changes experienced by the aircraft, and to manage documents related to aircraft configuration changes (EO, EI, EES, etc.).
- Flight Data Services: to provide the required data and information for indication of aircraft status and for analysis.
- Technical Publication Services: to maintain and provide documents required for executing aircraft maintenance and analysis of problems.

b. Aircraft Engineering

The function of the Aircraft Engineering unit is to perform engineering analysis requested by Aircraft Reliability Engineering and to provide engineering support to the shops and production function (Hangars and Line Maintenance). As shown in Fig. 2.1, the Aircraft Engineering unit consists of the sections Avionics, Systems, Power Plant, Structure, Cabin and Material Processes. It indicates the aircraft systems, except the Material Processes. The function of each section is to provide engineering analysis and services according to its specialisation.

2.2.2 Modification Committee

As mentioned earlier, the Modification Committee (ModCom) has a function to evaluate and approve aircraft modification proposals. The AS-IS organisation structure of ModCom is shown in Fig. 2.2. ModCom does not include a representative from the Operations Directorate because all modification proposals have been consulted to the Operations Directorate before submitted to ModCom.

In the AS-IS situation, the policies with respect to the ModCom are following [GIA Technical Procedure Manual (TPM)]:

a. ModCom is a committee who has authorisation to recommend any modification to an aircraft and/or engine and on maintenance and operation procedure based on the aspects of safety, operational, economics and passenger comfort. The role of this committee is to approve and control any modification, including costs.

b. ModCom is chaired by the Director of Engineering and Maintenance (E&M).

c. The chairman of ModCom will select the members of the committee.

d. The Operational (Daily) Executive of ModCom, i.e. Vice President of Maintenance Engineering, will conduct a regular meeting. This regular meeting evaluates also previous modification proposals which have been implemented.

e. The main activity of the ModCom is to evaluate the required costs and all aspects (safety, economy and passenger comfort) described in the proposal are technically feasible.

Observation 2:

As mentioned in the Observation 1 of section 2.1 earlier in this chapter, in the AS-IS situation the implemented modifications are limited to proposal from mandatory documents, free of charge SB's, alert items (reliability analysis) or from Engineering Change Requests (ECR's). Due to this fact, the role of modification committee is not significant, because these proposals do not really require an evaluation from the committee. Of course, except from a budget point of view.

2.3 Modification Process (M0)

This section discusses the AS-IS situation of the process of modification at the top level, where all categories of initiatives are covered (see Fig. 2.3). M0 within the brackets indicates the top level process of aircraft modifications. The objective of the discussion is to identify areas which need to be improved. Basic information to develop this description comes from the Technical Procedure and Manual (TPM), Work Instructions (WI's) of Garuda Engineering and Maintenance, interviews with engineers and real implementation ('real world') of the TPM and WI by Garuda Engineering and Maintenance. This process is made

as general as possible by using information from outside Garuda, which is mostly open information.

Figure 2.3 shows the AS-IS process of modifications at the top level. Sections 2.5 until 2.8 discuss the process of each modification initiative into more detail. The modification process consists of:

a. Preliminary evaluation of the initiatives, divided into:
   - monitoring and evaluating aircraft reliability performance
   - check the effectivity)[9] of incoming bulletins (AD Notes, SB/SL, All Operators Letter (AOL), Fleet Issues Summary Report (FISR), etc.)
   - develop Engineering Change Request (ECR).
b. Perform engineering analysis where the modification initiatives are evaluated technically and economically. Evaluation and approval of modification proposal by the Modification Committee are also carried out in this sub-process. End product of this sub-process is an Engineering Order (EO) or Engineering Information (EI)[10].
c. Implementation of the issued Engineering Order.
d. Assessment of the improvement, to evaluate whether the project improvement has been realised.

A short explanation of the categories of aircraft modification initiatives were discussed in sub-section 1.3.1. Explanations of each activity (box) of the modification process are following.

2.3.1 Monitor and Evaluate Aircraft Reliability Performance (M1)

The activity of box M1 in Fig. 2.3 is to monitor and evaluate periodically the reliability performance of the aircraft fleet. This activity is actually not part of the modification process, but in order to know how the modification initiatives are derived and evaluated, this activity is described. This activity is also carried out for assessment of the improvement (M6).

This activity is usually called the Maintenance Reliability Program (see also Appendix C) and conducted through:

a. recording and reporting periodically of technical delays and cancellations, pilot reports (PIREPS[11]), incidents (and accidents), findings (hangar, shop) and removal and installation of components (rotables).

b. evaluation (development of *performance standards*[12] and evaluation of current performance by using these standards) and initial identification of the root causes. A copy

[9] **Effectivity** means the operator operates and maintains the systems or components described by the MB's.
[10] **Engineering Order (EO)** is an order for modification to be implemented, including the guidance for implementation. Engineering Information (EI) is informative only, to explain occurring phenomena.
[11] **PIREPS** is complaints of the pilot written in the Aircraft Flight Log (AFL).
[12] **Performance standards** are standards defined between operator and the regulatory authority (e.g. concerning in-flight shut down (IFSD) rate, incident rate, etc.), standards defined by operator (dispatch reliability, removal rate of components, etc.) and standards defined by marketing function (interior and various services standards).

of the Aircraft Reliability Performance Report will be sent to the Regulatory Authority and the manufacturer. Exceedance of performance standards or major findings will lead to a reliability action request by Reliability Management section, forwarded to the Aircraft Engineering unit for analysis of primary causes (ATA-100 six digits failure modes) and determination of corrective action.

The input of this process is the operation and maintenance data of the own fleet. The output is a reliability report and a reliability action request when necessary. The reliability report contains:

- aircraft operation summary including the rate of technical delays, technical incidents and technical cancellations
- number of pilot reports (PIREPS[13]) per ATA-100 two digits
- number of technical delays per ATA-100 two digits
- engine operation summary (engines flight hours, In- Flight Shut Down (IFSD) rate)
- and engine removal and shut down record (reason of removal/shut down).

The Reliability Management section develops the reliability report and conducts the evaluation. Recording is carried out by Line Maintenance, or other relevant units (Hangars, Shops, Engineering).

Observation 3:

Reliability Monitoring is carried out up to certain level of detail. Procedure of evaluation, computer systems and the skills of the engineers are satisfying the standards and regulations. One lack identified is the completeness of data recording. The detail of the recorded data is hardly sufficient to make root cause analysis, e.g. delays and cancellations are assigned only to ATA-100 two digits and the descriptions of the failure modes are frequently not clear. The recorded data of corrective actions resulted by Pilot Reports and inspection findings is frequently not clear as well.

2.3.2 Check Effectivity of Documents (M2)

The activity of box M2 in Fig. 2.3 is to check the effectivity of the in-coming documents. The documents from the Regulatory Authority (AD Notes) and from the manufacturer/vendors (SB/SL) will be checked whether they are concerning items (aircraft, engine, components) that the operator use (effectivity). When the documents are effective, it will be accompanied with the Engineering Evaluation Sheet (EES)[14] (see Fig. 2.4a, b and c) and forwarded to the Aircraft Engineering unit for engineering analysis.

There are two types of input for this activity, as shown in Fig. 2.3, i.e.:

- AD Notes, from the Regulatory Authority (discussed in section 2.7)

[14] **Engineering Evaluation Sheet (EES)** is a form used by Garuda Engineering and Maintenance to evaluate the economic feasibility of modification initiatives. See also section 2.4.

- manufacturer/vendors bulletins: Service Bulletin (SB), Service Letter (SL), All Operator Letter (AOL), Fleet Issues Summary Report (FISR).

The output of this activity is sorted documents where effective documents will be accompanied with the EES form and forwarded to the Aircraft Engineering unit. This activity is conducted by the Technical Publication (Tech-Pub) section. In sub-section 1.1.2, under the heading of *aircraft modifications*, some figures of effective AD's and SB's were given.

Observation 4:

Effectivity check of documents is not more than selection and registration of effective documents. Potential cost savings or opportunity revenues are not identified. As a matter of fact, this activity is not conducted by engineers, but by administrative staff.

2.3.3 Develop Engineering Change Request (ECR) (M3)

The activity of box M3 in Fig. 2.3 is to develop an Engineering Change Request (ECR) based on identified discrepancies between customer demands and existing services through recording of complaints, demands and competitor analysis (projection for future needs) and finally to define the requirements for the aircraft configuration.

The input of this activity are the needs or requirements of the customer (passenger, cargo), while the output is an Engineering Change Request to modify the existing aircraft. This activity is conducted by the Operation or Marketing function of the airline, under technical support from the Aircraft Engineering unit.

Observation 5:

In the activity of ECR development, the engineers of the Aircraft Engineering unit can be considered as passive, waiting for the request from the Operation or Marketing function.

2.3.4 Perform Engineering Analysis (M4)

The activity of box M4 in Fig. 2.3 is to perform an engineering analysis on request of the Reliability Management section, to assess incoming AD Notes and manufacturer bulletins which are effective, and to analyse and provide support in developing an Engineering Change Request (ECR) to the Marketing or Operations function of the Airline. During evaluating/assessing the incoming AD Notes or manufacturer/vendors bulletins, the Engineering Evaluation Sheet (EES) form is used. Completed EES forms will be forwarded to the Modification Committee for feasibility evaluation and approval to 'go-ahead'. This activity is conducted by the relevant section of the Aircraft Engineering unit.

Evaluation by the Modification Committee consists of:

a. checking the estimated cost for the modification as described in the EES. This is done by the Daily Executive of the Modification Committee (see sub-section 2.2.2).

b. evaluate all aspects (safety, technical, economic) mentioned in the EES and to decide whether the proposed modification is acceptable. The Modification Committee will carry out this evaluation. The criteria for acceptance are :
   - it is an AD Note, or
   - the modification kit is free of charge, or
   - it is a solution of the problem from Internal Engineering initiatives **and** it is within acceptable cost (of the modification budget).

The approved initiative will be followed-up with the development of an Engineering Order. Therefore the final product of this analysis is an Engineering Order (EO) including the guidance for implementation. If the EO is informative only then it is called Engineering Information (EI). The development of EO/EI is normally using guidance described in the SB/SL.

The input for performing the engineering analysis is a request from the Reliability Management section (output of sub-section 2.3.1), effective AD Notes, effective manufacturer/vendors bulletins (output of sub-section 2.3.2) and Engineering Change Request (ECR) (output of sub-section 2.3.3). The output of this activity is an Engineering Order (EO) or Engineering Information (EI). This EO/EI can lead to hardware modification, changes of the Aircraft Maintenance Manual (AMM), changes of the Flight Operation Manual, or changes of individual Maintenance Task content or interval. Other output is a completed EES form.

2.3.5 Implement Engineering Order (M5)

The activity of box M5 in Fig. 2.3 is to implement the Engineering Order (EO). This activity consists of planning for the required work and resources (material and manpower) and execution of the modification.

The input of this activity is the EO from Aircraft Engineering, while the output is an implemented modification as ordered in the EO. The relevant unit (Production, Engineering, Shop, Line Maintenance, Training, etc.) will carry out this activity.

Observation 6:

The material and man-hours used for the modification are recorded. When there is problem encountered, it is reported to the engineers. Normally immediate action is taken, and if the problem is not solved, the modification will be pending. However, information of the used material and man-hours is not verified against the estimated costs mentioned in the EES form.

2.3.6 Assess Improvement (performance, cost savings) (M6)

The activity of box M6 in Fig. 2.3 is to assess improvement of the item after a modification has been implemented. It can be done only when sufficient detailed operation and maintenance data to analyse the item has been collected. The degree of realisation as

compared to the projection is called the effectiveness of the modification. If the modification is not effective to solve the problem being faced, then the problem is re-analysed by the Aircraft Engineering, with support from the Reliability Management section.

The *Effectiveness Report* form, as shown Fig. 2.5*, is developed to verify (demonstrate) the expected benefits and cost of implementing modifications* with Fig. 2.4b as reference. The effectiveness report is also intended to identify if any (unpredicted) negative effects appear after implementation. Discussion on the effectiveness report together with EES is given in section 2.4.

The input of this activity is operating information before and after modification (post mod). These input can be obtained from the records of operating data. The output of this activity is an indication whether the projected improvement (corrective action) has been realised. The section of Reliability Management will conduct this activity.

The section of Configuration Change Management will monitor the sending and reception of the EES and EO/EI. The duration of each evaluation or analysis can be tracked from this monitoring records and will adapt applicable documents to the modification.

Observation 7:

In the AS-IS situation, the assessment of an improvement activity is conducted in the form of re-analysis of unsolved problems by the issued EO's. Assessment of every EO has not been done yet. However, in the Technical Procedure and Manual, it is supposed to be carried out. This is due to a high workload of the engineers.

2.4 Economic Evaluation

Economic consideration of all types of modification initiatives, in the AS-IS situation, is described in a form so called the Engineering Evaluation Sheet (EES, see Fig. 2.4b). EES is applied as well for AD Notes. Demonstration of the projected cost savings and performance improvement is recorded in the Effectiveness Report (see Fig. 2.5). These two forms play a very important role for economic evaluation of aircraft modifications. This section discusses and assess the AS-IS situation of these two forms. Analysis and recommendations for the TO-BE situation are given in Chapter 4, after discussing the LCC-OPS model for aircraft modifications in Chapter 3. The basis for assessment are the LCC concept and the process of *target establishment, verification and demonstration* of cost savings and performance improvement, as described in section 1.1.2. The results of the assessment are described in Observation 9, below.

The EES form consists of three pages (Fig. 2.4a, b, c). The first contains the administration records, i.e. reference, applicability, priority and the consequences of the modification. The second page contains the record of cost analysis, which will be discussed later, as the focus

of this section. The third page contains description of further actions and approval from relevant managers. The Effectiveness Report form contains:

- administrative records
- expected benefits or conditions
- realised benefits or conditions
- unpredicted negative impacts which occurs
- analysis of discrepancies (if any) and conclusions.

Cost analysis consists of two major components, namely the modification costs per aircraft and the annual savings on aircraft. The modification costs cover the cost of labour, material (including modification kits), special tools and downtime. The annual savings cover the reduction of labour cost, cost due to weight reduction, prevented delays and prevented flight returns. The feasibility criteria of cost analysis is the Break Even Point (BEP), i.e. the required time to make the total savings equal to the modification costs.

The applied labour rate in the year of 1999 is USD 30,-, while the delay cost per minute is USD 200,-. The delay cost is estimated based on the total delay cost in a year, divided by the total number of delays in the year. Cost reduction due to weight reduction is USD 0.2 per take-off revenue per kg weight reduction (no explaination on this cost reduction factor).

Observation 8:

a. The existing EES form is used more as an administrative record than a medium for economic evaluation. However, to make a detailed analysis of the modification initiatives, a supporting tool is required. EES (cost analysis form) solely is too limited. The LCC-MODS model (discussed in Chapter 3) is aimed to fulfil this need.

b. Because of the projected and demonstrated cost savings and performance improvement are in different formats, it will be difficult to have direct evaluation between these two items.

c. Downtime cost, as an opportunity revenue, is not included in the modification costs.

d. It is not specified where the reduction of labour cost comes from.

e. Reduced material cost is not included, for instance due to reliability improvement.

f. Delay and cancellation cost per minute must be a function of aircraft size (type).

g. Fuel cost savings due to weight reduction must be a function of aircraft size (type).

h. Availability improvement as well as technical improvement (fuel savings due to reduction of power required, parasite drag reduction, accuracy of indication) are not quantified in cost savings or opportunity revenue.

i. *The use of break even point (BEP) as feasibility criterion has limitations due to ignoring cost savings after the BEP. Furthermore, when the savings are not in annual basis, then a method to transform the savings to annual basis, is required.*

2.5 Internal Engineering Initiatives

A modification initiative is categorised as an Internal Engineering initiative when the driver of the initiative is experienced with the own fleet in maintenance and operation. A Maintenance Reliability Program is applied to evaluate and analyse the reliability performance of the fleet. Information from manufacturer/vendor (through not implemented SB/SL), in most cases, is used to find a problem solution. If there is no SB/SL supporting problem solving, then the engineer will consult the manufacturer/vendor through direct contact or during technical user meetings. The characteristics of this modification initiative are concentrated on the reliability performance of the fleet. However, in general, economic consideration is very limited due to limited cost recording in maintenance. This category of modifications is the basic for every airline.

In the Garuda Engineering and Maintenance organisation, the Maintenance Reliability Program is called the Reliability Control Program (RCP). An Airline Maintenance Reliability Program must be approved by the local regulatory authority, before its implementation. Maintenance Reliability Programs contain an essential set of rules and practices for managing maintenance programs, as a guidance for continuous surveillance, control and audit of maintenance performance. The objective is to monitor the reliability performance of the aircraft, system or component and to determine the required action to solve any reliability performance degradation or any problem. The action can be a corrective or preventive action [GIA RCP Manual, 1997]. Appendix C describes the Maintenance Reliability Program into more detail, based on various sources, especially the FAA Advisory Circular 120-17A: Maintenance Control by Reliability Methods.

In order to be used as input for the analysis, the operating history of the aircraft has to be pre-processed (prepared) by the Engineering Reliability section to become a Reliability Report (Weekly, Monthly and Quarterly). From these reports analysis is started.

Generally, analysis of the results of reliability monitoring can be divided into two categories, i.e.:

i. The *alert type* analysis which uses the information of Pilot Reports and Maintenance Reports (PIREPS and MAREPS[15]) and component/LRU reliability. Items which show alert level exceedance or up-trends will be investigated. This category is also called “trend-driven analysis”.

ii. The *non-alert type* analysis which uses the information of Service Difficulty Report (SDR), findings from various sources (line maintenance, shop, engineering, etc.) and technical incidents. These can be categorised as “event driven analysis”.

The process of modification due to Internal Engineering initiatives is a combination between the activity boxes of Monitor and Evaluate Aircraft Performance (box M1), Perform Engineering Analysis (M4), Implement EO/EI (box M5) and Assess Improvement (box M6) of Fig.2.3. But, activity box M5 and M6 are the same activity for all types of modification initiative. Therefore, they are excluded from discussion in this section. The box of Monitor

[15] MAREPS are findings discovered by mechanic during aircraft inspections.

and Evaluate Aircraft Reliability (Performance) (**M1**) itself is divided into two sub-boxes of activity, based on the two categories described above, i.e.:

- Alert Type analysis (M1-1, M1-2, M1-3 and M4)
- Non-Alert type analysis (M1-4, M1-5 and M4).

Figure 2.6 shows the process of Internal Engineering Initiatives of aircraft modifications. The dashed box indicates the group of activities included in each category.

2.5.1 Alert Type Analysis (M1-1, M1-2, M1-3 and M4)

Alert type analysis method incorporates statistical reliability standards to measure current reliability performance of an item. This analysis normally applies two criteria, i.e. alert exceedance and up-trend. Alert level standard (upper control limit, UCL) is calculated every six months, based on 12 months previous data.

As shown in Fig. 2.6, the process of alert type analysis begins with recording the operating and maintenance data, evaluation of aircraft performance, continued by *investigation of the problem* and finding solution through engineering analysis and selecting relevant SB/SL's, development of Engineering Order (EO) when a solution is identified, or issuance of a follow-on report when the problem is not solved. *This described process has been verified with the 'real world' of Garuda Maintenance Engineering by tracing several modification cases.*

There are three reasons an investigation has to be conducted by a reliability engineer:

a. alert exceedance, when the number of events in certain period significantly exceeds the upper control limit (UCL) (see Appendix C for alert level calculation and trend analysis). The event includes Pilot Reports (PIREPS), Maintenance Reports (MAREPS) and unscheduled removals.
b. up-trend, when the trend analysis indicates that the failure rate is significantly increasing.
c. high rate, when the failure rate is higher than an 'acceptable' value. For general components, the acceptable value is not more than one failure per 1000 FH.

The process of Alert Type Analysis is following.

a. Record operation and maintenance data (M1-1)

The activity of this box is to record operating and maintenance data. Input for this activity is the data on aircraft operation, delays and cancellations, Pilot Reports and Maintenance Reports, Findings and Component removals and repairs. The use of this data depends on the category of the analysis mentioned earlier. The Alert Type Analysis uses the data of Pilot Reports and Maintenance Reports (PIREPS & MAREPS) and the status of Components. Table C.2 of Appendix C shows the data area, sources and data-elements. The rest of the data will be used for Non-Alert Type Analysis, described in sub-section 2.5.2.

The output of this activity is a database for evaluation of aircraft performance. The Aircraft Maintenance Record section is responsible for collecting and entering the data to the computer systems by administrative staffs. Data recording is conducted by completing the

available forms (PIREPS, MAREPS, Service Difficulty Report, etc.) directly by mechanics who accomplish the maintenance activities.

b. Evaluate aircraft performance (M1-2)

This activity box is to perform a statistical analysis whether the performance of the aircraft, systems or components are within specified levels (see section C.2 of Appendix C for the methods). This analysis is carried out together with the preparation of the monthly reliability report, as a secondary result. The input of this activity is data on PIREPS, MAREPS or Component Unscheduled Removals (ATA-100 two digits and part number) collected from the aircraft reliability performance database (the results of M1-1). The output is an Alert Notice, when the upper control limit is exceeded, when an up-trend or high-rate is indicated. In the monthly reliability report, graphical presentation of aircraft performance as PIREPS and Component failure rate are also given.

This activity is carried out by the section Reliability Management. The controls are the statistical criteria of alert exceedance, upward trend or high rate. The alert levels and limits of maximum acceptable failure rate are determined from previous operating experience of own fleet or information from other operators (World Fleet Average, WFA, via the manufacturer).

c. Investigate the problem (initial analysis) (M1-3)

The activity of this box is to investigate Alert Notices, as a result of the evaluation of aircraft reliability performance (M1-3). The Reliability Management section (in charge), in liaison with the relevant Aircraft Engineering section, will make an initial investigation whether the alert level exceedance requires further detailed analysis. This is aimed to prevent from 'false alarm' or any irrelevant causes, e.g. not appropriate reporting. A Corrective Action Decision Diagram, shown in Fig. 2.10, is used for this investigation to identify whether the problem falls under the category of "nil action". If it does, then the problem is considered closed. Otherwise, the category and the required action will be determined by using the same decision diagram. Discussion of the Corrective Action Decision Diagram is given in section 2.9.

When the section Reliability Management is unable to determine the proper corrective action, the Alert Notice will be sent to Aircraft Engineering by using the Reliability Action Request form. Relevant specialists of Aircraft Engineering will conduct a detailed technical investigation to determine the proper corrective action for the problem and issue Engineering Order or Engineering Information.

d. Perform engineering analysis (M-4)

This activity box is to analyse the Alert Notice (PIREPS/MAREPS or Components) to find out the cause of the problem, e.g. improper operating procedures, inadequate line maintenance procedures, inadequate training, hardware failure and internal part failure or malfunction. For upward trends, an additional investigation is made by the relevant section of aircraft engineering with particular attention on airworthiness. The input of this activity is the Reliability Action Request of an Alert Notice. Supporting information to solve the problem are the Service Difficulty Report (SDR) Summary, Manufacturer service experience in the

form of applicable Service Bulletins (SB's) or Service Letters (SL's), or direct contact to the manufacturer.

The output of this activity is a solution to the problem, which is specified in an Engineering Order (EO) when it requires action, or Engineering Information (EI) when it is for information only. This EO/EI may lead to hardware modification, changes of the Maintenance Manual, the Operations Manual, or the *Maintenance Requirement Item (MRI)* of the Maintenance Program.

In some cases the problem is pending due to incompleteness (unavailability) of information and for this situations a Follow-On Report is issued. A Follow-On Report is used to monitor the progress of the analysis conducted by an Aircraft engineer, when the problem is unsolved within specified period (normally 10 days). In the Follow-On Report, the activities which have been, are being and will be done, are mentioned. A summary of Follow-On Reports is published quarterly, for consideration in the Engineering Review Committee (ERC) meeting, conducted quarterly (see also Table C.1 of Appendix C).

Observation 9:

a. *In the AS-IS situation, the main function of the process above is to evaluate the reliability performance of the fleet and to give a warning when the performance is below an established level (alert level exceedance, up trend or hi-rate). This warning indicates that a problem exists and needs to be solved immediately.*

b. *The Reliability Management section is supposed to make an initial investigation of the root causes of deviations from the standards. In practice this is not done. Investigation of the problem cause through Root Cause Analysis and determination of corrective actions are only conducted by the Aircraft Engineering unit.*

c. *Concentration on reliability performance only, leads to neglecting the involvement of cost during evaluation of alternatives solution (corrective actions), both maintenance and operating cost (e.g. delay and cancellation cost). For this reason, recording of maintenance and operation costs data is necessary.*

d. *Information from manufacturer/vendor bulletins is frequently not sufficient in order to make decisions to implement modification. Information like estimated improved MTBF, implementation cost and projected savings are rarely shown in such bulletins.*

2.5.2 Non-Alert Type Analysis

The non-alert type analysis method is based on information from Service Difficulty Reports (SDR), Technical Incident reports and Technical Delay and Cancellation reports. These reports are the result of day-to-day monitoring of aircraft airworthiness performance. An SDR is issued when a major defect occurs. Non-alert type analysis are **event driven**

problems. Due to the nature of the problem being reported, i.e. it may have significantly affected airworthiness of the aircraft, then it usually leads to a delay or a cancellation.

When a significant problem (one of those three above) is detected by a field engineer from Line Maintenance, Base Maintenance , Shop or Maintenance Engineering function, an investigation has to be carried out by the related unit (Line Maintenance, Base Maintenance, Shop) and continued with a final analysis by Aircraft Engineering [GIA TPM]. The activities within the non-alert type analysis, as shown in Fig. 2.6, are following.

a. Issue RMR (M1-4)

This activity box is to issue a Reliability Monitoring Report (RMR), which describes the discovered problem in those three reports mentioned earlier, and the supporting data. The RMR is then forwarded to the relevant units to make a preliminary analysis. The Reliability Management section is responsible to conduct this activity.

b. Make preliminary analysis (M1-5)

This activity box is to perform a preliminary analysis of the problem described in the RMR. The unit which identified the problem, as mentioned earlier, will make a preliminary analysis of the problem, to determine the appropriate corrective action. However, the responsibility for the final corrective action is under the Aircraft Engineering unit. The input of the activity is the completed RMR form, as a basis for the analysis. The output is a preliminary analysis report.

c. Make engineering analysis (M4)

This activity box is to perform a final (engineering) analysis. The preliminary analysis is forwarded to the Aircraft Engineering unit, so that the preliminary result can be further analysed for detailing or verification of the problem solution. An Engineering Order or Engineering Information is normally issued to rectify the problem. In some cases the problem is pending (unsolved) due to incompleteness (unavailability) of information.

Observation 10:

The main objective of the analysis is to prevent the problem to occur again, and mostly it happened only for a certain aircraft tail number. When ***some*** *alternatives for corrective action can be found for the identified problem, application of the LCC concept is relevant for weighing the alternatives.*

2.6 Manufacturer/Vendors Bulletin (SB/SL)

Manufacturer/vendor bulletins are technical publications issued by the manufacturer or vendors to improve the performance of aircraft, engine or component, as corrective actions to the reported problems by the operators. Manufacturer/vendor bulletins include Service Bulletins (SB), Service Letter (SL), All Operator Letter (AOL), Service Information Letter (SIL), Fleet Issues Summary Report (FISR). *Because Service Bulletins (SB's) are the major source of aircraft modifications, the term SB in this thesis means all those type of bulletins.*

Performance improvements, in this context, can be a corrective action of the reported problems (complaints or findings, incidents) or an introduction of a new technology, or both. Figure 2.7 illustrates this process. When the problems *may* have safety effects, then the issued SB is classified as a Mandatory SB. Implementation of Mandatory SB's depends on airlines policy, because it has no implication to the release of airworthiness certificate (approval).

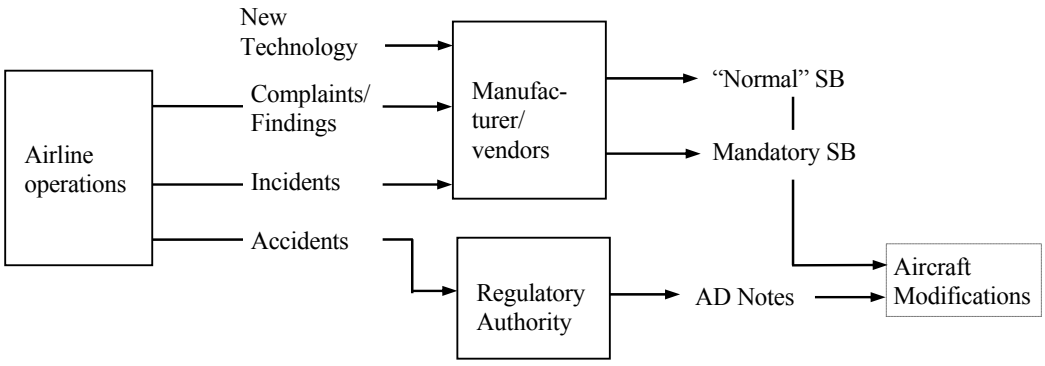


Fig. 2.7 The development of manufacturer/vendors/Regulatory Authority bulletins.

Reported and investigated aircraft accidents lead to issuance of AD Notes for the suspected causes (items) of the accidents. Therefore, Mandatory SB's have a big chance later to become AD Notes when the concerned items by the Mandatory SB's are suspected as the cause of (in future) accidents being investigated. AD Notes for aircraft modifications do not describe the guidance for implementation. This is the task of the manufacturer/vendor to provide such guidance, in the form of SB. This is the reason why Service Bulletin is discussed earlier than AD Notes, in this thesis. AD Notes for aircraft inspections normally refer to the Aircraft Maintenance Manual (AMM).

The decision to implement an SB depends on the projected economical advantages of implementation. When the airlines does not have the data/information to assess the advantages of the SB (in terms of reliability), then normally the SB will be pending. These pending SB's will be used when any operational problems (Internal Engineering initiatives, section 2.5) are discovered.

Figure 2.8 shows the AS-IS situation evaluation process of Service Bulletins, combined with evaluation of AD Notes [GIA TPM]. Further details of the process are following.

a. Check Effectivity of Service Bulletins (M2-3)

The activity of this box is to check the effectivity of incoming SB's. Effective SB's will be forwarded to the Aircraft Engineering unit or to the engineering section of Component Maintenance (Workshop), according to the contents of the bulletins. The incoming SB's are enclosed with the Engineering Evaluation Sheet (EES) form.

The input of this activity are Service Bulletins from the manufacturer or vendors, while the output are effective SB's. The Technical Publication Services will carry out this activity.

b. Perform Initial Engineering Analysis on MB's (M2-4)

The activity of this box is to perform *initial* engineering analysis to the effective SB's by the engineering section of Component Maintenance (Workshop). It is called initial engineering analysis because a further detailed analysis has to be made by the relevant Aircraft Engineering section. The detailed analysis is conducted before the issuance of EO. Initial engineering analysis needs to be carried out because for certain cases the engineering section of Component Maintenance (Workshop) has more complete information on the components being analysed (e.g. historical component test result data).

The input of this activity are effective SB's which specifically concerns aircraft system components. The output is draft (proposed) EO or draft Engineering Information (EI).

c. Perform Engineering analysis, Check and Approve EO (M4)

These activities are conducted by the relevant section of the Aircraft Engineering unit. There are two activities in this box, i.e.

- perform engineering/technical analysis for the effective SB's (without initial engineering analysis)
  - evaluate the draft of Engineering Order (EO) submitted by the engineering section of Component Maintenance (Workshop). This draft will be approved if it is technically feasible.

The input of these activities are effective SB's indicated by the Technical Publication Services (output of M2-2) and draft EO's prepared by the Workshop Production Engineering (output of M2-4). The output are EO's, if the SB's are economically feasible to be implemented. If the results of analysis are information only, then Engineering Information (EI's) are issued, as the output of this activity.

<u>*Observation 11:*</u>

The AS-IS situation at GIA does not comply with the TPM, where the Technical Publication Services should perform preliminary evaluation all incoming SB's. Thus, not only to check the effectivity of the SB's. The TPM cannot be implemented due to the lack of engineers. Attempts to comply with the TPM can be seen in the latest 'rotation' of engineers within the Maintenance Engineering function. In this rotation, several experienced (senior) engineers

are placed at the Configuration and Change Management section (see section 2.2. Organisation), where the initial evaluation of the incoming SB's is assigned to this section.

The use of incoming SB's are limited for corrective action for problems from Reliability Action Requests, Engineering Change Requests (ECR's) and operational reasons. Implementation of manufacturer bulletins due to cost savings is very limited (see also Observation 1, section 2.1). This is due to unavailability of information (on cost savings and reliability improvements) to judge the SB's, especially information supplied by the SB's themselves. It is also due to the lack of evaluation decision diagram (procedure) for SB's.

2.7 Airworthiness Directives (AD Notes)

As mentioned in Chapter 1, Airworthiness Directive is an instruction letter from the Regulatory Authority to inspect or modify an item, which must be carried out before a due date as a correction for **unsafe conditions** of the aircraft, and it is applicable for aircraft, engine or components. The objective of having a standardised process for handling of AD Notes is that AD Notes are evaluated and implemented before the due date and that they are controllable. Generally there is **no** economic consideration relevant for AD Notes, except for planning of implementation. However, in some cases some alternatives to comply with the AD Note are available. These alternatives are called Alternative Means Of Compliance (AMOC). For this situation, application of the LCC concept can be relevant, as it is shown by the example discussed in Appendix I.

Implementation of an EO due to an AD Note can be combined with a routine maintenance check. When at the coming check the due date of the AD Notes is exceeded, then a special down time for implementation of the EO is required. If the Production Unit (Base/Hangar Maintenance) does not have the capability to implement the Mandatory EO, the Mandatory EO will be sub-contracted to a repair station/contractor.

Figure 2.8 shows the AS-IS situation of the process of AD Note evaluation combined with the evaluation of Manufacturer Bulletins [GIA TPM]. The evaluation process of AD Notes consists of "Check Effectivity of AD Notes" (M2-1) and "Make Engineering Analysis" (M4). No further relevant breakdown can be made.

a. Check effectivity AD Notes (M2-1)

The activity of this box is to check the effectivity of incoming AD Notes to own fleet. Aircraft Reliability Engineering then makes copies/print outs of the effective AD Notes and encloses it with an Engineering Evaluation Sheet (EES) which is stamped 'Mandatory' and forward it to the relevant Aircraft Engineering section. The input of this activity is all AD Notes from the Regulatory Authority. The output is effective AD Notes enclosed with EES.

A copy of AD Notes will be sent to the Quality Assurance unit, to be used as a reference to audit the progress control of implementation of the AD notes. The Quality Assurance will make a recording of these AD Notes.

b. Search SB References (M2-2)

Generally, AD Notes which require aircraft modifications refer to particular SB's for implementation. It means that the manufacturer/vendor has to provide these SB before the due date of the AD Notes. In most cases, the SB's have been available before the issuance of the AD Notes. An example of AD Notes issuance earlier than the SB references is the AD 98-20-40 concerning the replacement of all wiring of the Fuel Quantity Indicating Systems (FQIS) of B747-200.

The activity of this box is searching SB references as mentioned in the AD Notes. Of course, both the AD Notes and SB's must be effective for the own fleet. This is carried out by the relevant engineer of the Aircraft Engineering unit. In practice, this activity is conducted together with the Engineering Analysis (M4). The input of this activity is the effective AD Notes and the record of effective SB's. The output are the relevant SB's mentioned in the AD Notes, as reference.

c. Perform Engineering analysis (M4)

The activity of this box, for AD Notes, is to perform an Engineering analysis. In fact, there is no real analysis in this activity, but preparation of a Mandatory EO. This EO is based on Service Bulletins mentioned in AD Notes, as references for implementation of modification (see also section 2.6). The input of this activity is the effective AD Notes with an EES form identified earlier and relevant SB for the AD Notes. The relevant Aircraft engineer will conduct this transformation.

Observation 12:

These activities are conducted properly, especially to satisfy regulation requirements, namely implementation of AD Notes before the due date. When AMOC is available, the application of the LCC-OPS model for aircraft modifications can be relevant. This can be done in the same manner as evaluating Manufacturer/Vendor bulletins, as discussed in section 2.6.

2.8 Engineering Change Request (ECR)

The Operations or Marketing function may request a modification to increase revenue, to improve passenger satisfaction, airlines image or to comply with operational standards/regulations [GIA Technical Procedure Manual, 1997]. When there is a change of the payload demands (e.g. first class, business, economy, cargo, freighter, combi), then the configuration of the aircraft has to be adjusted. Internal proposal for this type of aircraft modifications is called Engineering Change Request (ECR). ECR is a request for modification of the Garuda fleet from outside the Engineering and Maintenance (E&M) function, for instance from the Operation or Marketing function.

Although ECR's come from the airline organisation, in most cases the guidelines for implementing the modifications are already provided by the manufacturer. The guidelines are in the form of various manuals for conversion to change seating configurations and conversion from passenger to cargo or combi. Service Bulletins also provide guidelines for aircraft modifications, which are not included in those manuals. The ECR's are forwarded to the Aircraft Engineering unit for engineering analysis.

Figure 2.9 shows the AS-IS process of ECR's evaluation. The following describes further details of the AS-IS situation process.

a. Develop ECR proposal (M3-1)

The activity of this box is to develop an ECR proposal, which uses a standard ECR form including determination of the internal due date. The standard form of ECR is shown in Fig. 2.10. After the requester (e.g. the Marketing function) has filled in the ECR form, the form is then forwarded to the Aircraft Engineering unit for completion. Then the requester and the Aircraft Engineering unit determine the internal due date for implementation of the ECR.

The input of this activity are deficiencies or specific demands identified by the requester. It can be a deficiency between current services and customer (market) needs. The ECR proposal must contain the reason of the request, the references and description of the requested modification (changes).

b. Develop: work statement, cost analysis and implementation plan (M3-2)

The activities in this box are to develop a work statement, to perform cost analysis and to define an implementation plan for the ECR proposal. The work statement contains the details for the required work in order to comply with the requested modification (change). Cost analysis, normally, concerns only the required labour and material cost for implementation. These activities are conducted by Project Engineering, which consists of relevant sections within the Aircraft Engineering unit to analyse the ECR.

When Project Engineering accepts the ECR, it will be forwarded to relevant engineers within the Aircraft Engineering unit for development of Engineering Order. Otherwise, it will be returned to the requester. Criteria for acceptance are based on the technical feasibility, the costs required and availability of a time slot for implementation.

c. Develop Engineering Order (M3-3)

The activity of this box is to develop an Engineering Order (EO). The accepted ECR will be forwarded to the relevant engineer to develop an Engineering Order (EO). Relevant manuals and bulletins will be used for this purpose.

An example of a modification due to ECR is the replacement of the Omega Navigation System for an Integrated Flight Management and Global Positioning System which is indicated for economic, crew satisfaction and operational improvement reasons (see these categories in Fig. 2.10 as 'Reason for Request'). However, this example shows that economic consideration includes only the cost to implement the modification, as detailed in the

APLICANT'S JUSTIFICATION [ECR No. AB4/ME-006/96]. The operational improvement reason is actually an operational requirement, because existing navigation system won't be supported anymore after the due date, namely September 1997 [Federal Radio-navigation Plan, USA DOD and DOT, 1994], and it is **not** for crew satisfaction.

However, the Aircraft Engineering unit has responded rightly by issuing a Mandatory Engineering Order with priority 'To comply with Government/Regulatory Authority Requirements [EO No. A3/M34-56-0301]. This modification requires approval from the Regulatory Authority because it is considered as Major Repair/Alteration.

Observation 13:

The example of aircraft modification due to ECR above indicates that cost considerations in this area is limited only to the implementation costs. The changes of operating cost are not included yet.

2.9 The Logic of the Modification Analysis

As mentioned in sub-section 2.5.1, a Corrective Action Decision Diagram is used during the investigation of the discovered problem in the alert type analysis (alert exceedance, up-trend or high rate). This section discusses the AS-IS situation of the Corrective Action Decision diagram, based on the Reliability Program Manual of several airlines and the 'real world'.

Figure 2.11 shows the Corrective Action Decision Diagram where the input is a failure data. There are six (6) categories where the problem can fall under.

a. Evaluation of the problem begins with question: "1. Does the failure data indicate a significant reduction in failure resistance?". When the answer is 'No', the problem falls under category C1 (nil action) and the Reliability Management section will consider the problem as closed (e.g. due to false alarm).

b. When the answer of question 1 is 'Yes', then it goes to question 2, which addresses the airworthiness significance of the reduction of failure resistance. If it is **not** airworthiness significance, then evaluation will be on the desireability of maintenance task revision on economic basis (question 3). If it is not economical to revise the maintenance task, then it will fall under "nil action" category (C2).

c. If the reduction of failure resistance is significant and it is not airworthiness significance, but maintenance task revision is economically justified, then the maintenance task revision must be incorporated (category 3).

d. If the reduction of failure resistance is airworthiness significance, **there is** an adverse relationship between age and reliability and revision of maintenance task is economically

justified (question 5), then to incorporate the revised maintenance task is the solution (category 3).

e. If maintenance task revision in point d is not justified economically, then economic feasibility of a modification initiative will be evaluated (question 7). If the modification is economically justified, then the modification must be accomplished (category 5).

f. If the modification in point e is not feasible economically, than the maintenance task frequency needs to be increased (category 4).

g. If the reduction of failure resistance is airworthiness significance, but **there is no** adverse relationship between age and reliability, and revision of maintenance task will restore failure resistance, then to incorporate the revised maintenance task is the solution (category 3).

h. If maintenance task revision in point g will not restore failure resistance, but modification is justified economically (question 8), then modification is necessary (category 5).

i. If the modification in point h is not justified economically, then the acceptability of the failure consequences (question 9) will be evaluated. If the failure consequences are acceptable, maintenance task revision and further reliability monitoring is necessary (category 6).

j. If the failure consequences in point i is not acceptable, then modification must be accomplished (category 4).

Economic considerations can be seen in questions 3, 5, 7 and 8. If the reduction of failure resistance is **not** airworthiness significance (question 2), then incorporation of revised maintenance task or modification may be selected due to the *desirability from economic point of view*. How to evaluate economic desirability is not mentioned in the manuals of GIA.

Observation 14:

a. *The logic of analysis (Fig. 2.11) is implemented limitedly due to unavailability of information and lack of engineers.*
b. *The logic shown in Fig. 2.11 is more appropriate for maintenance task evaluation, assuming that the failure mode and mechanism has been identified. This is due to the preference to revise maintenance task than to accomplish modification.*
c. *Question 3 and 5 should address also to modification for restoring failure resistance.*
d. *Question 8 should address to the effectiveness of modification, instead of the economic justification. This is because the reduction of failure resistance is airworthiness significance and task revision is not able to restore failure resistance.*
e. *Question 9 should be more specific, especially concerning failure consequences in safety, operation and cost (including delays and cancellation costs). It means acceptability criteria should include also economic considerations, as far as possible. However, principally safety consequences are not acceptable.*

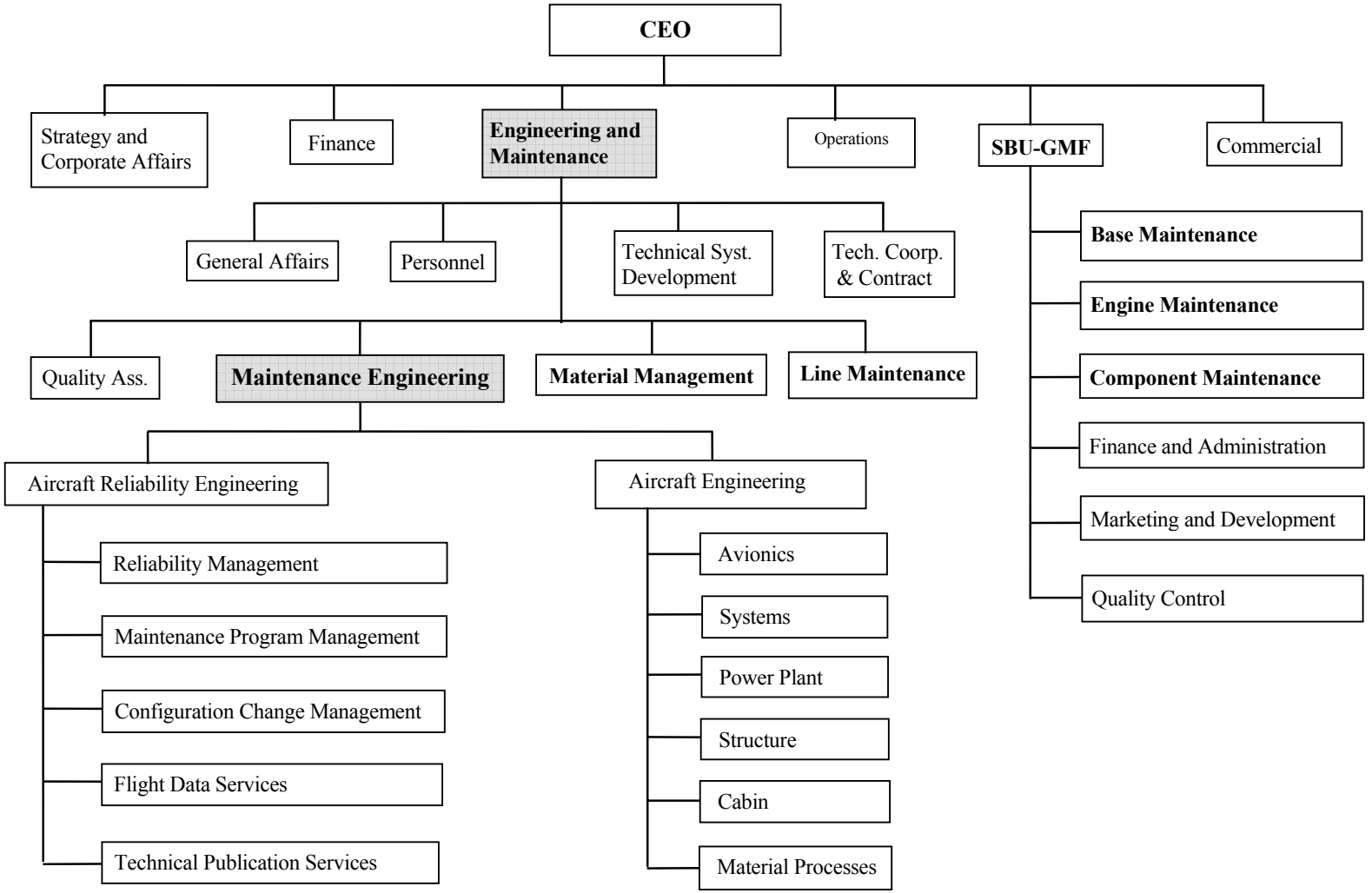
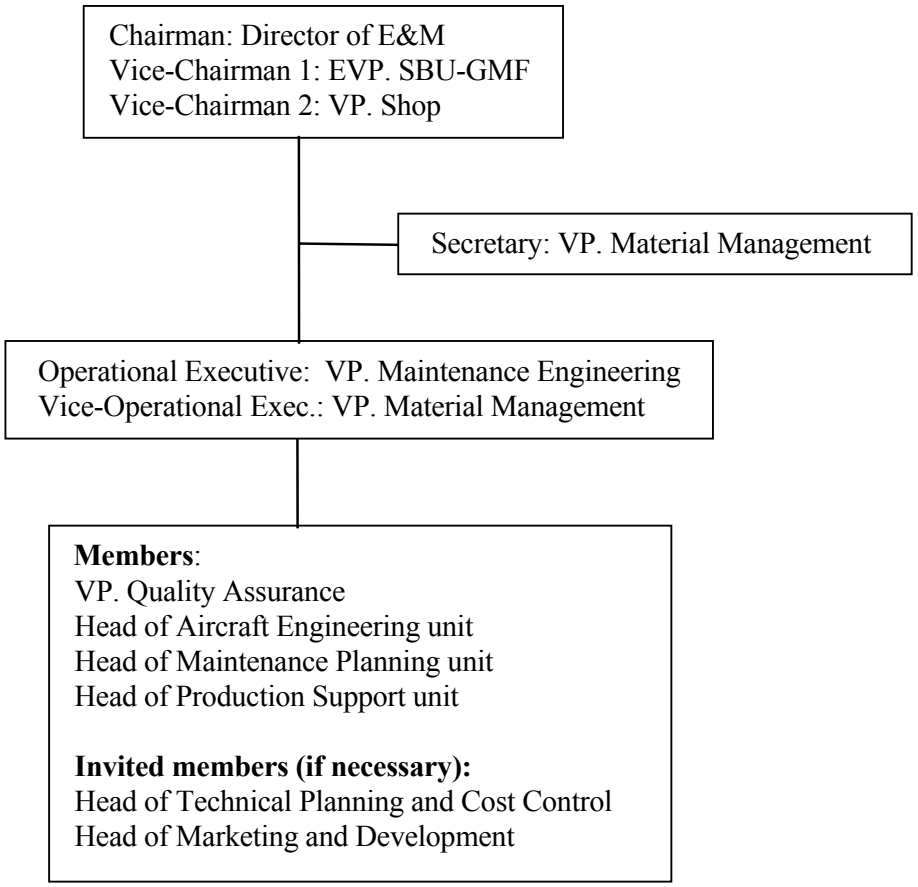


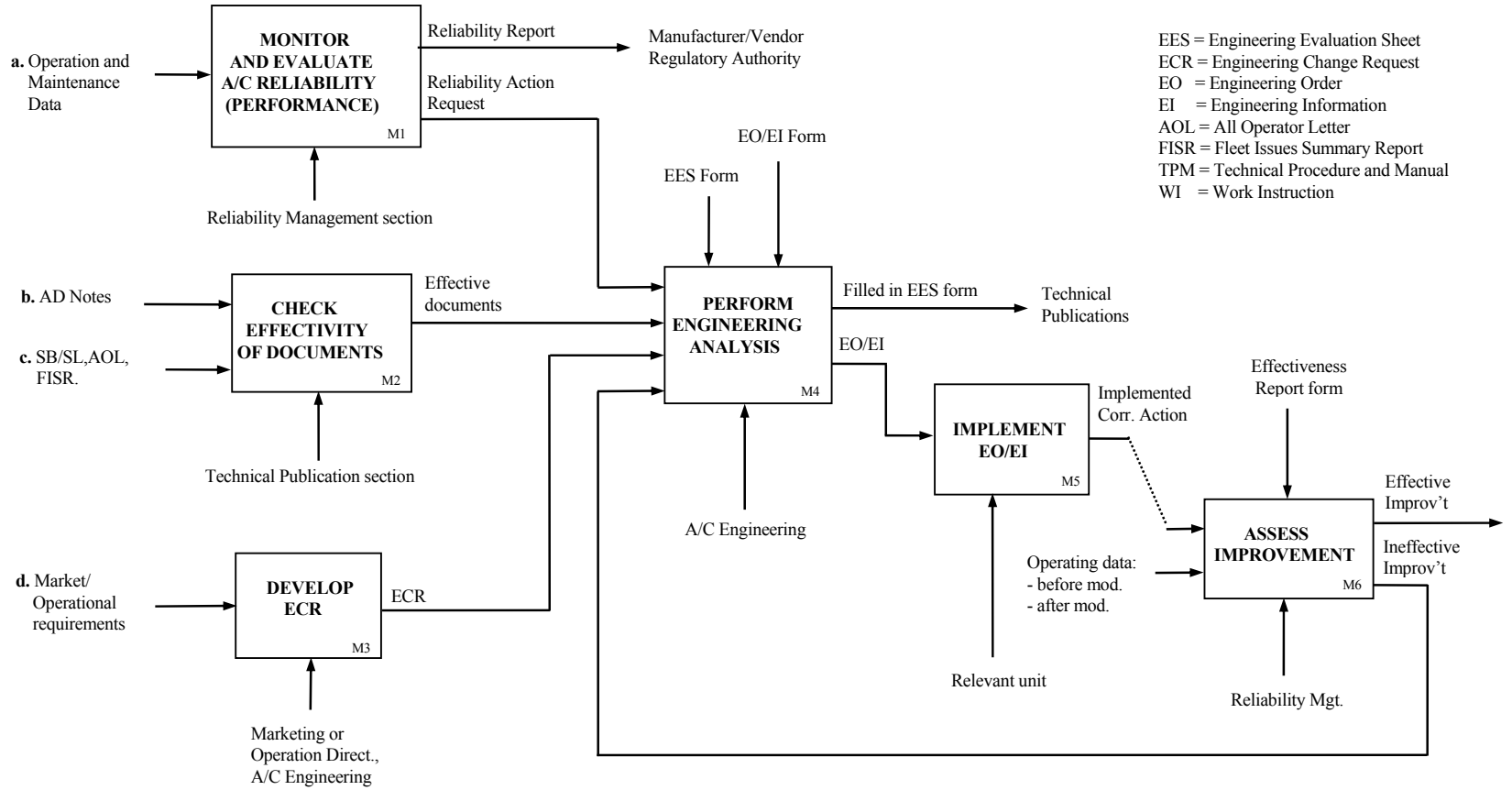
Fig. 2.1 The organisation structure of Garuda Indonesia Airlines (May 1999)



Legend:
E&M = Engineering and Maintenance
SBU = Strategic Business Unit
GMF = Garuda Maintenance Facility

Fig. 2.2 **AS-IS:** The Organisation Structure of Modification Committee [GIA TPM, 1997]

AS-IS SITUATION: MODIFICATION PROCESS



NUMBER: M0	NODE: A0	TITLE: FIG. 2.3 **AS-IS**: MODIFICATION PROCESS [GIA TPM's AND WI's]	AUTHOR: E. SUWONDO
	CONTEXT: TOP		DATE : 12 FEB. 2005

Page 1 of 3

ENGINEERING EVALUATION SHEET	**EES NO. :** **ORIG.ISSUE DATE :** **REV. ISSUE DATE :**	**UNIT CONCERN :** **A B C D E F**

SOURCE :	SOURCE NAME	SOURCE NO	ISSUE DATE
[ ] Airworthiness Directive (AD) [ ] MNF'S SB/SL/SIL/AOL [ ] Vendor's SB/SL/SIL/AOL [ ] OTHERS (_____)			

SUBJECT :	A/C Type : Eng/APU Type : Component : Equipment : Part :
ATA : SUB-ATA :	
Compliance : [ ] Mandatory/Alert [ ] Recommended [ ] Option	Effectivity :

Reason of Evaluation

[ ] Airworthiness Req.	[ ] Improvement in Maintainability	[ ] Standardization
[ ] Safety	[ ] Improvement in Reliability	[ ] Product Change
[ ] Economics	[ ] Optimize A/C Operation	[ ] Passenger Satisfaction

EVALUATION

1. Consequence : [ ] Affect [ ] Not Affect
Description :

2. Reason of EES Revision :

Fig. 2.4a Engineering Evaluation Sheet (EES) page 1/3

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COST ANALISYS

Prepared by :	Approved by :	Date :

MODIFICATION COSTS PER AIRCRAFT

	man-hours		rate			
LABOUR	.....	x	$30	=	.....	$
MATERIAL, KITS	.....			=	.....	$
TOOLING	.....			=	.....	$
OTHER COSTS	.....					
	.....					
	.....			= TOTAL	.....	$
According to calculation dated	.....				.....	$ A

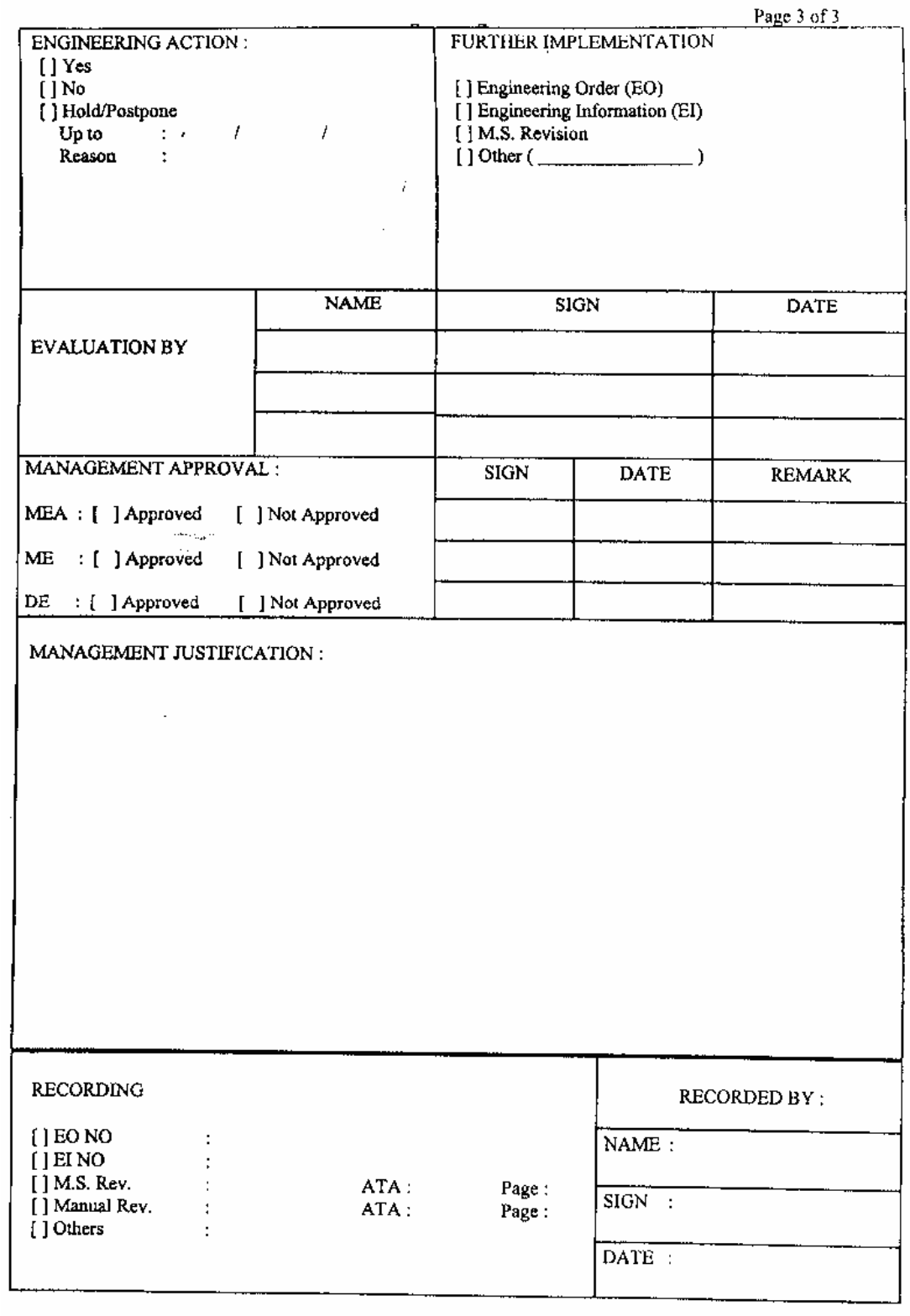
ANNUAL SAVING ON AIRCRAFT

	man-hours		rate				
LESS LABOUR	.....	x	$ 30		=	.....	$
	Revenue T/O per year		weight saving (kg)	rate			
LESS EXTRA WEIGHT	.....	x	x	$ 0.2	=	.....	$
	Minutes per year			rate			
PREVENTED DELAYS	.....	x	$ 200 / minute.		=	.....	$
	number per year		rate				
PREVENTED FLIGHT RETURNS	.....	x			=	.....	$
OTHER SAVINGS	.....						
	.....						
	.....				=	.....	$
					TOTAL	.....	$ B

note : other saving e. q. :
increasing MTBR of LRU

$$BEP = \frac{A}{B} = \text{YEARS}$$

Fig. 2.4b Engineering Evaluation Sheet (EES) page 2/3



Page 3 of 3

ENGINEERING ACTION :	FURTHER IMPLEMENTATION
[ ] Yes [ ] No [ ] Hold/Postpone Up to : / / Reason :	[ ] Engineering Order (EO) [ ] Engineering Information (EI) [ ] M.S. Revision [ ] Other (_____)

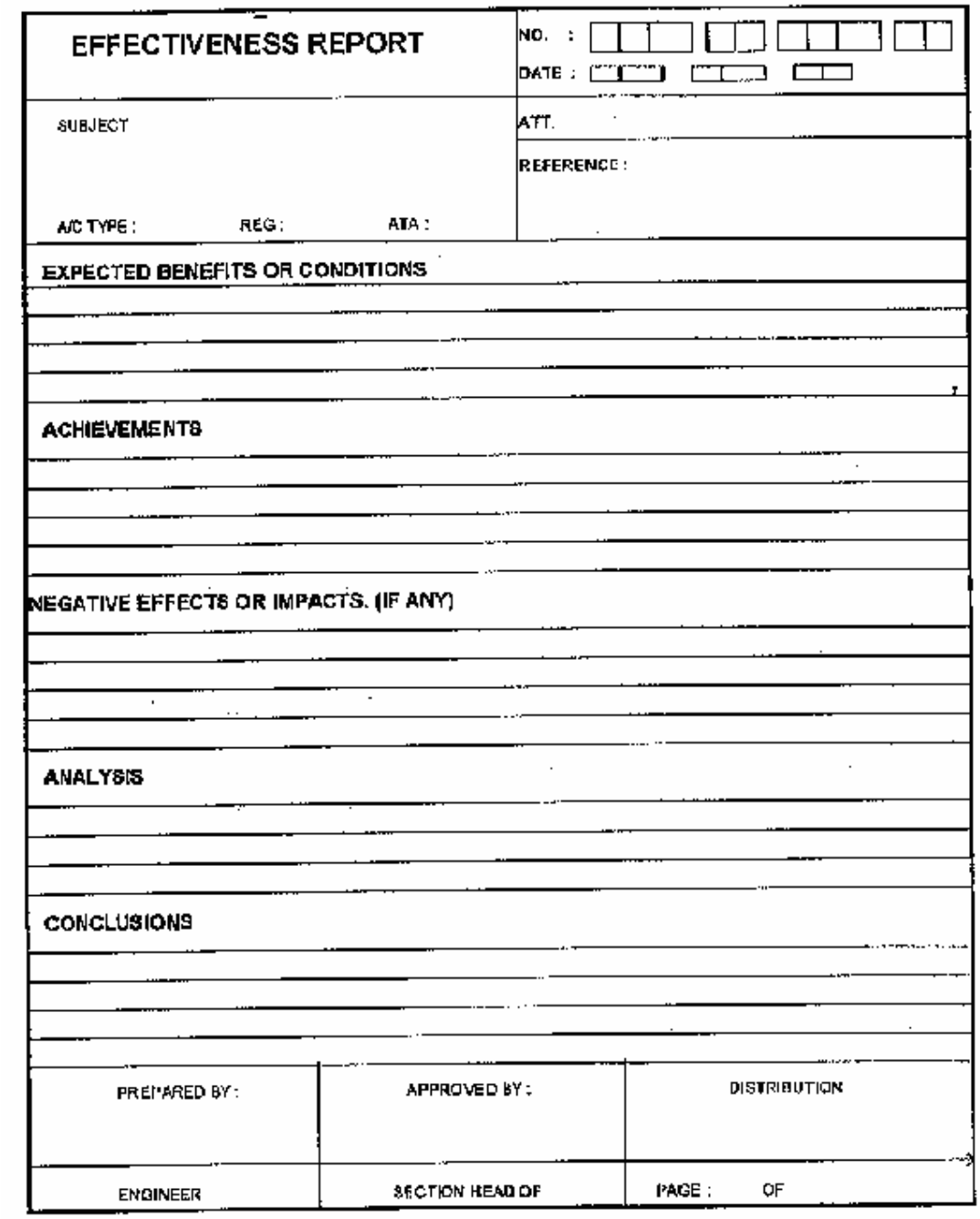
	NAME	SIGN	DATE
EVALUATION BY			

MANAGEMENT APPROVAL :	SIGN	DATE	REMARK
MEA : [ ] Approved [ ] Not Approved			
ME : [ ] Approved [ ] Not Approved			
DE : [ ] Approved [ ] Not Approved			

MANAGEMENT JUSTIFICATION :

RECORDING				RECORDED BY :
[ ] EO NO	:			NAME :
[ ] EI NO	:			
[ ] M.S. Rev.	:	ATA :	Page :	SIGN :
[ ] Manual Rev.	:	ATA :	Page :	
[ ] Others	:			DATE :

Fig. 2.4c Engineering Evaluation Sheet (EES) page 3/3



EFFECTIVENESS REPORT

NO. :

DATE :

SUBJECT

ATT.

REFERENCE :

A/C TYPE : REG : ATA :

EXPECTED BENEFITS OR CONDITIONS

ACHIEVEMENTS

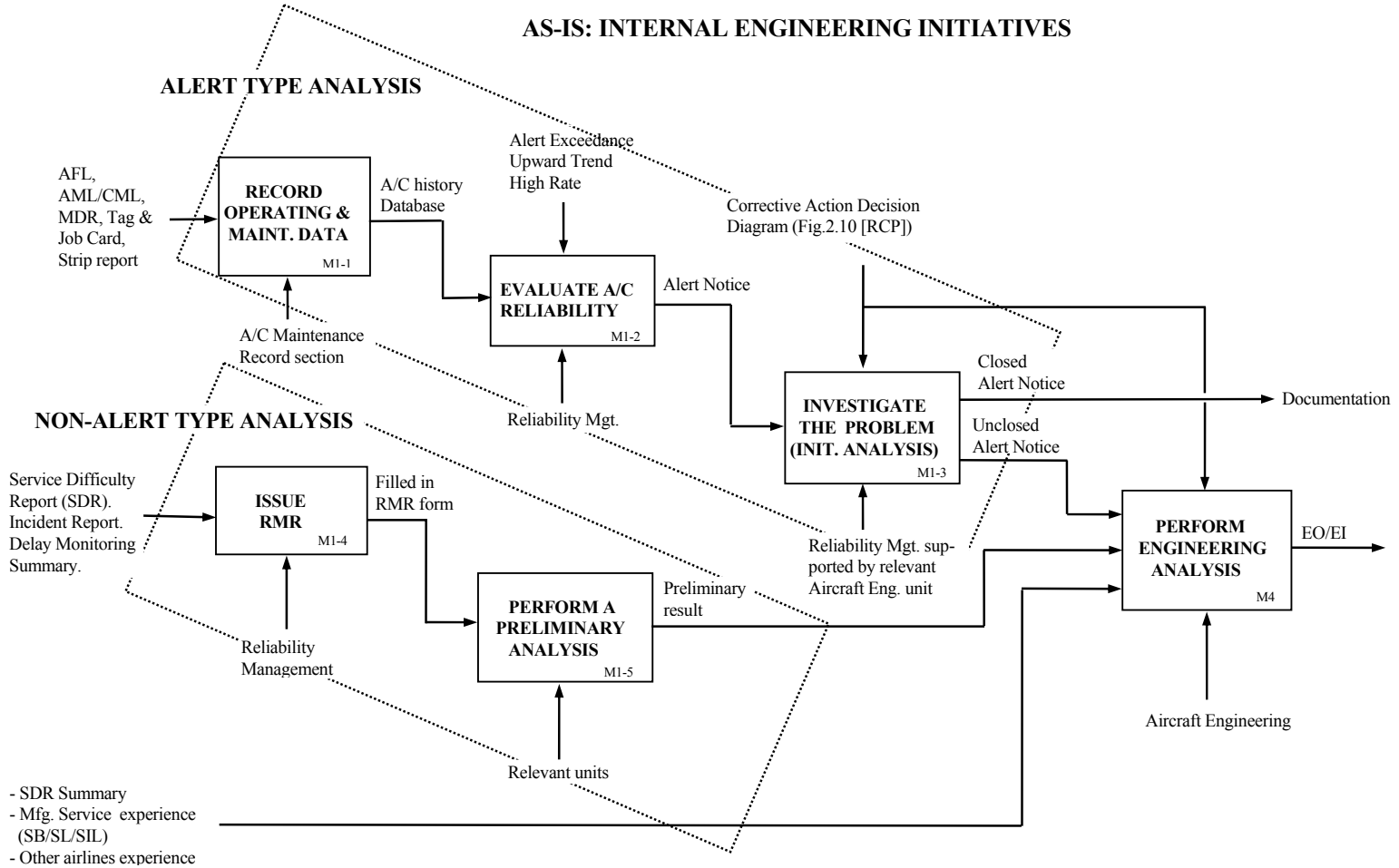
NEGATIVE EFFECTS OR IMPACTS. (IF ANY)

ANALYSIS

CONCLUSIONS

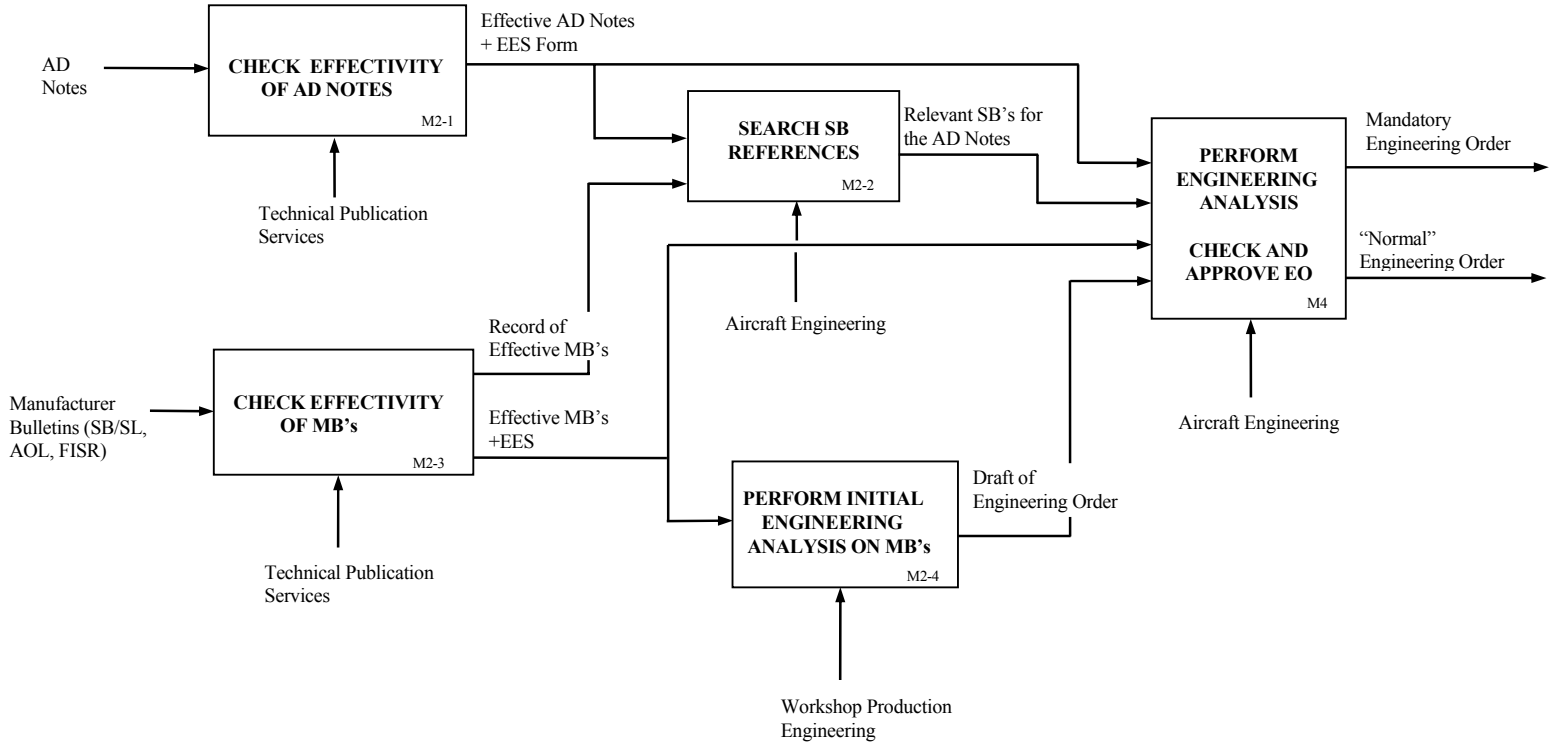
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ENGINEER	SECTION HEAD OF	PAGE : OF

Fig. 2.5 Effectiveness Report Form



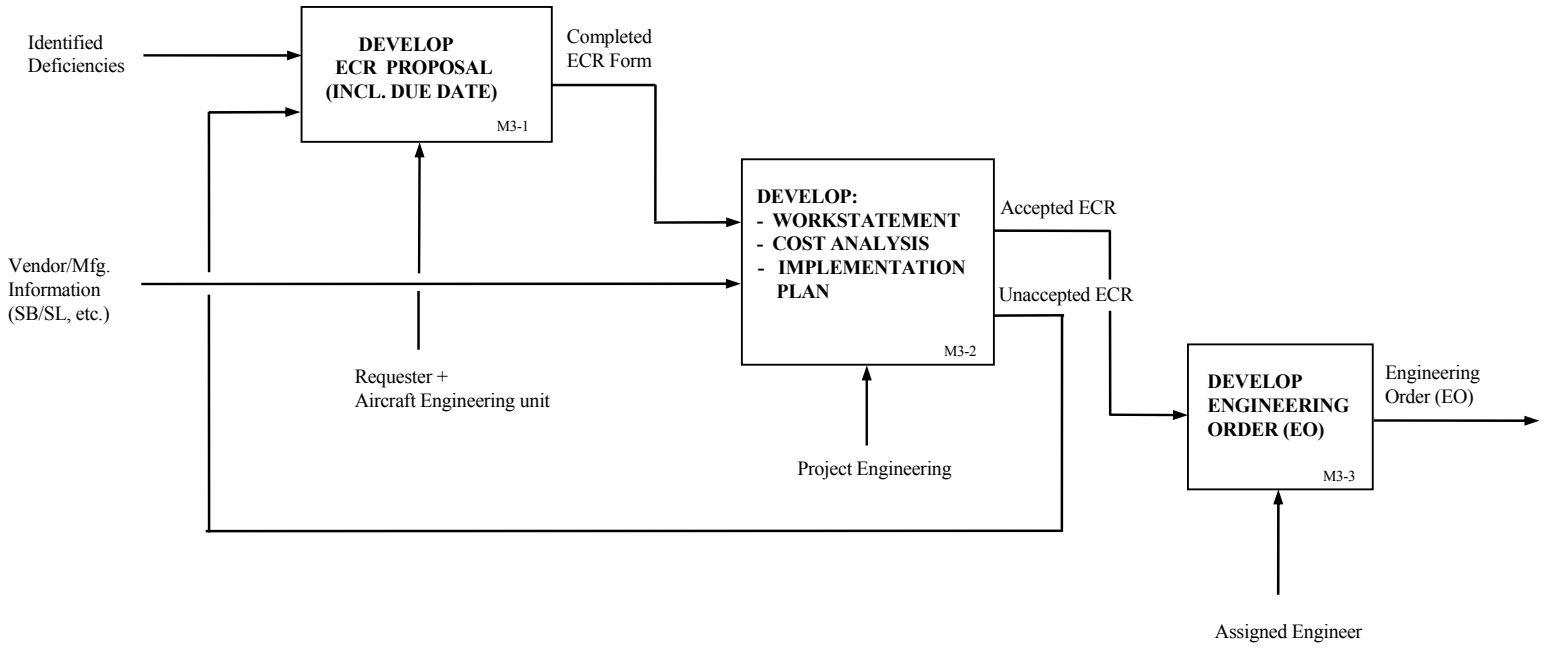
NUMBER: M1 & M4	NODE: A1 CONTEXT: M0	TITLE: FIG. 2.6 **AS-IS**: INTERNAL ENGINEERING INITIATIVES [GIA WI, TPM, RCP]	AUTHOR: E. SUWONDO DATE : 25 FEB. 2005

AS-IS SITUATION: AD NOTES AND MANUFACTURER BULLETINS EVALUATION PROCESS



NUMBER: M2	NODE: A1 CONTEXT: M0	TITLE: FIG. 2.8 **AS-IS:** EVALUATE AD NOTES & MANUFACTURER BULLETINS	AUTHOR: E. SUWONDO DATE : 25 FEB. 2005

AS-IS SITUATION: EVALUATION PROCESS OF ENGINEERING CHANGE REQUEST



NUMBER: M3	NODE: A1 CONTEXT: M0	TITLE: FIG. 2.9 **AS-IS:** EVALUATE ENGINEERING CHANGE REQUEST [GIA TPM]	AUTHOR: E. SUWONDO DATE : 25 FEB. 2005	

Garuda Indonesia

MAINTENANCE & ENGINEERING

ENGINEERING CHANGE REQUEST

(This form is to be filled up by the applicant from outside Technical Directorate and submitted to Engineering Services - Garuda Indonesia)

Subject: **Request No.:** **Issue date:** **Reference:** **ATA :**	
AIRCRAFT **TYPE :** **REG. NO.:**	
Engine/APU/Component **Type :** **Serial No. :** **Due Date:**	

REASON FOR REQUEST

( ) ECONOMIC ( ) OPERATIONAL IMPROVEMENT

( ) PASSENGER SATISFACTION ( ) SPECIAL REQUIREMENT

( ) CREW SATISFACTION ( ) OTHERS

CHANGE REQUEST DESCRIPTION:

APPLICANT	**REQUESTED BY**	**APPROVED BY**	**APPROVED BY**
SIGNATURE			
NAME/ID NO.			
POSITION			
DEPARTMENT			

Fig. 2.10a AS-IS: Engineering Change Request form (page 1 of 2)

Garuda Indonesia

MAINTENANCE & ENGINEERING

COMPLIANCE REQUIREMENT:

APPLICANT'S JUSTIFICATION:

Fig. 2.10b AS-IS: Engineering Change Request form (page 2 of 2)

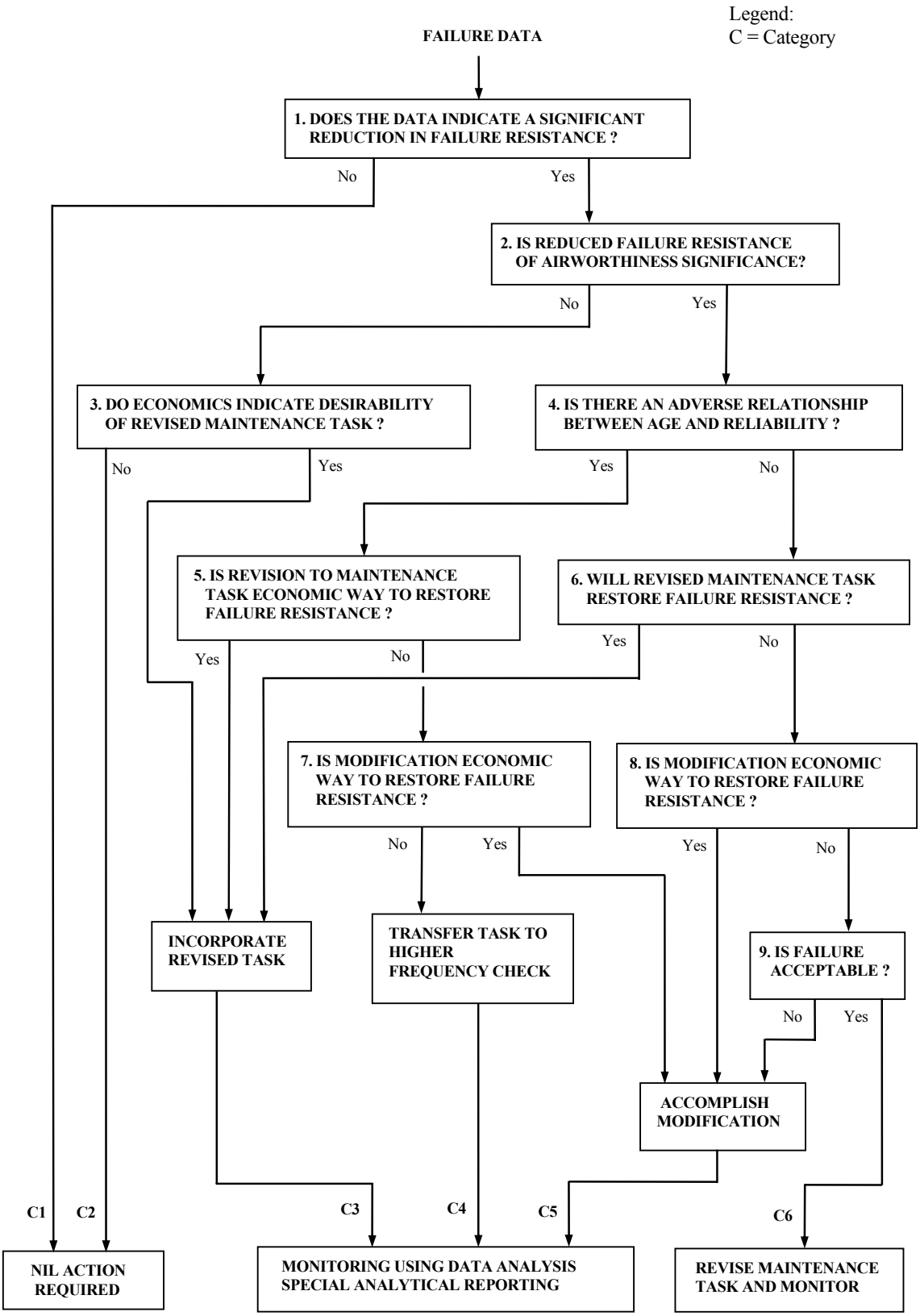


Fig. 2.11 **AS-IS:** Corrective Action Decision Diagram [GIA Reliability Program Manual]

Chapter 3

LCC-OPS for Aircraft Modifications

This chapter describes the development of the LCC-OPS model for aircraft modifications (called LCC-MODS). It covers the framework of the model, the methods of cost and potential savings estimation, the required data input as well as the data sources. The main function of the LCC-MODS model is to produce a complete LCC-MODS Form (see also section 4.2 of Chapter 4).

3.1 Framework of LCC-OPS for Aircraft Modifications

This section describes the framework of LCC-OPS for aircraft modifications (called LCC-MODS). As mentioned earlier, LCC-OPS is an LCC model applied in the operation phase which takes into account the impact of performance improvement as an opportunity revenue. The opportunity revenue is added to the LCC savings. The typical characteristics of the operating phase are that major aircraft functional parameters (e.g. capacity, speed, range) are fixed, and improvements are more aimed to increase aircraft reliability, availability and to reduce operating costs. Generally, only Engineering Change Requests (ECR) have impact to aircraft functional parameters, for instance due to conversion from passenger into combi or cargo.

LCC-OPS consists of four main components, i.e.:
a. modification costs
b. changes of operating costs
c. changes of revenue
d. length of the life cycle (period of evaluation).

These four components are similar to the top level LCC-OPS model shown in Fig. 1.3. The framework of LCC-MODS is shown in Fig. 3.1, which is actually a Cost Breakdown Structure (CBS). Explanations of these four main components are following.

Ad a). Modification cost consists of the labour required for implementation, engineering man-hours to develop an Engineering Order, material cost (modification kit), the cost of special tools and extra down time required to implement the modification.

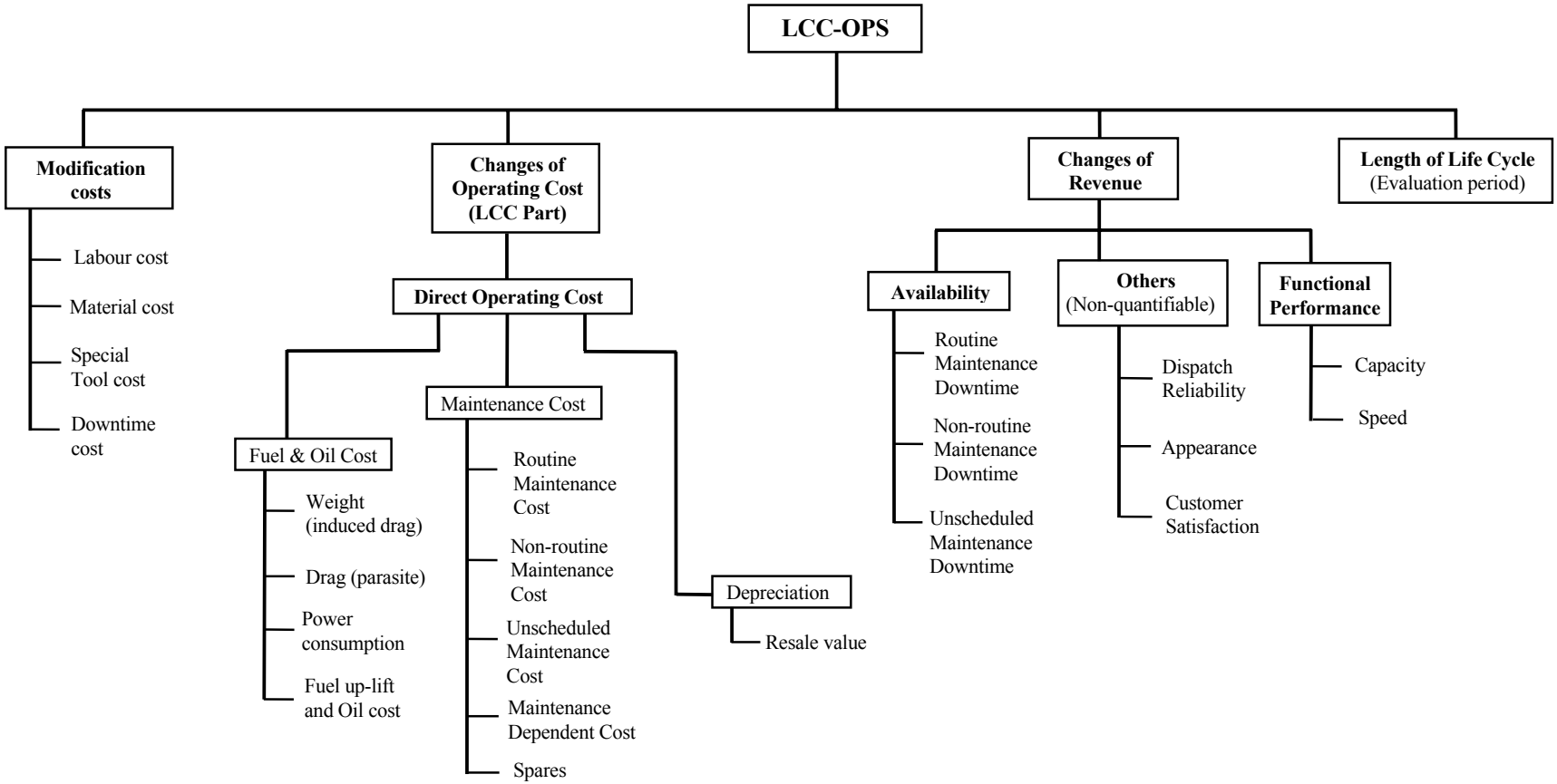


Fig. 3.1 The LCC-OPS model for aircraft modifications

Modification is normally conducted during scheduled maintenance. However, in some cases an extra down time is required specifically for the modification.

Ad b). Changes of operating costs are resulting from the modification. They normally include the reduction of fuel cost, maintenance cost and depreciation cost. Fuel cost reduction comes from induced drag reduction (weight reduction) and possible parasite drag (Cd_0) and power consumption (direct to the item) reduction. Maintenance cost reduction is the main point of consideration, where it is the result of the changes of routine maintenance, elimination of non-routine and unscheduled maintenance. Maintenance dependent costs and spares cost are important maintenance cost components to be considered. Maintenance dependent costs cover only the 'real' costs resulting from delays and cancellations, while the loss of revenue due to aircraft unavailability is included in point c below. Reduction of depreciation cost comes from the possible increase of resale value.

Ad c). Changes of gained revenues due to changes of aircraft availability. Changes of aircraft availability comes from the changes of routine maintenance downtime, non-routine maintenance downtime and unscheduled maintenance downtime. However, the changes of revenue depends on the utilisation of the aircraft, therefore it is considered as an 'opportunity' revenue.

Ad d). Length of life cycle is the evaluation period, in this consideration.

During analysis of problems identified by the Reliability Engineering function, LCC-MODS is applied to evaluate whether the solution of the problem leads to LCC savings. Of course, this consideration is applicable only for non-safety consequence failures.

In some cases, users of the model may develop their own Cost Breakdown Structure or to select a more appropriate Cost Estimation Method (CEM). This is to improve the results of the evaluation. For this reason, the model provides facilities to make these possible. The options for CEM are for instance development of a parametric model from raw data or the use of a simulation model. Appendix G provides possible methods of cost component estimation, where the criteria for selection are discussed in Appendix F.

Some detailed analysis can be included in the model as well, e.g.:
a. sensitivity analysis
b. cost drivers identification
c. LCC profile development
d. (cost) risk analysis.

3.2 Cost Element Estimation Methods

The definition of cost components and the method of cost elements calculation are shown in Table 3.1, from 3.1.a until 3.1.f. Most of the calculation methods are detailed engineering, for instance labour cost is equal to the number of required labour man-hours times the labour rate for each of capacity group. However, the selection of the cost elements calculation

method depends on the availability of data. Comparison method, as an example, can be used to calculate the required extra downtime to implement modification (EXTDT in Table 3.1a), by referring to the complexity of the system. The calculation of oil consumption cost is using the factor method, i.e. as a percentage of fuel cost.

3.3 Input of LCC-MODS

Table 3.2a until 3.2d show the input for the LCC-MODS model. The input are divided into groups according to the level of system hierarchy.

a. aircraft level: aircraft fleet data, general data and operating cost data
b. subsystem/component level: modification cost per aircraft, modification title and aircraft changes.
c. maintenance activities: maintenance pre-mod (before modification) and maintenance post-mod (after modification).

The LCC-OPS model for Aircraft Modifications is developed with the Microsoft Excel Program. Figures 3.2a, b, c show the display of the input for the LCC-OPS model for Aircraft Modifications. The post-mod maintenance data entry form is similar with Figure 3.2c.

Data sources will be identified during the discussion of the TO-BE situation processes (section 4.4 of Chapter 4). This is because the data sources are strongly related to the evaluation process.

	A	B	C	D	E	F
1	**LCC-MODS**		**AIRCRAFT DATA**		by Edy Suwondo	
2						
4	**AIRCRAFT FLEET DATA:**			**OPERATING COST DATA:**		
5	Aircraft type:	B747-200	series	RPK	0.13	USD/seat/km
6	Number of aircrafts	6	units	Annual operating days	285	days
7	Flight distance	6000	km	Fuel consumption/block hour	11230	kg/hr
8	Block hour	7.00	hour	Oil cost to fuel cost ratio	0.01	kg/kg
9	Frequency of flight/day	2	/day	Fuel consmp. to weight factor	0.01857	kg/(kg.hr)
10	Number of pax (capacity)	431	pax	Fuel consmp. to power factor	0	kg/(kW.hr)
11	Load factor	0.65		Fuel to parasite drag factor	0.01	kg/(dc.hr)
12				Avg. technical delay duration	3.21	hr
13	**GENERAL DATA:**			Delay and cancellation cost	200	USD/min
14	Labour rate, average	30	USD/hour	Begin of evaluation period	1/1/2000	mm/dd/yy
15	Engineering rate, average	40	USD/hour	End of evaluation period	12/31/2004	mm/dd/yy
16	Fuel price/gallon	0.6128	USD			
17	Fuel density	0.8	kg/litre			
18	Interest rate	0.12	/year			
19						
20						
21						

Aircraft / Modification / Maint-premod / Maint-postmod / Results / LCC-OPS Form /

Fig. 3.2a Aircraft level input for the LCC-OPS for Aircraft Modifications

	A	B	C	D	E	F	G	H
1	**LCC-MODS**			**MODIFICATION DATA**				by Edy Suwondo
2								
4	MODIFICATION COST PER AIRCRAFT:			MOD. TITLE RETROFIT FQIS WITH BFGOODRICH				
5	Price of modification kit	32828	USD	REFERENCE:	BO SB 747-28-22	DATE:	3-Apr-00	
6	Number of modification kit	9	units	ATA	28	SUB-ATA	2841	
7	Engineering hours for mod.	0	hours	PART NO:	28412826			
8	Labour hours for modification	1400	hours	AIRCRAFT CHANGES:				
9	Extra downtime to modify	360	hours	Required spares (delta)		0	units/year	
10	Number of additional tools	0	units	Unit spares price		300	USD	
11	Cost per additional tool		USD	Empty Weight (MZFW) reduc		-20	kg	
12	Material (others):	-120000	USD	Parasite drag		0	%	
13	AD 98-20-40 kit avoidance	-90000	USD	Power required (kWatt)		0	kWatt	
14	AD 99-08-20 kit avoidance	-30000	USD	Fuel up-lift		1572	kg	
15			USD	Oil consumption		0	kg	
16	Labour (others):	-46500	USD	Capacity		0	pax	
17	Labour avoidance for AD's	-1550	hours	Block hour		0	hour	
18	Eng. hrs avoidance for AD's	0	hours	End value		168725	USD	
19								
20	Downtime (others):	-11,238,017	USD	Others:		0	USD	
21	Downtime avoidance	-360	hours					
22			hours					
23								

Fig. 3.2b Subsystem/component level input for the LCC-OPS for Aircraft Modifications

	A	B	C	D	E	F	G
1	**LCC-MODS**		**MAINTENANCE PRE-MOD**			by Edy Suwondo	
2							
4	Routine maint. code:	Labour hour	Material cost	Downtime	Nr./year	Total Cost	Total Time
5	B4/S28-41-0302	8	20		1	1300.0	0.00
6	B4/S28-41-0303	8	15		1	1275.0	0.00
7	B4/S28-41-0304	8	10		1	1250.0	0.00
8	B4/S28-41-0305	8	35		1	1375.0	0.00
9	MS 2841020301	13	20		0.2	410.0	0.00
10	MS 2841020302	45.5	70		0.2	1435.0	0.00
11							
12				TOTAL =		7045.0	0.00
13	Non-routine maint. name:	Labour hour	Material cost	Downtime	Nr./year	Total Cost	Total Time
14						0.0	0.00
15						0.0	0.00
16						0.0	0.00
17						0.0	0.00
18						0.0	0.00
19				TOTAL =		0.0	0.00
20	Unscheduled maint. name:	Labour hour	Material cost	Downtime	Rem. in LC	Total Cost	Total Time
21	Connector plug-3		306	3.21	1.333	407.9	4.28
22	Connector plug-4		306	3.21	1.5	459.0	4.82
23	MT Jumper plug 37-14		4675	3.21	3	14025.0	9.63
24	MT Jumper plug 47-14		3969	3.21	1.167	4631.8	3.75
25	R1 Receptacle-1105		12900	3.21	0.5	6450.0	1.61
26	R4 Receptacle-1205		11555	3.21	0.333	3847.8	1.07
27							
28				TOTAL =		29821.5	25.14
29	Total 'direct' maintenance cost:	36,867	Maint. Dependent cost:		301,727	Opport. rev.	784,911

Fig. 3.2c Maintenance activities input for the LCC-OPS for Aircraft Modifications

3.4 Output of LCC-OPS for Aircraft Modifications

The final output of the LCC-OPS is a completed LCC-MODS Form. Before the result is put onto the LCC-MODS Form, it is shown in the "Results" worksheet. Figures 3.3 shows the "Results" worksheet of the LCC-MODS model. Figures 3.4a and 3.4b show the LCC-MOD Form. The results of the LCC-OPS model for Aircraft Modifications consist of:

a. Modification costs
b. Direct Maintenance Cost (DMC) reduction
c. Maintenance Dependent Cost (MDC) reduction
d. Spares cost reduction
e. Fuel cost reduction
f. Increase of resale value
g. Other cost reduction
h. Opportunity revenue increase
i. LCC-OPS per aircraft
j. LCC-OPS at fleet level.

The distribution of the expenses and the savings in the course of the evaluation period are shown in a table and a chart, in the "Results" worksheet.

	A	B	C	D	E	F	G	H
1	**LCC-MODS**	**RESULTS**		by Edy Suwondo				
2								
4								
5	Modification costs	337,450	USD	Year	Expenses	Savings (USD)	Total PV (USD)	
6	Downtime cost for modification	11,238,017		0	337,450	496,466	159,016	
7	Direct maintenance cost savings	-36,867	USD	1		496,466	443,273	
8	Maintenance dependent cost savings	-301,727	USD	2		496,466	395,780	
9	Spares cost reduction	0	USD	3		496,466	353,375	
10	Fuel Cost reduction	-1,023,601	USD	4		496,466	315,513	
11	Increase of resale value	-168,725	USD					
12	Other cost reduction:		USD					
13	AD Notes Avoidance	-11,404,517	USD					
14	Opportunity revenue	-784,911	USD					
15	**LCC-OPS per aircraft**	1,666,957	USD					
16	Period of evaluation	5.0	years					
17	Period of evaluation	5.00	years					
18	LCC-OPS at fleet level	10,001,743	USD					
19	**ADDITIONAL CRITERIA:**							
20	Payback Period (with interest)	0.6797	years					
21	Return On Investment (ROI)	147.1	%					
22	Internal Rate of Return (IRR)	Not applicable	%					

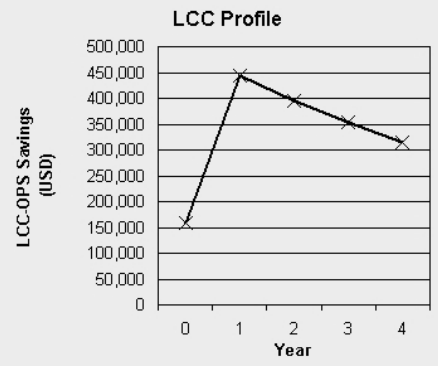


Fig. 3.3 The "Results" worksheet of the LCC-OPS for Aircraft Modifications

LCC-MODS FORM

Designed by Edy Suwondo

page 1/2

No: LO 18-10-00 Date: 14-Apr-03 A/C Type: B747-200

ATA: 28 SUB-ATA: 2841 Part No.: 28412826

TITLE: **RETROFIT FQIS WITH BFGOODRICH**

REF: BO SB 747-28-2205 DATE: 3-Apr-00

TARGETS SUMMARY (PER AIRCRAFT):

LCC-OPS SAVINGS **1,666,957** USD **Period (years): 5.00**

INVESTMENT REQ. **337,450** USD

Performance improv. No delay due to FQIS

Other Benefits: Increase aircraft availability

Priority: [ ] Mandatory [ ] Recommended [ ] Pending

Prepared by: Checked by: Approved by:

Date:

ENGINEERING VERIFICATION:

Result: [ ] Feasible [ ] Not feasible [ ] Pending

Justifications:

Reference: Engineering Analysis Report: AER/xx/yy/zz

Prepared by: Checked by: Approved by:

Date:

DEMONSTRATION SUMMARY (see page 2/2 for detail):

Investment req. (USD): Operating cost (USD):

LCC-OPS SAVINGS: USD

Performance: Improvement is not measurable/noticed

Negative impacts:

Reference: Operation Report: OR/xx/yy/zz

Prepared by: Checked by:

Date:

Fig. 3.4a The proposed LCC-MODS Form (page 1/2)

LCC-MODS FORM

Designed by Edy Suwondo

page 2/2

PROJECTED SAVINGS PER AIRCRAFT:

Maintenance Dependent Costs:		Numbers	Projected (USD)	Realised (USD)
Delay:		7.833	301,727	
Cancellation :				
Others :				
Direct Maintenance:		Numbers or hours	Projected (USD)	Realised (USD)
Routine Maintenance :	DMC:		7,045	
	Down time:	0.0	0	
Non-routine Maint.:	DMC:		0	
	Down time:	0.0	0	
Unsched. Maint.:	DMC:		29,822	
	Down time:	25.14393	784,911	
Spares:			0	
Fuel reduction due to:	Weight:	Fuel weight reduct.	116,424	
	Power:		0	
	Parasite Drag:		0	
	Others:	Fuel up-lift reduct.	907,177	
Subtotal (A):			2,147,106	
IMPLEMENTATION PER A/C:		Units	Projected (USD)	Realised (USD)
Direct costs:				
	Material:	9	295,450	
	Labour:	1400	42,000	
	Ground time (AOG) :	360	11,238,017	
Indirect costs:				
	Engineering man-hour :	0	0	
Others :	AD Notes avoidance		-11,404,517	
Sub-total (B):			170,950	
Evaluation period (years):		5.0		
Increase resale value (C):			168725	
LCC-OPS (A-B+C), Amortised, PV:			**1,666,957**	

OTHER BENEFITS:

Increase aircraft availability:	[ ] Yes	[ ] No
Passenger satisfaction:	[ ] Yes	[ ] No
Crews convenience:	[ ] Yes	[ ] No

NOTES :

Fig. 3.4b The proposed LCC-MODS Form (page 2/2)

3.5 Application of LCC-OPS on Case Study

This section describes shortly the application of LCC-OPS for aircraft modifications (LCC-MODS). The details of the application and the results can be seen in Appendix I. The author applied the proposed LCC-MODS during his visit to Garuda Maintenance Facility (GMF) at Cengkareng Airport, Jakarta. The use of the LCC-MODS model is acceptable by GMF while the Indonesian DGAC considers it as a good method for modification analysis. The objective of the LCC-MODS application is to evaluate whether the cost components are complete and the required data is available. The modification example below is selected because it includes also the impact of the modification to the operating cost and the reliability of the aircraft.

3.5.1 Description of the problem

The existing Fuel Quantity Indication System (FQIS) of B747-200 is addressed to be modified due to AD 98-20-40 (wiring replacement) and AD 99-08-02 (wiring inspection, insulation resistance test and installation of flame arrestor). At the same time, BFGoodrich, Ltd. introduced a new designed FQIS . Retrofit with this new FQIS and in addition with a small inspection will result in complying with these AD Notes, as recommended by Boeing. The existing FQIS had introduced significant problems which led to delays in the past. Meanwhile, the new designed FQIS is more reliable and accurate, but it requires some acquisition cost and a significant ground time for installation.

The objective of the LCC-MODS model application is to compare the LCC-OPS of those two alternatives, i.e. implement the above AD Notes or retrofit with the new design FQIS. Comparison will be on the required cost for implementation, cost savings and opportunity revenues during operation for each alternative. A specific aircraft operation route is chosen and will be used to investigate the fuel cost savings and opportunity revenue.

For the existing FQIS, evaluation includes the required costs of modification to comply with the AD Notes (ground time, material and man-hours), material and labour for inspections due to Engineering Order and inspections due to scheduled maintenance program. As discussed in Appendix I, the cost resulted by schedule interruption (delay) is estimated by using the material consumption records. This is due to the lack of information on delay at ATA-100 six digits or component level.

For the new designed BFGoodrich FQIS, evaluation includes the price of modification kits for nine tanks per aircraft, the ground time, man-hours and the fuel cost savings due to accuracy improvement. The impact of weight increase is included as well. Reliability improvement results in no need for preventive maintenance, therefore no extra maintenance costs are incurred.

3.5.2 The process of the LCC-MODS model application

First of all, relevant cost components and elements are identified for each of the alternatives above, after describing the problem as discussed in sub-section 3.5.1. A Cost Breakdown Structure (CBS) is developed to support this activity (Fig. I.1 of Appendix I). The existing FQIS is considered as the baseline, where all cost components of the CBS are relative to this

baseline. Estimation (calculation) of these cost components is then carried out. The labour rate used is USD 30/hour. Estimation is done for 5 years basis, namely for the period of beginning of 2000 until end of 2004.

Because of the existing FQIS had introduced significant delays in the past, the component failures (unscheduled maintenance) which may occur in the evaluation period must be estimated. The estimation is based on the total number of components consumed since aircraft delivery and the period of ordering components (see section I.5 of Appendix I).

Estimated additional ground time for installing the new FQIS is 15 days when conducted together with C or D-check [BFGoodrich, 1997]. This time estimate is equal to the required ground time to comply with the AD Notes. Therefore, there are no opportunity revenue differences due to installation between these two alternatives.

In order to estimate the opportunity revenue, it is assumed that the aircraft is operated from Bali to Japan on the route of Denpasar-Narita-Denpasar (DPS-NRT-DPS), with two departures per day. The average fuel burn per departure is 78,600 kg, and the average block hour is 7.0 hours. Both B747-200 and B747-400 have ever been operated on this route, therefore the operation data is available.

The investment costs to implement the modification is depreciated up to the end of aircraft economical life to calculate the increase of aircraft resale value at the end of the evaluation period.

3.5.3 The results of the LCC-MODS model application

From Table I.4 in Appendix I, the LCC-OPS savings for 5 years by implementing the BFGoodrich FQIS is USD 1,666,957.-. It takes into account the savings due to there is no need anymore to implement the AD Notes, called 'cost of avoidance' (because the BFGoodrich FQIS is an AMOC of the AD Notes) and the opportunity revenue due to the reliability improvement.

Sensitivity analysis of the BFGoodrich FQIS is concentrated on the changes of the LCC-OPS due to changes of number of delays, because delay cost is a high cost contributor and its value depends on the number of failures. Sensitivity analysis is intended to estimate the risk of the implementation if the estimate of the contributing parameters is inaccurate. The result shows that LCC-OPS savings are considerably sensitive to the number of failures, i.e. 8.322% /failure. However, occurrence of one failure for the period of evaluation is considered as too high, based on the experience of the users of the BFGoodrich FQIS.

As shown in Table J.4, a major cost savings comes from fuel cost reduction due to improvement of the FQIS accuracy. The improvement of reading accuracy is the objective of the BFGoodrich FQIS design, therefore sensitivity analysis on this is not carried out. However, it is necessary to verify the achieved reading accuracy of the FQIS after implementation (demonstration).

Based on the results above, the author considers there is **no** need to include bonus or penalty in the (future) acquisition contract, as far as the accuracy and reliability of the new FQIS are concerned.

3.5.4 Problems discovered by applying the LCC-MODS model

As mentioned earlier, there is no records anymore on component removal and failure confirmation or finding records for the FQIS components, to estimate the reliability of the FQIS. FQIS problems occurred long before this investigation is carried out (more than five years before the investigation). Engineers reports that there were a lot of delays and cancellations due to the FQIS problem. Data which can be discovered is the component consumptions since aircraft delivery and the dates of the component ordering. Of course, it is far from accurate. However, an order of magnitude can be obtained for the expected failure of the FQIS.

The censoring method is applied for this purpose to utilise the data of survivors. *It is assumed that the failing components failed at the average age, i.e. the mid of the ordering period*. Therefore, for censoring [Nowlan and Heap, 1978], (see also Appendix I)
MTBF = (# survivors * evaluation period + # failures * average age) / # failures
As comparison, calculation of MTBF without censoring is given as well, i.e.
MTBF = (Qty/ac * # aircraft * average age) / # failures

The evaluation period of the historical data is the time since aircraft delivery (1980) up to the time where the evaluation was conducted (end of 1999), therefore it is equal to 20 years. The expected number of failures at aircraft age of 20 years, Ef(20), can be calculated as follows (see also Appendix I).
Ef(20) = Integer (20/MTBF) * Qty/ac * # aircrafts

Table 3.1a Cost component definition and calculation method (see also Fig. 3.1)

Cost component/element	Calculation method
Modification costs (C_M)	$C_M = C_{ML} + C_{MM} + C_{MT} + C_{MD}$ Where: C_{ML} = Labour cost of modification C_{MM} = Material cost of modification C_{MT} = Tooling cost of modification C_{MD} = Downtime cost of modification
Labour costs (C_{ML})	C_{ML} = LABHR * LABRT + ENGHR * ENGRT Where: LABHR = required maintenance labour hour LABRT = Maintenance labour rate ENGHR = Engineering hour (to develop EO) ENGRT = Engineering hour rate
Material costs (C_{MM})	C_{MM} = PRMK * NRMK Where: NRMK = Number of modification kits per aircraft (including spares) PRMK = Price per modification kit
Tool costs (C_{MT})	C_{MT} = NRATL * PRATL Where: NRATL = Number of the required additional tools per aircraft PRATL = Price per tool
Downtime costs (C_{MD})	C_{MD} = EXTDT * RVPH Where: EXTDT = Extra downtime for modification RVPH = Revenue per hour RVPH = LF * NRPAX * FLDIS * RPK / BLHR Where: LF = load factor NRPAX = number of passengers (capacity) FLDIS = Flight distance RPK = revenue passenger kilometre BLHR = block hour
Changes of operating cost per trip (C_O)	$C_O = C_{OF} + C_{OM} + C_{OD} + C_{OC} + C_{ON}$ Where: C_{OF} = Changes of fuel and oil costs C_{OM} = Changes of maintenance cost C_{OD} = Changes of depreciation cost C_{OC} = Changes of cockpit crew cost C_{ON} = Changes of non-direct operating cost

Table 3.1b Cost component definition and calculation method (continued)

Cost component	Calculation method
Changes of fuel and oil cost (C_{OF})	$C_{OF} = C_{OFW} + C_{OFD} + C_{OFP} + C_{OFU} + C_{OFO}$ Where: C_{OFW} = due to weight changes C_{OFD} = due to parasite drag changes C_{OFP} = due to power consumption changes C_{OFU} = due to fuel up-lift changes C_{OFO} = due to oil cost changes
Changes of fuel cost due to weight changes (C_{OFW})	C_{OFW} = (EWCHG + FULCHG)* FTWR * BLHR * FUPPG /3.785/FUDEN Where: EWCHG = aircraft empty weight changes FULCHG = fuel up-lift changes FTWF = fuel reduction to weight reduction factor (depends on aircraft type) BLHR = block hour FUPPG = fuel price per gallon 3.785 = conversion factor from gallon to litre FUDEN = fuel density, in kg/lt.
Changes of fuel cost due to parasite drag (C_{OFD})	C_{OFD} = PDCHG * FTDF * BLHR * FUPPG /3.785 /FUDEN Where: PDCHG = parasite drag (Cd_0) changes FTDF = fuel reduction to parasite drag reduction factor (depends on aircraft type) BLHR, FUPPG, FUDEN = as earlier
Changes of fuel cost due to (direct) power consumption changes (C_{OFP})	C_{OFP} = PRCHG * FTPF * BLHR * FUPPG /3.785 /FUDEN Where: PRCHG = power consumption changes FTPF = fuel reduction to power consumption reduction factor (depends on system specifications) BLHR, FUPPG, FUDEN = as earlier
Changes of fuel cost due to changes of fuel up-lift (C_{OFU})	C_{OFU} = FULCHG * FUPPG /3.785 / FUDEN Where: FULCHG = fuel up-lift changes FUPPG, FUDEN = as earlier

Table 3.1c Cost component definition and calculation method (continued)

Cost component	Calculation method
Changes of oil cost (C_{OFO})	C_{OFO} = OCCHG * OTFR * BLHR * FUPPG / 3.785 /FUDEN Where: OCCHG = oil consumption changes per block hour OTFR = oil cost to fuel cost factor (depends on engine types) BLHR, FUPPG, FUDEN = as earlier
Changes of maintenance cost (C_{OM})	$C_{OM} = C_{OMS} + C_{OMN} + C_{OMU} + C_{OMD} + C_{OMP}$ Where: C_{OMS} = due to routine maintenance changes C_{OMN} = due to non-routine maintenance changes C_{OMU} = due to unscheduled maintenance Changes C_{OMD} = due to maintenance dependent cost Changes C_{OMP} = due to required spares changes
Changes of routine maintenance cost (C_{OMS})	$C_{OMS} = \sum(POSMNR_i*(POSMLB_i + POSMMT_i)) - \sum(PRSMNR_i * (PRSMLB_i + PRSMMT_i))$ Where: $POSMNR_i$ = frequency of routine maintenance i at post-modification (projection) (annual) $POSMLB_i$ = labour cost of routine maintenance i at post-modification = LABRT * required labour hours $POSMMT_i$ = material cost of routine maintenance i at post-modification $PRSMNR_i$ = frequency of routine maintenance i at pre-modification (existing) (annual) $PRSMLB_i$ = labour cost of routine maintenance i at post-modification = LABRT * required labour hours $POSMMT_i$ = material cost of routine maintenance i post-modification (projection)
Changes of non-routine maintenance cost (C_{OMN})	$C_{OMN} = \sum(PONMNR_i*(PONMLAB_i + PONMMT_i)) - \sum(PRNMNR_i * (PRNMLB_i + PRNMMT_i))$

Table 3.1d Cost component definition and calculation method (continued)

Cost component	Calculation method
	Where: $PONMNR_i$ = frequency of non-routine maintenance i at post-modification (projection) (annual) $PONMLB_i$ = labour cost of non-routine maintenance i at post-modification = LABRT * required labour hours $PONMMT_i$ = material cost of non-routine maintenance i at post-modification $PRNMNR_i$ = frequency of non-routine maintenance i at pre-modification (existing) (annual) $PRNMLB_i$ = labour cost of non-routine maintenance i at post-modification = LABRT * required labour hours $PONMMT_i$ = material cost of non-routine maintenance i post-modification (projection)
Changes of unscheduled maintenance cost (C_{OMU})	$C_{OMU} = \sum(POUMNR_i*(POUMLB_i + POUMMT_i)) – \sum(PRUMNR_i * (PRUMLB_i + PRUMMT_i))$ Where: $POUMNR_i$ = frequency of unscheduled maintenance i at post-modification (projection) (annual) $POUMLB_i$ = labour cost of unscheduled maintenance i at post-modification = LABRT * required labour hours $POUMMT_i$ = material cost of unscheduled maintenance i at post-modification $PRUMNR_i$ = frequency of unscheduled maintenance i at pre-modification (existing) (annual) $PRUMLB_i$ = labour cost of unscheduled maintenance i at post-modification = LABRT * required labour hours $POUMMT_i$ = material cost of unscheduled maintenance i post-modification (projection)
Changes of maintenance dependent cost (C_{OMD})	$C_{OMD} = (\sum POUMDT – \sum PRUMDT)* 60 * DACC$ Or (depends on availability of data) $C_{OMD} = (\sum POUMNR – \sum PRUMNR)* AVDEL*60 * DACC$ Where: POUMNR, POUMNR are as earlier DACC = delay and cancellation cost/minute

Table 3.1e Cost component definition and calculation method (continued)

Cost component	Calculation method
	AVDEL = average delay duration in hours PRUMDT = downtime of unscheduled maintenance pre-modification (annual) POUMDT = downtime of unscheduled maintenance of post-modification (annual)
Changes of required spares (C_{OMP})	C_{OMP} = RSPCHG * SPAPR Where: RSPCHG = changes of the number of required spares in the life cycle SPAPR = unit spares cost
Annual changes of depreciation cost (C_{OD})	C_{OD} = ENVCHG/(EEVAL-BEVAL)*365 Where: ENVCHG = initial value - end value EEVAL = end of evaluation date BEVAL = begin of evaluation date
Changes of revenue (R)	$R = R_A + R_F + R_N$ Where: R_A = changes of revenue due to changes of availability in the life cycle R_F = changes of revenue due to changes of functional performance (capacity, speed) R_N = changes of revenue due to changes of passenger satisfaction (non-quantifiable)
Changes of revenue due to availability changes (R_A)	$R_A = R_{AS} + R_{AN} + R_{AU}$ Where: R_{AS} = changes of revenue due to changes of scheduled maintenance time in the life cycle R_{AN} = changes of revenue due to changes of non-routine maintenance time in the life cycle. R_{AU} = changes of revenue due to changes of unscheduled maintenance time in the life cycle
Annual changes of revenue due to changes of scheduled maintenance time (R_{AS})	R_{AS} = (∑PSMDT-∑PRSMDT)*RVPH Where: RVPH = revenue per hour, similar as in C_{MD} PRSMDT = downtime of scheduled maintenance pre-modification (annual) POSMDT = downtime of scheduled maintenance of post-modification (annual)

Table 3.1f Cost component definition and calculation method (continued)

Cost component	Calculation method
Changes of revenue due to Changes of non-routine maintenance time (R_{AN})	$R_{AN} = (\sum PRNMDT - \sum PONMDT) * RVPH$ Where: RVPH is as earlier PRNMDT = total downtime of non-routine maintenance pre-modification (annual) PONMDT = total downtime of non-routine maintenance of post-modification (annual)
Changes of revenue due to Changes of unscheduled maintenance time (R_{AU})	$R_{AU}=(\sum PRUMDT - \sum POUMDT) * RVPH$ Where: PRUMDT, POUMDT and RVPH are as earlier
Changes of revenue due to Changes of functional performance (R_F)	$R_F = R_{FC} + R_{FS}$ Where: R_{FC} = Changes of revenue due to capacity changes R_{FS} = Changes of revenue due to speed changes
Changes of revenue due to capacity changes (R_{FC})	R_{FC} = CPYCHG * RVPH * BLHR * FLFRE * ANUTL Where: CPYCHG = changes of capacity (number of pax) RVPH, BLHR, FLFRE, ANUTL are as earlier
Changes of revenue due to speed changes (R_{FS}) Note: Block speed normally depends on the Air Traffic Controller (ATC)	R_{FS} = BLHCHG * RVPH * FLFRE * ANUTL Where: BLHCHG = changes of block hour (fraction) RVPH, FLFRE, ANUTL are as earlier

Table 3.2a Input of the LCC-MODS model based on Table 3.1.

Input name (following LCC-MODS model)	Input variable	Input unit	Estimated cost component(s)
a.1. AIRCRAFT FLEET DATA:			
Aircraft type (string variable)	ACTYP	None	None
Number of aircrafts	NRAC	None	Total fleet LCC-OPS
Flight distance	FLDIS	km	Revenue
Block hour	BLHR	hour	Downtime cost
Frequency of flight (daily)	FLFRE	times/day	Revenue, downtime cost
Number of passenger (capacity)	NRPAX	None	Revenue, downtime cost
Load factor (average)	LF	None	Revenue, downtime cost
a.2. GENERAL DATA:			
Labour rate	LABRT	USD/hour	Labour cost (mod.)
Engineering rate	ENGRT	USD/hour	Engineering cost
Fuel price/gallon	FUPPG	USD/gallon	Operating cost savings
Fuel density	FUDEN	kg/gallon	Operating cost savings
Interest rate	INTRT	/year	LCC-OPS profile
a.3. OPERATING COST DATA:			
RPK (Revenue Passenger Kilometre)	RPK	USD/(seat. km)	Revenue, downtime cost
Annual operating days (days)	ANUTL	days/year	Revenue, downtime cost
Fuel consumption/block hour (kg)	FUCON	km/hr	Fuel cost
Oil cost to fuel cost ratio	OTFR	kg/kg	Oil cost
Fuel consumption to weight factor	FTWF	kg/(kg. hr)	Fuel cost reduction
Fuel consumption to required power factor	FTPF	kg/(kW. hr)	Fuel cost reduction
Fuel consumption to parasite drag factor (dc = drag count, 1 dc = 0.001).	FTDF	kg/(dc. hr)	Fuel cost reduction
Average delay duration	AVDEL	hours	Maintenance dependent cost
Delay and cancellation cost	DACC	USD/minute	Maintenance dependent cost
Begin of evaluation period	BEVAL	(date)	Depreciation, LCC-OPS
End of evaluation period	EEVAL	(date)	Depreciation, LCC-OPS

Table 3.2b Input of the LCC-MODS model based on Table 3.1.

Input name (following LCC-MODS model)	Input variable	Input unit	Estimated cost component(s)
b.1. MODIFICATION TITLE:			
Modification Title (String)	MODTTL	String	Modification attributes
Reference	REFNR	String	Modification attributes
Date	REFDAT	Date	Modification attributes
ATA	ATANR	String	Modification attributes
Sub-ATA	SUBATA	String	Modification attributes
Part Number	PARTNR	String	Modification attributes
b.2. MODIFICATION COSTS PER AIRCRAFT:			
Price of modification kit	PRMK	USD/unit	Modification cost
Number of modification kit	NRMK	Units/aircraft	Modification cost
Engineering hours for modification	ENGHR	Hours	Modification cost
Labour hour for modification	LABHR	Hours	Modification cost
Extra downtime to modify	EXTDT	Hours	Modification cost
Number of additional tools	NRATL	Units	Modification cost
Cost per additional tool	PRATL	USD/Unit	Modification cost
Material (others)	MATOTH	USD	Modification cost
Labour (others)	LABOTH	hours	Modification cost
Downtime (others)	DTOTH	hours	Modification cost
b.3. AIRCRAFT **CHANGES**			
Required spares (delta)	RSPCHG	Units	Spares cost
Unit spares price	SPAPR	USD/Unit	Spares cost
Empty weight (or Maximum Zero Fuel Weight)	EWCHG	Kg	Fuel cost reduction
Parasite drag (dc = drag count)	PDCHG	Dc	Fuel cost reduction
Power required	PRCHG	kWatt	Fuel cost reduction
Fuel up-lift	FULCHG	kg	Fuel cost reduction
Oil consumption	OCCHG	kg	Oil cost reduction
Capacity	CPYCHG	number of pax	Opportunity revenue
Block hour	BLHCHG	hours	Opportunity revenue
End value	ENVCHG	USD	Depreciation cost reduction
Other	OTHCHG	USD	Other cost reduction

Table 3.2c Input of the LCC-MODS model based on Table 3.1.

Input name (following LCC-MODS model)	Input variable	Input unit	Estimated cost component(s)
c.1. MAINTENANCE PRE-MODIFICATION			Maintenance cost reduction, opportunity revenue. PRSMTDM (Total Direct Maintenance Cost due to Scheduled Maintenance at Pre-mod status), PRSMTDT (Total Down Time due to Scheduled Maintenance at Pre-mod status) PRNMTDM (similar, for Non-routine Maintenance) PRNMTDT (similar, for Non-routine Maintenance) PRUMTDM (similar, for Unscheduled Maintenance) PRUMTDT (similar, for Unscheduled Maintenance)
Routine maintenance name	PRSMNM	String	
Labour hour	PRSMLB	Hours	
Material cost	PRSMMT	USD	
Downtime	PRSMDT	Hours	
Annual frequency	PRSMNR	Times/year	
Non-routine maintenance name	PRNMNM	String	
Labour hour	PRNMLB	Hours	
Material cost	PRNMMT	USD	
Downtime	PRNMDT	Hours	
Annual frequency	PRNMNR	Times/year	
Unscheduled maintenance name	PRUMNM	String	
Labour hour	PRUMLB	Hours	
Material cost	PRUMMT	USD	
Downtime	PRUMDT	Hours	
Number of removal in the evaluation period (LC)	PRUMNR	Times/year	

Table 3.2d Input of the LCC-MODS model based on Table 3.1.

Input name (following LCC-MODS model)	Input variable	Input unit	Estimated cost component(s)
c.2. MAINTENANCE POST-MODIFICATION			Maintenance cost reduction, opportunity revenue
Routine maintenance name	POSMNM	String	
Labour hour	POSMLB	Hours	POSMTDM (Total Direct Maintenance Cost due to Scheduled Maintenance at Post-mod status), POSMTDT (Total Down Time due to Scheduled Maintenance at Post-mod status)
Material cost	POSMMT	USD	
Downtime	POSMDT	Hours	
Annual frequency	POSMNR	Times/year	
Non-routine maintenance name	PONMNM	String	PONMTDM (similar, for Non-routine Maintenance)
Labour hour	PONMLB	Hours	
Material cost	PONMMT	USD	PONMTDT (similar, for Non-routine Maintenance)
Downtime	PONMDT	Hours	
Annual frequency	PONMNR	Times/year	
Unscheduled maintenance name	POUMNM	String	POUMTDM (similar, for Unscheduled Maintenance)
Labour hour	POUMLB	Hours	
Material cost	POUMMT	USD	POUMTDT (similar, for Unscheduled Maintenance)
Downtime	POUMDT	Hours	
Number of removal in the evaluation period (LC)	POUMNR	Times/year	

Chapter 4

TO-BE Situation of Aircraft Modifications

This chapter describes the TO-BE situation of the Aircraft Modifications process, where the use of the LCC-MODS model is a part of. This chapter begins with analyses of the AS-IS situation and then it is followed with a description on the proposed LCC-MODS Form. Each category of modification initiatives is then discussed, including the proposed cost analysis route. A logic for evaluation of modifications is added, together with the cost monitoring sub-process. This chapter is closed with discussion of the sources of the required data input to implement the TO-BE situation, as well as the organisational issues.

4.1 Analysis of the AS-IS Situations

This section analyses the observations presented in Chapter 2. These analysis lead to recommendations for the TO-BE situation of the Aircraft Modification process. The observations are analysed according the subject being concerned. The TO-BE situation itself is discussed in the next sections.

Table 4.1 shows the subjects being concerned which are collected from the observations in Chapter 2. There are five subjects being concerned, i.e. the approval criteria of modification proposals, the evaluation process, the data available, the tool for evaluation and the logic of analysis. The point of concerns are indicated in the second column of Table 4.1. The third column indicates in which observation number, in Chapter 2, the point of concerns are discussed. The following will analyse each of the point of concern.

4.1.1 Approval criteria

A modification proposal will be approved for implementation when it is mandatory and close to the due date, it may have a safety impact, it is an alert item, it is a request from the Operations or Commercial function, or if the modification kit is free of charge. It means

Table 4.1 Grouping of the observations

Subject	Point of concerns	Observation (Chapt. 2)
Approval criteria	Implementation of MB's due to cost savings is very limited	1, 2, 5, 11
Evaluation process	Incoming bulletins are not checked for potential cost savings and performance improvement	4, 11
	Aircraft Reliability unit is supposed to perform initial analysis of alert items	9
Data	Data recorded on PIREPS and MAREPS is not complete	3
	Realisation of the material and man-hours during production for Mod are not well reported	6
	Performance improvement and cost savings are not tracked	7, 9, 13
	SB/SL does not provide sufficient information on reliability improvement estimate and cost savings	9
Tool	EES is more an administrative medium than economic evaluation	8
Logic	Corrective Action Decision diagram is too maintenance task oriented	14

that a modification proposal will be approved if it is safety related and urgent matter, or if it is free of charge. The conclusion can be drawn is that *the implementation of aircraft modifications due to total cost savings is very limited*. This is due to modification budget or engineering staff shortage. With respect to Service Bulletins, there is not sufficient information (on cost savings and reliability improvements) to judge the SB's, especially information supplied by the SB's themselves. *This situation can be improved by a proper evaluation of the implemented modifications (demonstration process) through the use of the proposed LCC-MODS Form.* So far, operators have to collect the required data/information themselves.

Due to the applied criteria of approval above, the role of the Modification Committee (ModCom) becomes very limited.

4.1.2 Evaluation Process

In-coming bulletins are not checked for potential cost savings and performance improvement

As described in the Observation 11 of section 2.6 concerning Manufacturer Bulletins, the AS-IS situation does not comply to the Technical Procedure and Manual, where the section

of Technical Publication Services should perform preliminary evaluation to the incoming SB's. What currently is done, is only to check the effectivity of the SB's (Observation 4).

In the current 'rotation' of engineers, several experienced (senior) engineers are placed at the Configuration and Change Management section (CCM), where the initial evaluation of the incoming SB's is assigned to this section. It may include seeking information from experience of other operators or the use of the World Fleet Average (WFA) to identify potential problems (proactive approach). However, an evaluation diagram to judge whether an MB will be implemented is necessary to provide a standardised logic. The lack of such diagram can be the reason of the reluctant to make preliminary evaluation of the in-coming bulletins. The evaluation diagram of Fig. 4.5 is proposed to fulfil this lack. Explanation of Fig. 4.5 is presented in sub-section 4.3.2. Manufacturer Bulletins Evaluation diagram.

Based on the analysis above, *recommendations for improvement of the process of aircraft modifications due to Manufacturer Bulletins are following* (see also Fig. 4.3).

a. make an initial assessment on LCC savings if the MB's is implemented, before detailed analysis by the Aircraft Engineering unit is conducted. This initial assessment is made by the Configuration and Change Management (CCM) section. The output is cost-effective MB's in the form of *LCC-OPS savings target*
b. use Fig. 4.5 as a MB's Evaluation diagram
c. make a list of performance (reliability) and cost driver problems (sub-section 4.3.3) to support the use of MB's Evaluation diagram
d. use the proposed LCC-MODS Form (see Fig. 4a and b) to record the *estimated LCC-OPS savings* and performance improvements (by the CCM), as well as the verification (by the Aircraft Engineering unit) and demonstration (by Production, Operation and Maintenance)
e. *verify (technical feasibility) the targeted LCC-OPS savings and performance improvement* before the Engineering Orders from the MB's are implemented
f. establish a "Cost Database" systems to collect cost data for cost monitoring and cost prediction
g. approval from the Modification Committee is still required to check whether the projected performance improvement and LCC-OPS savings are realistic. For this reason the Modification Committee should comprise of, at least, the following persons:
    - head of the Aircraft Engineering unit, for authorisation
    - manager of the Reliability Management section, for reliability verification
    - manager of the Configuration Change and Control Management, for configuration and cost verification
    - manager of relevant section of the Aircraft Engineering, for technical judgement

The previously described process contains only the *target establishment and technical verification (see also Observation 3). The demonstration sub-process need to be added to follow the structured evaluation process* shown in Table 1.3. The demonstration sub-process includes evaluation of the implementation cost (material, man-hours and downtime), the operation cost savings and performance (reliability) against the projected ones. The LCC-MODS Form provides the facility to record these demonstrations.

The AS-IS situation of the demonstration sub-process is as follows.

Realisation of the material and man-hours during implementation of modifications are not well reported.

Based on Observation 7, the material and man-hours used for the modification are recorded. However, information of the used material and man-hours is not evaluated against the projected costs mentioned in the EES form.

A database record on realised material and man-hours for modifications will be useful for making an estimate/projection of the required man-hours and material of the next modifications. The record is already available, but the accessability for Reliability Engineering Unit so far does not exits.

Performance improvement and cost savings are not tracked

Based on Observation 7, the assessment of every EO, on the effectiveness in reducing cost and/or improving performance, has not been done yet. However, in the Technical Procedure and Manual (TPM), it is supposed to be carried out. This is due to a high workload of the engineers. *The recommendation is to follow the TPM, not only to re-analyse the unsolved problem of EO's*.

Long term evaluation on (potential) cost savings of the implemented and unimplemented manufacturer/vendor bulletins need to be done, to evaluate how far the airline has followed the manufacturer suggestions and the total cost savings has been achieved. This is to measure the effectiveness of the bulletins in solving the problems and to estimate potential cost savings.

Reliability Engineering unit is supposed to perform initial analysis on alert items

The Reliability Control Program (RCP) Manual of Garuda mentions that the Reliability Management section makes an initial investigation (analysis) of the root causes of deviations from the standards, in liaison with the Aircraft Engineering unit [Garuda RCP Manual, 1997]. *In practice, this is not done, all analysis are conducted by the Aircraft Engineering unit* (see Observation 9 in sub-section 2.5.1 of Chapter 2). If this is done properly, the initial analysis can lead to work load reduction of the Aircraft Engineering unit. So far, only 50% of the Reliability Action Requests are closed[16] and the rest led to Follow-On Reports [Engineering Review Committee Meeting, July 27, 1998]. It means that *an improvement on the actual process needs to be made*. *Being consistent with the procedure described in the RCP Manual is recommended to solve this problem*. However, lack of expertise to perform these initial investigations was an obstacle being faced by the existing organisation of Garuda, during the period of observation.

[16] A closed Action Request means the request has been completed and the problem identified is solved. If the problem still persists or any further action need to be conducted, a follow-on report will be issued.

4.1.3 Data

Data recorded on PIREPS and MAREPS is not complete

As described in *Observation 3* of section 2.3.1, the detail of the data is hardly sufficient to make root cause analysis. *It is recommended to improve the form for data recording of PIREPS and MAREPS and additional training for the mechanics on data recording*. The data must support also the estimation of LCC-OPS savings, as it will be discussed in section 4.4.

SB/SL does not provide sufficient information on reliability estimate and cost savings

Observation 10 indicates that information from manufacturer/vendor bulletins is frequently not sufficient in order to make decisions to implement proposed modifications. Information like estimated improved MTBF, implementation cost and projected savings are rarely shown in such bulletins. *To make SB's more interesting, the manufacturers have to indicate the required data to make estimate of reliability improvements and operating cost savings.*

4.1.4 Tool

EES is more as administrative medium than economic evaluation

Observation 8 indicates that the existing EES form is used more as an administrative record than a medium for economic evaluation. However, to make a detailed analysis of the modification initiatives, a supporting tool is required. EES solely is too limited.

Based on the *Observation 8*, there are three subjects which need to be considered, i.e.:
a. economical evaluation method
b. tool supporting the evaluation
c. a form to report and record the results of the modification, both of the projection and realisation (demonstration) of costs and performance (reliability).

As discussed in Chapter 1, LCC is selected as the economical evaluation method. Comparison between various economic evaluation methods is discussed in Appendix E. The LCC-MODS model is developed as a tool to support the evaluation of proposed modifications and to provide the required form for reporting and recording. This form, as well as the LCC-MODS model, makes the process of target establishment, verification and demonstration easier.

The LCC-MODS model takes into account aircraft downtime due to modification and maintenance, both scheduled and unscheduled, as an opportunity revenue. Of course, the changes of direct modification and direct maintenance costs are included as well, i.e. the labour and material.

There are various ways to estimate the delay and cancellation cost, nevertheless, it must be a function of aircraft size. LCC-MODS uses the method of delay and cancellation cost per minute per aircraft type, multiplied by the duration of the delay. Cancellation cost is assumed to be equal to a 24 hour delay. The delay and cancellation cost per minute per aircraft type or

per seat can be derived from the total annual cost of delays and cancellations for a particular aircraft type divided by the total duration of delays and number of cancellations for the related year.

Any modification has impact to aircraft performance and operating costs, including maintenance cost. The LCC-MODS model is designed so that the changes of aircraft performance which increase opportunity revenue and reduce operating costs, are quantified. This covers the changes of aircraft availability, fuel burn reduction and the direct maintenance costs. It must be noted that the changes of fuel burn due to weight changes is a function aircraft type (Maximum Take Off Weight, MTOW).

4.1.5 Logic of analysis

Concerning the Logic of Analysis discussed in section 2.9, Observation 14 indicates that the logic shown in Fig. 2.10 is more appropriate for maintenance task evaluation, assuming the failure mode has been identified. This is because the priority to revise maintenance tasks is above accomplishment of modifications. Recommendations are *improvement of the existing Corrective Action Decision diagram* (see Fig. 4.4) to include cost considerations and application of the LCC-MODS model for the identified problems. Sub-section 4.3.1 discusses this subject in more detail.

4.2 The LCC-MODS Form

The use the proposed LCC-MODS Form (shown in Fig. 3.4) is recommended, as stated in sub-section 4.1.2, to record the *estimated LCC-OPS savings* and performance improvements (by the CCM), as well as the verification and demonstration. Based on the discussion in section 4.1 above, the specifications of the LCC-MODS form are followings.

a. It needs to show the economical assessment of the bulletin/directive by the engineer (not what is mentioned in the bulletin) and contains a summary of the effectiveness evaluation of the modification. Modification is effective when the targeted performance (reliability) improvement and cost savings are achieved.

b. It needs to support the implementation of the three phases of the modification process described in section 1.1.2, i.e. target establishment, verification and demonstration.

c. The projected performance (reliability) improvement, cost savings and implementation costs need to put side by side with the realised ones, for easy comparison. A separate Effectiveness Report form is not required anymore.

d. It supports long term evaluation by obtaining:
   - an indication of the savings to be expected by implementing the bulletins (AD, SB, SL, etc.) after a long term

- an indication of the productivity of the engineers in terms of the number of SB's or Alert Notice's evaluated annually and the effectiveness of the corrective actions. A corrective action is effective when the problem indicated does not happen again

- an indication of the productivity of production (line and hangar maintenance) by analysing the required time to modify as compared to the estimate mentioned in SB's or experience of other operators

- a tracking facility on the impact of modification to aircraft performance (reliability).

e. Conclusions and recommendations from the Reliability Management section for the subject of modification might be necessary as a 'lesson learned' for the next analysis by engineers and evaluation by managers on similar cases.

4.3 TO-BE Process of Aircraft Modifications

Figure 4.1 shows the proposed TO-BE situation of the modification process (see Fig. 2.3 for the AS-IS situation). Based on the analysis of the AS-IS situation in sub-section 4.1.2 above, recommended changes of the Modification process are following, where *only necessary sub-processes are discussed.*

i. The proposed TO-BE Modification process contains the sub-processes of target establishment, engineering verification and demonstration, which are indicated by dashed boxes in Fig. 4.1. This is an implementation of the strategy described in section 1.1.2 of Chapter 1. The lower processes within those sub-processes are following (see Fig. 4.1):
    a. *Target establishment* consists of activity boxes of Monitoring and Evaluate Aircraft Reliability (M1), Monitoring and Evaluate Operation and Maintenance Costs (M2), Evaluate Manufacturer's Bulletins (M3), and Develop Engineering Change Request (M4)
    b. *Engineering verification* consists of activity boxes of Perform Engineering Analysis (M5) and Check Engineering Order on LCC-OPS Savings (M6)
    c. *Demonstration* consists of activity boxes of Implement Changes and Operate Aircraft (M7), which is considered as one activity box, and Evaluate Demonstrated Performance and Costs (M8)

ii. All type of modification initiatives are *accompanied with a completed LCC-MODS Form* (see Fig. 3.4), as a result of the LCC-MODS model application. The required information for application of the LCC-MODS model is discussed in section 4.4

iii. Monitor and Evaluate Aircraft Reliability (M1): *The Reliability Management section has to perform an initial investigation on root causes for the Alert Notices*, before sending them to the Aircraft Engineering unit, assuming that the Reliability Management section has sufficient information. This is to reduce the work load of the Aircraft Engineering unit by a better specified Reliability Action Request (problem definition). *By using the LCC-*

MODS model (discussed in Chapter 3), *prevented or eliminated failures modes will be quantified in LCC-OPS savings.* Figure 4.2 describes one level lower of activity box M1 (the alert type and non-alert type analysis), where the Reliability Improvement Decision Diagram is applied in the activity box M1-3

iv. *Monitor and Evaluate Operation and Maintenance Costs* (M2): is a new activity box introduced to include cost consideration for maintenance, as discovered in references [Copeland, B., 1995; Cribes, T.D., 1996; File, W.T., 1991; Wireman, T., 1986] of Chapter 1. This activity will monitor and evaluate the cost of aircraft operation and maintenance (see also Fig. 4.2). Co-ordination with the Operations Directorate will be necessary. Methods and standards need to be established to indicate cost alerts and trends. Items resulting from cost alert or up-trend need to be investigated, where the proposed *Cost Engineering section* will issue a *Cost Action Request* for this purpose. *By using the LCC-MODS model, prevented or eliminated cost drivers will be quantified in LCC-OPS savings.* This initiative of modification is categorised as Internal Engineering. Sub-section 4.3.3 will discuss this monitoring and evaluation into more detail

v. Evaluate Manufacturer Bulletins (including AD Notes) (M3): *Configuration Change Management section* will assess all incoming bulletins from the manufacturers and regulatory authorities, and *use the Manufacturer Bulletins Evaluation Diagram (Fig. 4.5) and the LCC-MODS model to assess LCC-OPS savings* (discussed in Chapter 3). Figure 4.3 describes M3 in one level lower. Cost-effective bulletins will be forwarded to the Aircraft Engineering unit for development of Engineering Orders. Not-cost-effective bulletins will be sent to the Technical Publication section for documentation (not shown in Fig. 4.1, but in Fig. 4.3). These not-cost-effective bulletins will be used later when new problems arise in the future, which are normally identified through the Reliability Program. Initial engineering analysis can be done also by the Workshop Production Engineering section, especially for component modifications. However, approval by the Engineering unit is still required

vi. Develop ECR (M4): *The Modification Committee* will participate actively in the development of Engineering Change Requests (ECR's), by providing information to *establish the target of LCC-OPS savings and performance improvements*

vii. *Check EO on LCC-OPS Savings* (M6): *The Modification Committee* will check the cost-effectiveness of the modification proposal or alternatives, i.e. performance (reliability) improvement and LCC-OPS savings of the Engineering Order for modification

viii. Implement Changes, Operate Aircraft (M7): No changes from the AS-IS situation

ix. *Evaluate the Demonstrated Performance and Costs* (M8): Implementation of the modification proposal will be recorded by relevant units (Maintenance Production, Line Maintenance or Operations) where the data is forwarded to the Reliability Management and Cost Management sections. *The Configuration Change Management section* will collect relevant reports of these two sections, *to evaluate whether the demonstrated modification is effective* (conform to the result of engineering verification). This evaluation of modifications includes the cost of labour, material and down time during production (hangar), and the savings during operation and maintenance. The period of

demonstration can be determined based on the estimated time to failure of the modified item or based on the results of the first inspection of the modified item.

There are three decision diagrams used for the TO-BE situation, i.e.: the Reliability Improvement Decision Diagram, the Manufacturer Bulletins Evaluation Diagram and the Cost Evaluation Decision Diagram. The Reliability Improvement Decision Diagram is used in the Alert Type Analysis route (see Fig. 4.2) and intended to replace the Corrective Action Decision Diagram in the AS-IS situation. The Manufacturer Bulletins Evaluation Diagram is used to evaluate the in-coming Manufacturer Bulletins (see Fig. 4.3). The Cost Evaluation Decision Diagram is used in the Cost Analysis route (see Fig. 4.2).

4.3.1 Reliability Improvement Decision Diagram

As discussed in sub-section 4.1.5 the Corrective Action Decision diagram need to be revised to include cost considerations and application of the LCC-MODS model for the identified problems. The following discuses the proposed decision diagram.

As mentioned in *Observation 14* about the Corrective Action Decision Diagram shown in Fig. 2.10 of Chapter 2, the diagram is more focused on maintenance task evaluation. A more *general* decision diagram is preferable. This decision diagram should evaluate corrective action alternatives[17] (maintenance tasks revision or modification) *based on cost-effectiveness, without first looking at the type of the corrective action* (maintenance tasks revision or modification). It can be seen explicitly in the Corrective Action Decision diagram that the priorities are (from high to low): nil action, maintenance tasks revision and then modification. However, the proposed decision diagram requires more information than the existing one. The proposed decision diagram (Fig. 4.4) is called *Reliability Improvement Decision Diagram*, due to its focus to improve aircraft reliability and (reduce) cost.

The proposed Reliability Improvement Decision diagram is an improvement of the Corrective Action Decision diagram shown in Fig. 2.10. Evaluation begins on the condition of the item: "1. Does the data indicate a significant reduction in failure resistance? ". This question addresses the dominant failure mode of the item. When there is NO significant reduction of failure resistance, it will lead to "Nil Action" (C1).

Condition degradation can be significant to the airworthiness of aircraft. Therefore, if there is a significant reduction of failure resistance (Yes answer), then the next question is "2. Is reduced failure resistance of airworthiness significance?". A "Yes" answer for this question requires to restore failure resistance, no matter how much it costs. However, information on the relationship between age and reliability will support selecting of an appropriate (provides the highest LCC-OPS savings) corrective action. Therefore the question posed is "3. Is there an adverse relationship between age and reliability?". A "Yes" answer leads to evaluation whether the maintenance tasks revision or/and modification provides LCC-OPS savings, with question "4. Can revision of maintenance tasks or/and modification provide LCC-OPS savings?". A "Yes" answer leads to a selection on the highest LCC-OPS savings between

[17] In the earlier discussions, any corrective action is referred to modifications. Here modifications are divided into maintenance task/interval revision and hardware modification to see the most beneficial (cost-effective).

these two alternatives. A "No" answer of Question 4 leads to the advise to look for applicable Service Bulletins or to consult the manufacturer or vendor.

When the answer of question 3 is "No", then the maintenance tasks revision or modification has to be able to restore failure resistance, otherwise a consultation to the manufacturer or vendor is necessary. In case the reduction of failure resistance is not of airworthiness significance (the answer of question 2 is "No"), then it needs to be checked whether revision of the maintenance tasks or modification can reduce LCC or improve cost-effectiveness (Question 4). A "Yes" answer will require selection of the alternative which provides the highest LCC reduction or is most cost-effective. A "No" answer for Question 4 leads to the advise to consult the manufacturer or vendor.

Maintenance tasks revision or modification is necessary for the following conditions:
a. maintenance tasks revision or modification can restore failure resistance for reduction of failure resistance which affects airworthiness, but there is no adverse relationship between age and reliability.
b. there is a significant reduction of failure resistance which affects airworthiness, there is an adverse relationship between age and reliability and revision of maintenance tasks or modification provides LCC-OPS savings.
c. reduction of failure resistance doesn't affect airworthiness, but maintenance tasks revision or modification provides LCC-OPS savings.

Application of the LCC-MODS model in the Reliability Improvement Decision Diagram is relevant to answer the questions of 4 and 6 of the diagram. The results of evaluation are recorded in the LCC-MODS Form.

4.3.2 Manufacturer Bulletins Evaluation Diagram

The Manufacturer Bulletins Evaluation diagram (Fig. 4.5) is applied after the initial assessment of the incoming MB's using the LCC-MODS model (see sub-section 4.3 point v). The diagram is aimed to support the decision whether the MB's will be analysed in more detail by Aircraft Engineering (or other relevant units), or it will be documented for solving future problems. This decision is considered important due to the significant effort required to perform such detailed engineering analysis, assuming it can be done with available data, as well as the required labour and material cost for implementation. The decision diagram provides a kind of 'priority level' of the incoming MB's.

During application of this diagram, information on 'pending' problems is very essential. These problems are initially identified by the performance (reliability) monitoring and evaluation (in the AS-IS and TO-BE situations) or cost monitoring and evaluation (in the TO-BE situation). Initial estimation of the LCC-OPS savings and performance (reliability) improvement gained by the MB's implementation will provide information on the cost-effectiveness of the MB's. In this evaluation diagram, performance means functional performance of the aircraft, e.g. rate of climb, take off landing characteristics, lift-drag characteristics, etc. This functional performance may have relationship with operating cost, especially fuel consumption.

Question 1 concerns the effectivity of the MB for the existing fleet of the operator described in the MB's. When the MB is not effective, the MB will be filed in the documentation. But, when the MB is effective, completion of the LCC-MODS Form is required and will be conducted by the Configuration Change Management (CCM) section, supported by the Reliability Management section for reliability information and the Cost Management section for cost information.

After the LCC-MODS form is completed, the next question posed is "2. Is the MB a solution for an existing performance (reliability) problem?". The MB may be the solution for a problem which has not been solved for some time (pending). Therefore the CCM section needs to check the list of pending problems (follow-on report). The MB accompanied with the completed LCC-MODS form will be forwarded to the Aircraft Engineering unit, if it is a solution for the existing 'pending' problem. Performance (reliability) problems are identified by a "Yes" answer for Question 4 of Fig. 4.5.

When the MB is not a solution for a performance (reliability) problem, then the next question is "3. Is the MB a solution for existing Operation and Maintenance (O&M) cost problem?". O&M cost problems are identified in the Cost Monitoring and Evaluation, conducted by the Cost Management section (see section 4.3.3). Significant increase of O&M costs (a "Yes" answer for Question 1 of Fig. 4.5) due to cost drivers requires a serious investigation, because the impact to the total O&M costs is significant. The MB will be forwarded to the Aircraft Engineering unit when it solves the O&M cost problem. The Aircraft Engineering will make an engineering analysis and prepare an Engineering Order (EO).

If the MB is not a solution for a performance (reliability) problem **nor** a Cost Driver problem, then a check of LCC reduction is conducted through question "4. Does LCC-MODS Form show significant LCC-OPS savings?". The MB need to be forwarded to the Aircraft Engineering unit when the answer is "Yes". This is for engineering verification and EO development. Otherwise, it will be filed for documentation.

4.3.3 Cost Analysis route

This sub-section specifically discusses the proposed TO-BE situation of the Cost Analysis route. In the AS-IS situation this route does not exist. The idea of the Cost Analysis route is taken from the Alert type analysis method, where it records, evaluate and analyse operation and maintenance cost data. The method incorporates (statistical) costs standards, to measure current operation and maintenance costs of an item. The evaluation applies three criteria, i.e.: alert exceedance, up-trend or high cost. Alert level can be calculated every six months, based on 12 months previous data. Trend analysis is based on the moving average method, where the period of average depends on the needs of analysis (three or six months). The high cost level is determined by using World Fleet Average data, as far as available, or benchmarking with 'colleague' operators.

As shown in Fig. 4.2, the process of the Cost Analysis route begins with recording the operation and maintenance cost data, reporting and evaluation of aircraft operation and maintenance cost, continued by *investigation of the identified problems*. The next activities

are to find a solution of the identified problems through engineering analysis or selecting a relevant SB/SL and then to develop of an Engineering Order (EO) when a solution is discovered, or to issue of follow-on report when the problem is not solved. Further detail of the process of Cost Analysis route is following.

a. Record Operations and Maintenance Cost data (M2-1)

The activity of this box is to record operations cost (especially fuel), maintenance cost (labour and material, spares, engineering, etc.) and maintenance dependent cost (delay and cancellation costs). Input of this activity is cost data from aircraft operations, the time and material required to rectify delays and cancellations, Pilot Reports and Maintenance Reports, Findings and Component (LRU's) removals and repairs.

The output of this activity is a database for evaluation of aircraft operations and maintenance costs (see Fig. 3.1 and Table 3.1 of Chapter 3). The Aircraft Operations and Maintenance Record section is responsible for collecting and entering the data into the computer systems.

b. Evaluate aircraft operation and maintenance costs (M2-2)

The activity of this box is to perform statistical evaluations whether the operation and maintenance costs of the aircraft, systems (ATA two digits) or components (part number) are within specified levels. Monthly as well as quarterly reports must be issued as a result of this evaluation. In the monthly operation and maintenance costs report, graphical presentation of aircraft and systems operation and maintenance costs are given. For components, report on Top 20 highest cost contributors (cost drivers) will be relevant. High costs resulting from major C and D checks can be evaluated by using event driven cost evaluation. The input of this activity is data gathered from the operation and maintenance costs database, as an output of the previous activity.

The output of this activity is a Cost Alert Notice which indicates that a problem exists, in the form of exceedance of a cost alert level, an up-trend or a high rate. This activity is carried out by the Cost Management section. The controls are the statistical criteria of alert exceedances, upward trends or high costs (see sub-section 4.3.4 and Appendix C Maintenance Control by Reliability Methods).

c. Investigate the problem (initial analysis) (M2-3)

If evaluation of aircraft operation and maintenance costs indicates that a problem exists, in the form of exceedance of a cost alert level, an up-trend or a high rate, an investigation needs to be made to identify the modes of degradation and to discover the root causes. The Cost Management section (in charge) will carry out this task with support of relevant Aircraft Engineering sections. The output of this activity is a Cost Action Request accompanied with a LCC-MODS Form as an initial estimate of the cost savings which may be gained by solving the discovered problem. The Cost Evaluation Decision Diagram shown in Figure 4.6 is used for this investigation to identify in which category the problem falls under.

There are four (4) categories where the problem can fall under. When the answer of question "1. Does the data indicate a significant increase of operation and maintenance costs?" in Fig. 4.6 is 'No' (fall under category C1 Nil Action) , then the Cost Management section will consider the Cost Alert Notice is closed, and it will be documented. Otherwise, it goes to question 2 and the next questions, until the category has been determined. Discussion on the Cost Evaluation Decision Diagram is given in sub-section 4.3.4.

If the Cost Engineering section is unable to determine a proper improvement action, the Cost Alert Notice will be sent to the Aircraft Engineering unit by using the Cost Action Request form, accompanied with a completed LCC-MODS Form. The format of the existing Reliability Action Request form can be used, because the essence of this request is put on the LCC-MODS Form.

d. Perform Engineering analysis (M5)

This activity box is to analyse the Cost Alert Action Request (Alert Exceedance, up-trend or high cost) to find out the cause of the problem. Relevant specialists of Aircraft Engineering will conduct a detailed technical investigation to determine the proper corrective action for the problem and issue an Engineering Order or Engineering Information. Treatment of the Cost Alert Notice is similar to Reliability Action Request, therefore it can refer to the discussion of "Perform Engineering analysis (M4)" of sub-section 2.3.4. When the problem is pending, e.g. due to incompleteness (unavailability) of information, a Follow-On Report will be issued.

4.3.4 Cost Evaluation Decision Diagram and Cost Monitoring

In order to implement the LCC concept, in other words to apply the LCC-MODS model, cost monitoring at various aircraft system levels must be conducted to provide aircraft operation and maintenance cost information. This information will be used to judge any modification initiative and for demonstration of implemented modifications. Cost information itself is a subject to be investigated for reducing aircraft LCC. Standards for cost evaluation must be established to indicate cost alerts and trend analysis. Identification of cost drivers and finally a root cause analysis must be made to develop corrective action.

This sub-section discusses the proposed Cost Evaluation Decision diagram which is applied for O&M costs evaluation and initial investigation and the method of cost monitoring. The proposed Cost Evaluation Decision diagram, shown in Fig. 4.6, is derived from the proposed Reliability Improvement Decision diagram shown in Fig. 4.4. The cost monitoring method is derived from the Pareto analysis, which is used for monitoring and evaluation of maintenance cost, as it can be found in reference [Duffuaa, S.O., 1999] of this chapter. As mentioned in sub-section 4.3.3, this method uses the idea of Alert Type Analysis of Reliability Program.

a. Cost Monitoring and Evaluation

The objective of cost monitoring and evaluation is to provide control over the O&M costs, so that they are kept within an 'acceptable' range. The degree of acceptability depends on the

company policies. When deviations are noticed, an analysis must be conducted. Cost monitoring and evaluation is applied to reduce the total maintenance cost through cost drivers identification. As it is mentioned earlier, there are three areas of cost monitoring:

- alert level exceedance, where the (upper) alert level is established by using previous operations and maintenance cost data
- cost trend analysis by using the moving average method
- cost drivers identification of an item or a cost centre, Activity Based Costing.

Alert level exceedance:

The aim of alert level exceedance monitoring is to identify whether the O&M cost is significantly exceeding the 'normal' value. If an exceedance is indicated, analysis should be performed at lower levels. The normal value is determined statistically based on the previous O&M costs data by using the alert level (control limits) method. The method of alert level determination is similar to the reliability monitoring and evaluation (see also Appendix C: Maintenance Control by Reliability Methods), i.e.:

Upper control limit, UCL = $\bar{X} + 3\frac{\sigma}{\sqrt{n}}$

where: $\bar{X}$ = mean (average) of the sample
σ = standard deviation
n = sample size, normally the latest 12 months data

It is recommended to apply a stepwise approach where in the beginning the O&M costs is assigned to ATA two digits (XX). Further analysis is required at least to four digits ATA (XXYY) and in the end to six digits ATA (XXYYZZ). The cost breakdown of the O&M costs at least consists of:

- energy cost (fuel consumption per flight hour, weight)
- direct maintenance cost: labour, material, spares, equipment and tools.
- maintenance dependent cost: delay and cancellation
- opportunity cost (downtime)

Estimation and reporting of these costs require information on the item specifications (e.g. weight, size, energy required), the reliability history (MTBF, MTBR, number of delays and cancellation per month), and the required time and material to conduct maintenance activities (scheduled and unscheduled).

Trend:

The well known method to evaluate trend is using the moving average method, but also other methods are used. This subject is discussed in Appendix C Maintenance Control by Reliability Methods.

Cost drivers identification:

The ABC analysis[18] is a useful method to determine cost drivers. The ABC analysis is based on the Pareto[19] law (the 20/80 rule), which states that the significant items in a group usually

[18] This is **not** Activity Based Costing.
[19] The name Pareto chart is derived from the Italian economist Vilferdo Pareto (1846-1923) who studied income distributions using this chart. Quality engineers use the chart to identify the causes of defects.

constitute only a small portion of the total number of items in that group. ABC analysis is performed by developing a Pareto chart. A Pareto chart is simply a frequency distribution of items or classes arranged by size. However, the standard procedure of the Pareto chart must be modified in order to identify items (sub-systems) or activities which make the highest contribution to the total cost. This is to avoid to much attention on items with a high frequency of failures but apparently has minor contribution to the total O&M costs.

The (modified) Pareto chart will indicate which item needs to be improved first in order to eliminate costly defects or reduce O&M costs effectively. The procedure of the (modified) Pareto chart is following:

- determine the period of evaluation, e.g. monthly, quarterly, etc.
- determine O&M costs (see alert level exceedance) assigned to each item
- sort the total O&M costs of each item in descending order
- plot item versus total O&M costs, starting with the largest O&M costs in the period and continuing in descending order.

A hypothetical example of a Pareto chart application for aircraft maintenance is shown in Fig. 4.7. The total O&M costs, in this example, is assigned to two digits ATA. The operating cost of the two digits ATA could be the power required and the fuel consumption due induced drag (weight related) or parasite drag (wetted area related). The more information available, the more detailed ATA numbers can be assigned. Items having the highest contribution to the total aircraft O&M costs must be monitored closely and if necessary investigations can be conducted to find out the root causes.

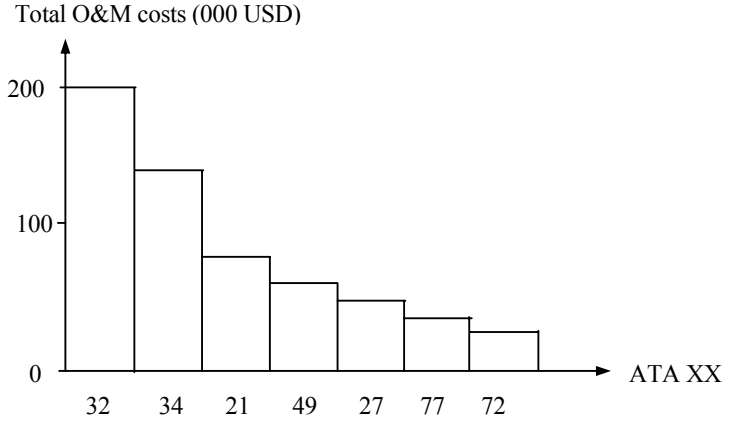


Fig. 4.7 Identification of cost drivers (Pareto chart, hypothetical)

b. Cost Evaluation Decision diagram

The proposed Cost Evaluation Decision Diagram for the TO-BE situation is shown in Fig. 4.6. The diagram begins question “1. Is the O&M data significantly increasing, showing high rate or up-trend?”. A “No” answer leads to “Nil action required”, called category 1. When the answer is “Yes”, it will be investigated further whether the failure significance of the causing item, with question “2. Is failure of the item of airworthiness significance?”. This question reminds the engineers that the revision of maintenance tasks or modification may require an

approval from the regulatory authority. A "Yes" answer to this question leads to investigation of the relationship between age and O&M costs, with question "3. Is there an adverse relationship between age and O&M costs?". If there is NO relationship, then it is recommended to consult the manufacturer or vendor (category 4), assuming that there is no SB/SL relevant for the identified problem (because it is airworthiness significance).

When there is an adverse relationship between age and O&M costs ("Yes" answer to 3), it will be checked with question "4. Can revision of maintenance tasks or/and modification provide LCC-OPS savings?". Available (relevant) SB/SL will be used to support answering this question. A "Yes" answer leads to selection whether to revise maintenance tasks or modify the item, with question "5. Does modification provide more LCC-OPS savings than maintenance tasks revision?". If revision of a maintenance tasks provides more LCC-OPS savings, then the revision of maintenance tasks will be incorporated (category 2). Otherwise, the modification will be accomplished (category 3).

When the failure of the causing item is NOT airworthiness significance (NO answer for question 3), then it will be checked with question "4. Can revision of maintenance tasks or/ and modification provide LCC-OPS savings?". A "No" answer leads to a recommendation to consult the manufacturer/vendor (category 4), while a 'Yes' answer leads to a question to select between revision of the maintenance tasks or modification. If revision of a maintenance tasks provides more LCC-OPS savings, then the revision of maintenance tasks will be incorporated (category 2). Otherwise, the modification will be accomplished (category 3).

4.4 Input Data Sources

The problems for application of the LCC-MODS model is the availability of data required for the analysis. The data available in Manufacturer Bulletins is not sufficient to perform analysis (see Table 4.1d). In order to make this data available, the manufacturer and vendor have to conduct reliability test on the components mentioned in their Manufacturer Bulletins. The problem of data un-availability becomes more complicated due to the large number of Manufacturer Bulletins which need to be evaluated. Therefore, evaluation of the in-coming Service Bulletins is costly in the sense of engineering man hours. In the future, the issued Manufacturer Bulletins must contain at least the 'minimum standard' data recording systems of aircraft operations and reliability, so that the analysis can be performed easily.

The main function of these recording systems to supply the required data for reporting systems. One of the 'standard' reporting systems is the Maintenance Control by Reliability Method, which is based on the AC120-17A, as discussed in Appendix C. This system helps to identify which reliability data need to be recorded (see Appendix C: Maintenance Control by Reliability Methods). A similar recording system can be applied for Operation and Maintenance costs recording and reporting.

Table 4.1 shows the sources of the required data for the LCC-MODS model for Aircraft Modifications. Because the data come from various sources, discussion on data input structure is not relevant, but refer to Table 3.1.

4.5 Organisation for the TO-BE Situation

The Modification Committee authorisation should be applied to all types of modifications, but so far, at GIA, it is limited to modifications resulting from AD Notes and Manufacturer Bulletins. Evaluation of modification initiatives by the Modification Committee should be conducted after the initiatives are economically and technically verified, i.e. after engineering analysis. Engineering Order influence on the LCC-OPS savings need to be checked, as stated in box M6 of the Fig. 4.1. The appropriate place for this is the Modification Committee.

As it has become clear in the observations, from each sub-section of Chapter 3, as well as later in the Maintenance Program Optimisation in Chapter 5, the role of cost consideration, at GIA, is very limited in the whole process. An improvement to rectify this lack is by introducing a new section called "Cost Management", i.e. a section in the Engineering unit which concerns on Operation and Maintenance costs related to aircraft reliability performance. The Cost Management section will collect all information concerning costs related to the performance of the aircraft. This covers the areas of:

- direct maintenance cost (labour, material) and downtime
- engineering man-hour required for analysis
- implementation costs of changes (hardware, maintenance program) and downtime
- weight to fuel cost relationships
- maintenance dependent cost (delay and cancellation cost)
- resale value
- material stock cost
- training cost
- test and repair cost

By the introduction of the Cost Management section, the activities of the unit of Engineering become to manage and change the aircraft configuration, as carried out by the section of Configuration Change Management, and to control the configuration of the aircraft by monitoring and evaluating aircraft reliability and cost, as carried out by the Reliability Management and the Cost Management sections. The name of Aircraft Reliability Engineering unit, in the AS-IS Situations, needs to be changed to become Aircraft Configuration Management. The proposed organisation for the Engineering unit is shown in Fig. 4.8.

Regarding LCC-MODS model, the following organisation elements are the main users the model:

a. Reliability Management section, for evaluation of potential LCC-OPS savings by reliability improvements
b. Cost Management section, for evaluation of potential LCC-OPS savings by Operation and Maintenance costs reduction

c. Configuration Change Management section, for evaluation of potential LCC-OPS savings due to incorporation of Manufacturer Bulletins (included AD Notes)
d. Modification Committee, for evaluation of LCC-OPS savings due to Engineering Change Requests by the Marketing or Operation functions.

Table 4.1a Source of the input of the LCC-MODS model (see also Table 3.1 and 3.2)

Input variable	Estimated cost component(s)	Source of information	Current availability* at GIA
ACTYP	None	Monthly Reliability report	Yes
NRAC	Total fleet LCC-OPS	Monthly Reliability report	Yes
FLDIS	Revenue	Operation data	Yes
BLHR	Downtime cost	Operation data	Yes
FLFRE	Revenue, downtime cost	Monthly Reliability report	Yes
NRPAX	Revenue, downtime cost	Operation data	Yes
LF	Revenue, downtime cost	Marketing data	Yes*
LABRT	Labour cost (mod.)	Finance data	Yes
ENGRT	Engineering cost	Finance data	Yes
FUPPG	Operating cost savings	Finance data	Yes
FUDEN	Operating cost savings	Finance data	Yes
INTRT	LCC-OPS profile	Finance data	No
RPK	Revenue, downtime cost	Marketing/WFA	Yes*
ANUTL	Revenue, downtime cost	Monthly Reliability report	Yes
FUCON	Fuel cost	Aircraft specifications/Operation data	Yes
OTFR	Oil cost	Aircraft specifications	Yes*
FTWF	Fuel cost reduction	Aircraft specifications	No
FTPF	Fuel cost reduction	Aircraft specifications	No
FTDF	Fuel cost reduction	Aircraft specifications	No
AVDEL	Maintenance dependent cost	Monthly Reliability report	Yes
DACC	Maintenance dependent cost	Finance report	Yes*
BEVAL	Depreciation, LCC-OPS	Input of analyst	Yes
EEVAL	Depreciation, LCC-OPS	Input of analyst	Yes

Current availability* = The data is currently ready for use, it is not a raw data from mechanics or flight crews.
Yes* = Currently available but limited and not well documented (the data must be collected).

Table 4.1b Source of the input of the LCC-MODS model (see also Table 3.1).

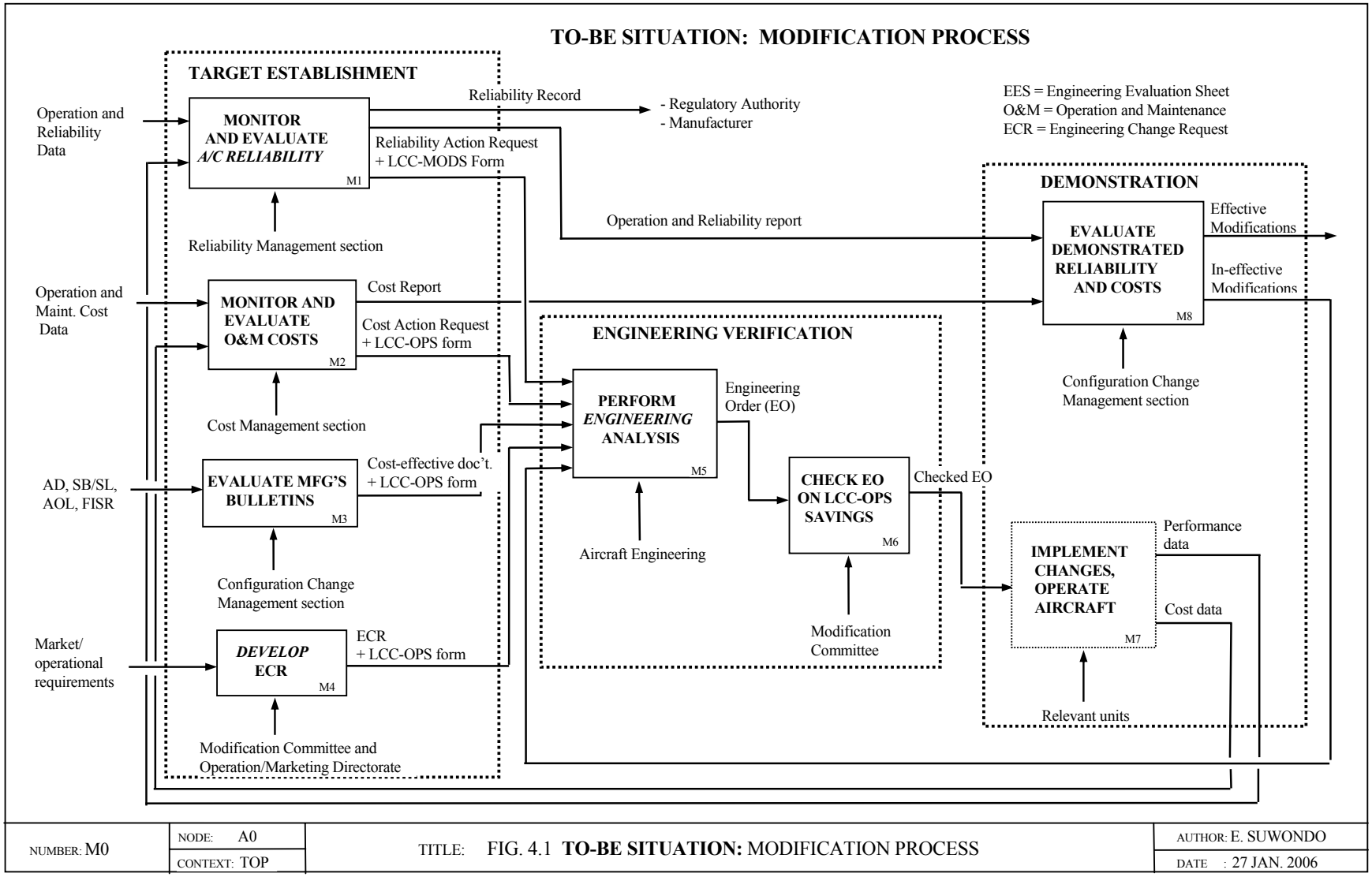
Input variable	Estimated cost component(s)	Source of information	Current availability
MODTTL	Modification attributes	SB	Yes
REFNR	Modification attributes	SB	Yes
REFDAT	Modification attributes	SB	Yes
ATANR	Modification attributes	SB	Yes
SUBATA	Modification attributes	SB	Yes
PARTNR	Modification attributes	SB	Yes
PRMK	Modification cost	Vendor price list	Yes*
NRMK	Modification cost	Aircraft specifications	Yes
ENGHR	Modification cost	Vendor estimate	Yes*
LABHR	Modification cost	SB or Vendor estimate	Yes
EXTDT	Modification cost	SB or Vendor estimate	Yes
NRATL	Modification cost	Vendor estimate	Yes*
PRATL	Modification cost	Vendor price list	Yes
MATOTH	Modification cost	Vendor estimate	Yes*
LABOTH	Modification cost	Vendor estimate	Yes*
DTOTH	Modification cost	Vendor estimate	Yes*
RSPCHG	Spares cost	Vendor estimate	No
SPAPR	Spares cost	Vendor price list	Yes
EWCHG	Fuel cost reduction	Vendor estimate	Yes*
PDCHG	Fuel cost reduction	Own estimate	No
PRCHG	Fuel cost reduction	Vendor data	Yes
FULCHG	Fuel cost reduction	Own estimate	Yes*
OCCHG	Oil cost reduction	Own estimate	No
CPYCHG	Opportunity revenue	Own estimate	Yes
BLHCHG	Opportunity revenue	Own estimate	No
ENVCHG	Depreciation cost reduction	Own estimate	No
OTHCHG	Other cost reduction	Own estimate	No

Table 4.1c Source of the input of the LCC-MODS model (see also Table 3.1)

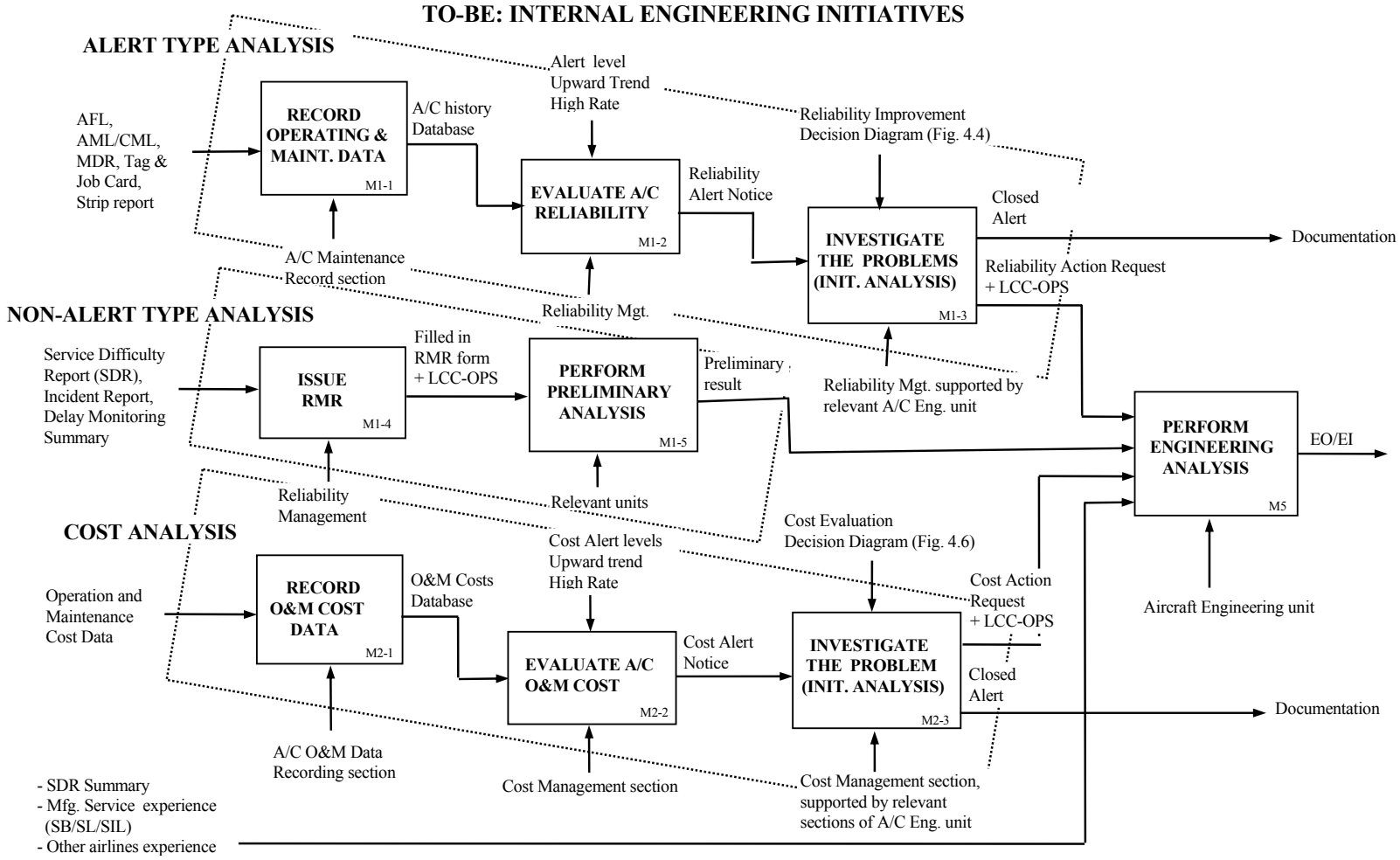
Input variable	Estimated cost component(s)	Source of information	Current availability at GIA
PRSMNM	Maintenance cost reduction, opportunity revenue.	Maintenance Program	Yes
PRSMLB		Job card accomplishment	Yes*
PRSMMT	PRSMTDM (Total Direct Maintenance Cost due to Scheduled Maintenance at Pre-mod status), PRSMTDT (Total Down Time due to Scheduled Maintenance at Pre-mod status)	Job card accomplishment	Yes
PRSMDT		Job card accomplishment	Yes
PRSMNR		Maintenance Program	Yes
PRNMNM	PRNMTDM (similar, for Non-routine Maintenance)	Maintenance Discrepancy Report	Yes
PRNMLB		Job card accomplishment	Yes*
PRNMMT	PRNMTDT (similar, for Non-routine Maintenance)	Job card accomplishment	Yes
PRNMDT		Job card accomplishment	Yes
PRNMNR		Maintenance Discrepancy Report	Yes
PRUMNM	PRUMTDM (similar, for Unscheduled Maintenance)	Maintenance Control Daily Report	Yes
PRUMLB		Job card accomplishment	Yes*
PRUMMT	PRUMTDT (similar, for Unscheduled Maintenance)	Job card accomplishment	Yes
PRUMDT		Job card accomplishment	Yes
PRUMNR		Maintenance Control Daily Report	Yes

Table 4.1d Source of the input of the LCC-MODS model (see also Table 3.1)

Input variable	Estimated cost component(s)	Source of information	Current availability
POSMNM	Maintenance cost reduction, opportunity	SB	No
POSMLB	revenue	SB	No
POSMMT	POSMTDM (Total Direct Maintenance Cost due	SB	No
POSMDT	to Scheduled Maintenance at Post-mod status),	SB	No
POSMNR	POSMTDT (Total Down Time due to Scheduled Maintenance at Post-mod status)	SB	No
PONMNM	PONMTDM (similar, for Non-routine	SB	No
PONMLB	Maintenance)	SB	No
PONMMT	PONMTDT (similar, for Non-routine	SB	No
PONMDT	Maintenance)	SB	No
PONMNR		SB	No
POUMNM	POUMTDM (similar, for Unscheduled	SB	No
POUMLB	Maintenance)	SB	No
POUMMT	POUMTDT (similar, for Unscheduled	SB	No
POUMDT	Maintenance)	SB	No
POUMNR		SB	No

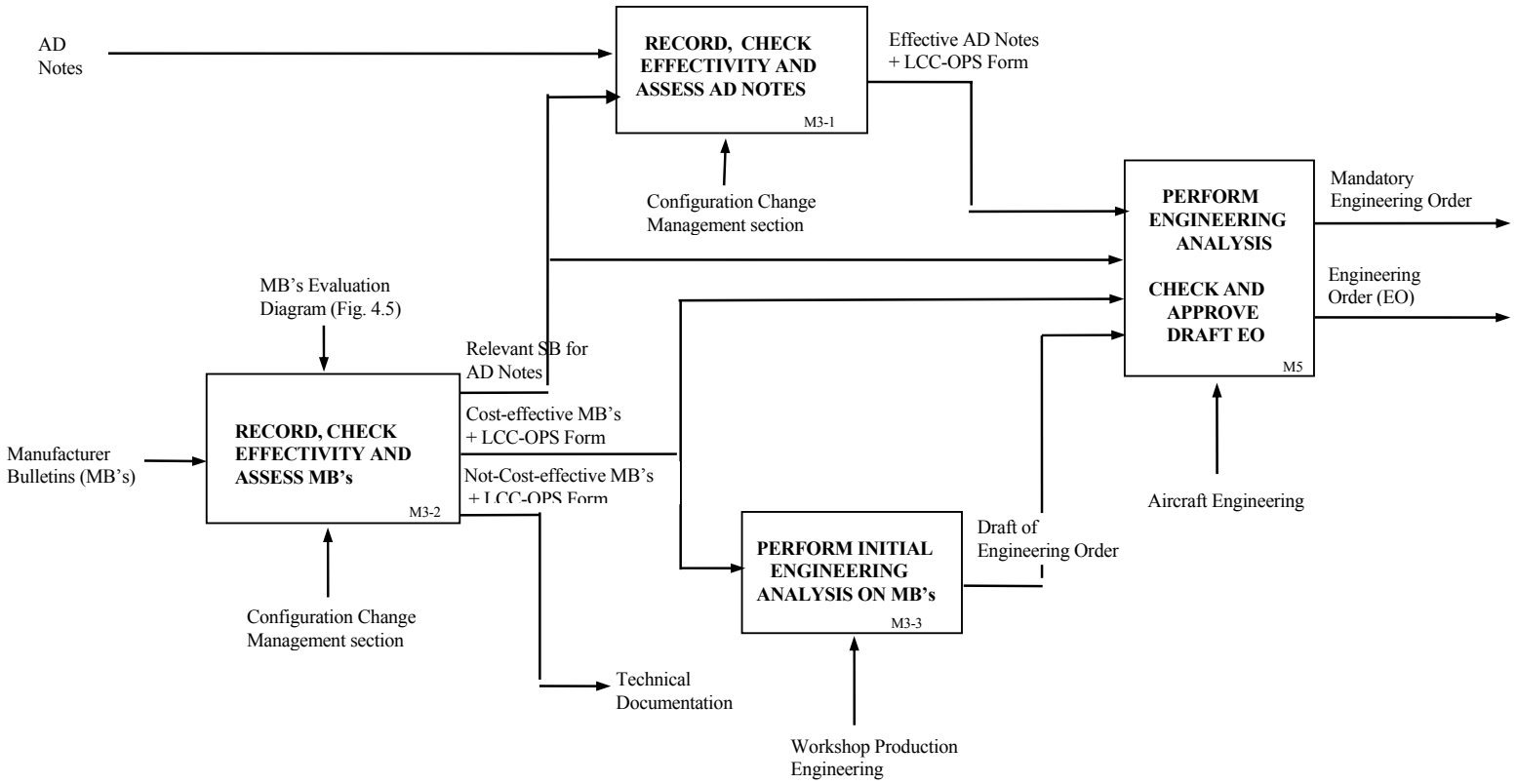


NUMBER: M0	NODE: A0 CONTEXT: TOP	TITLE: FIG. 4.1 **TO-BE SITUATION:** MODIFICATION PROCESS	AUTHOR: E. SUWONDO DATE : 27 JAN. 2006



NUMBER: M1-1	NODE: A1 CONTEXT: M0	TITLE: FIG. 4.2 **TO-BE**: INTERNAL ENGINEERING INITIATIVES	AUTHOR: E. SUWONDO DATE : 27 JAN. 2006

TO-BE SITUATIONS: AD NOTES AND MANUFACTURER BULLETINS EVALUATION PROCESS



NUMBER: M1-3	NODE: A1 CONTEXT: M0	TITLE: FIG. 4.3 **TO-BE:** EVALUATE MANUFACTURER BULLETINS	AUTHOR: E. SUWONDO DATE : 27 JAN. 2006

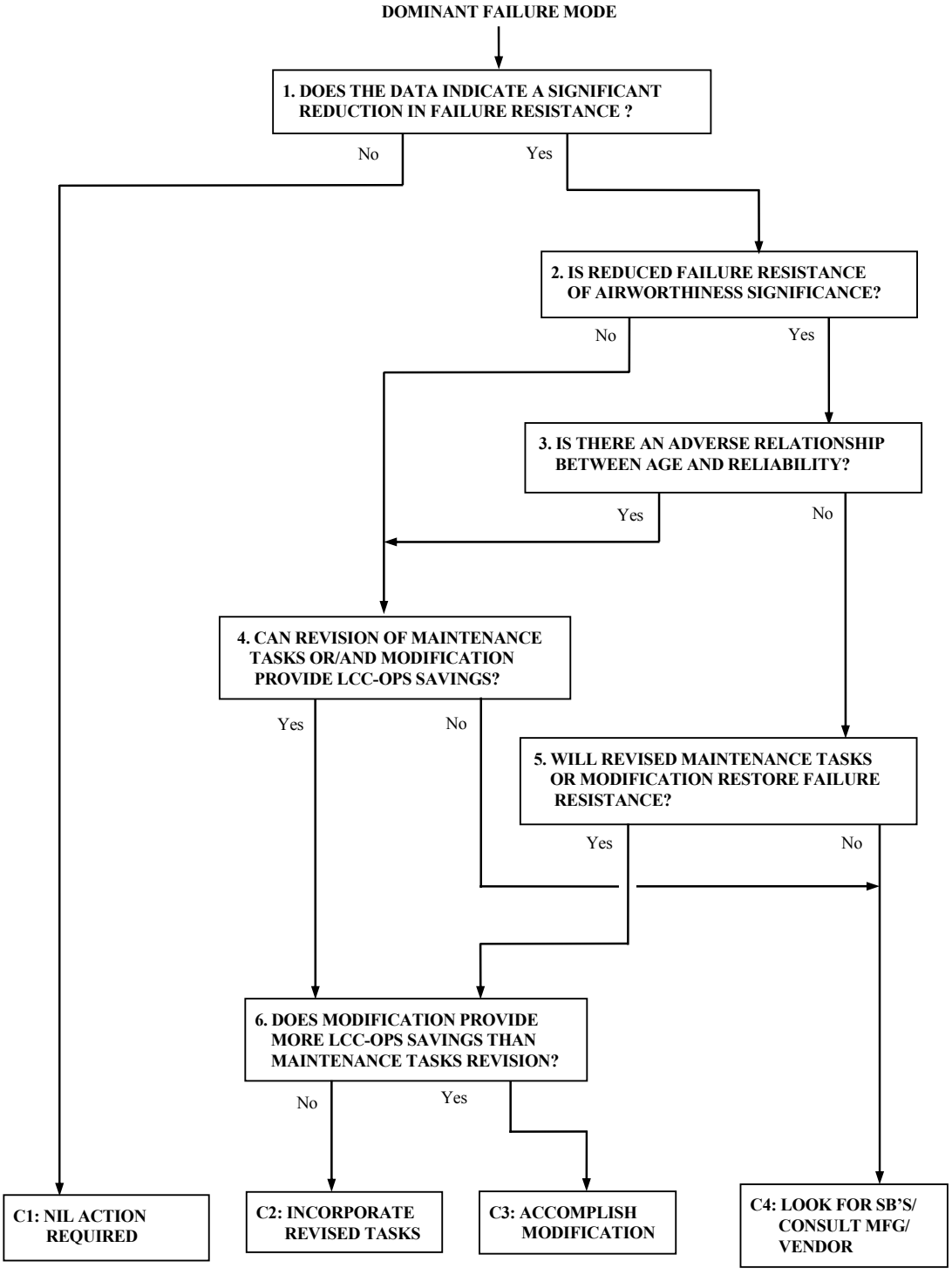


Fig. 4.4 **TO-BE:** Reliability Improvement Decision Diagram

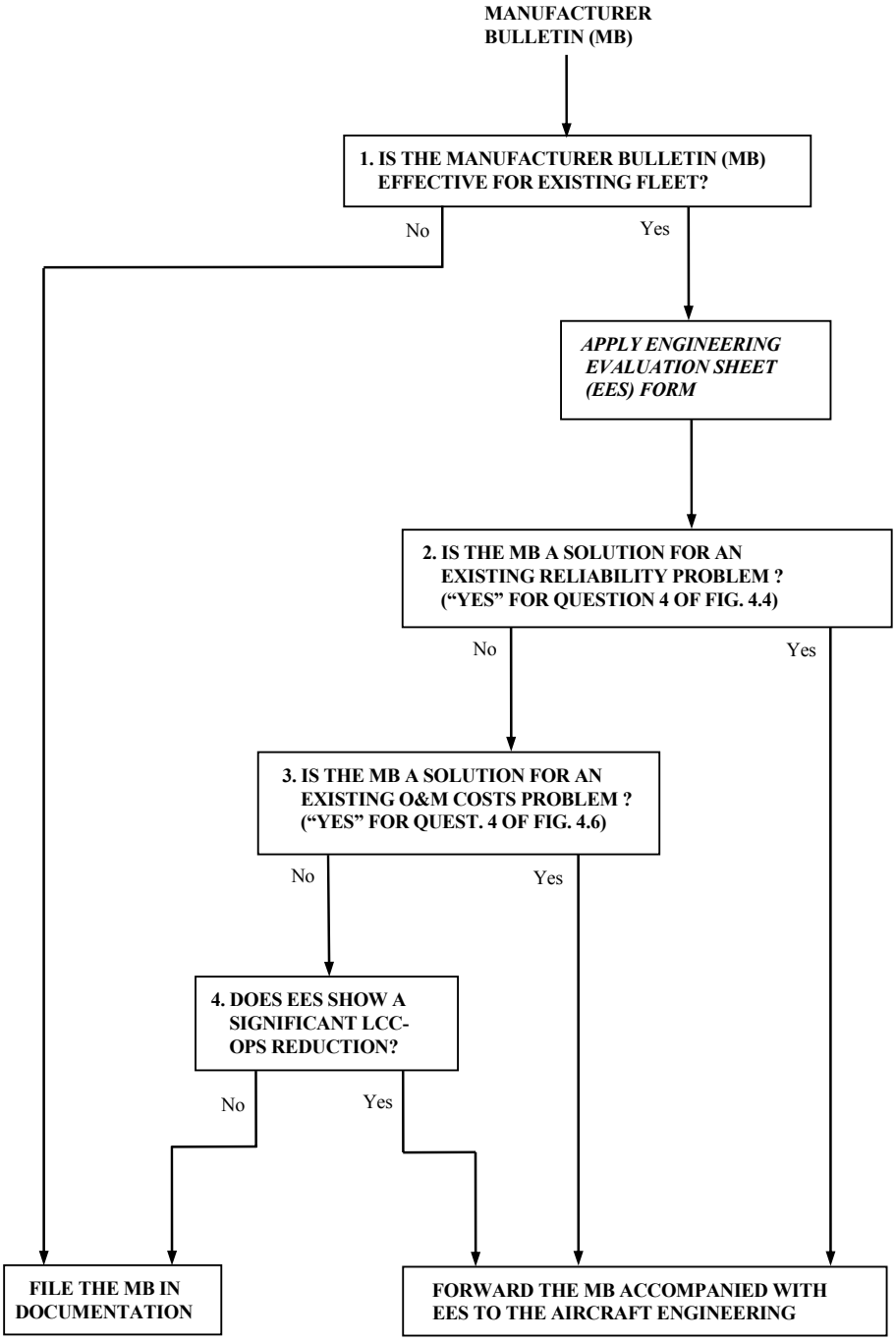


Fig. 4.5 **TO-BE:** Manufacturer Bulletins Evaluation Diagram

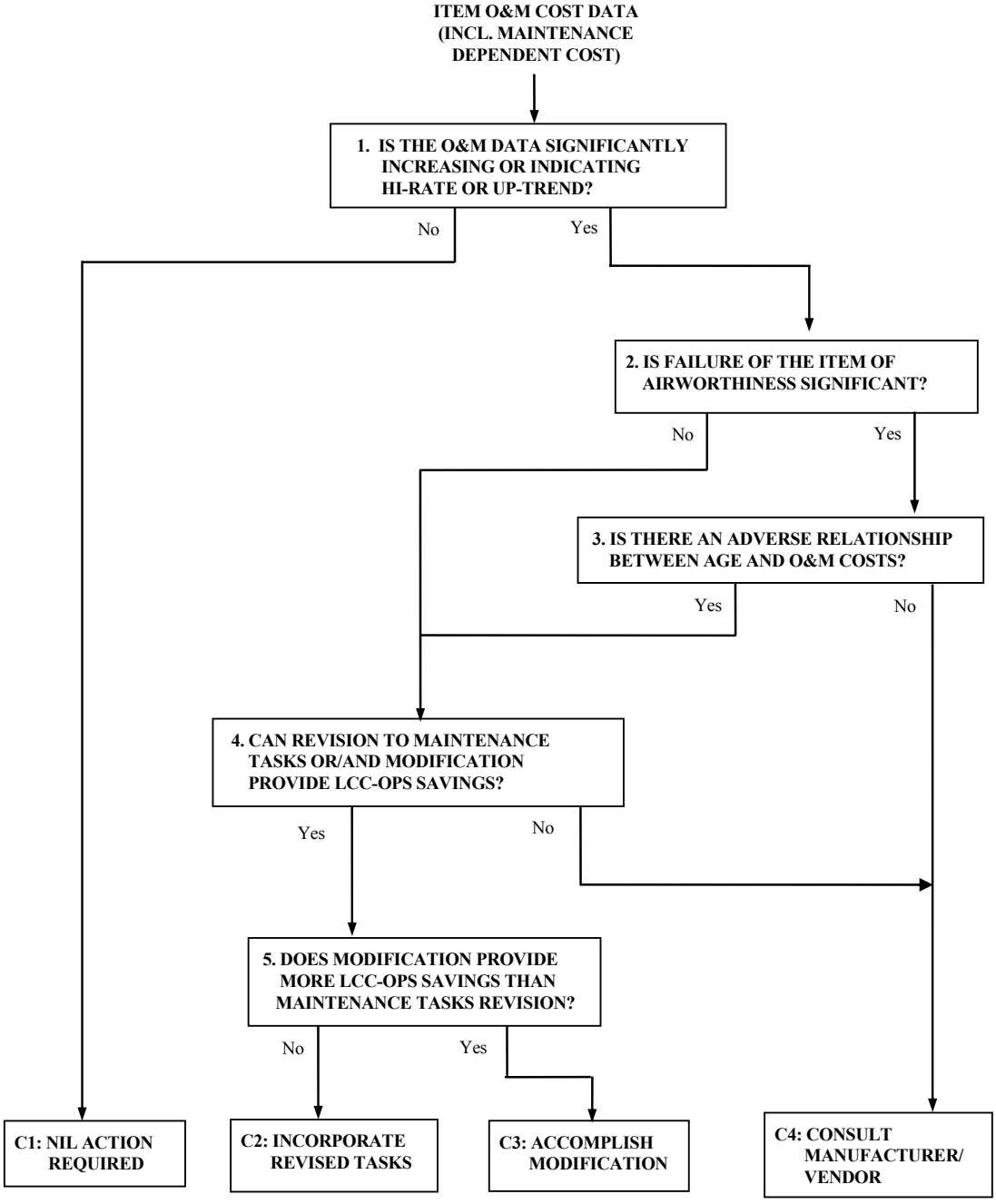


Fig. 4.6 **TO-BE:** Cost Evaluation Decision Diagram

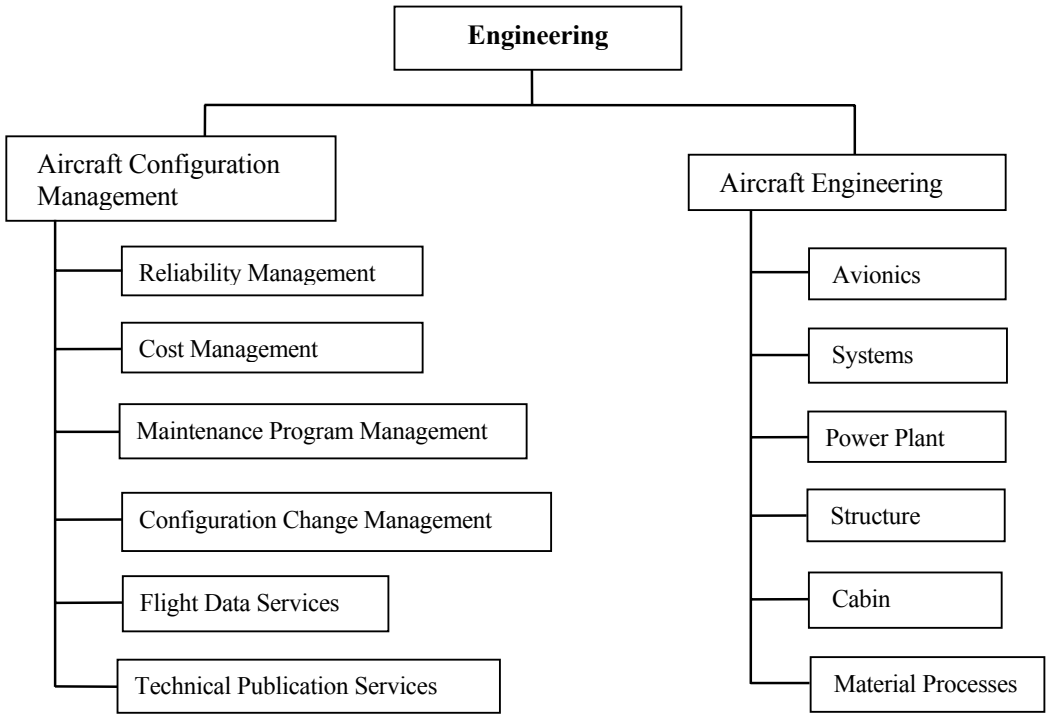


Fig. 4.8 **TO-BE**: Organisation diagram of Technical Services

PART III
MAINTENANCE PROGRAM OPTIMISATION

Chapter 5

AS-IS Situation of Maintenance Program Optimisation

This chapter describes a general introduction to aircraft maintenance programs, in order to be able to analyse the existing process of aircraft maintenance program optimisation and to identify the need of the LCC concept application. This chapter describes also the AS-IS situation of maintenance program development and revision[20] of Garuda Indonesia Airlines, as a basis to discuss the development and application of the LCC-OPS model for maintenance program optimisation and the maintenance optimisation process for the TO-BE situation, described in Chapters 6 and 7.

5.1 Maintenance Program: General

An aircraft maintenance program has the objectives to maintain the airworthiness and operational reliability of an aircraft in an economic way. The approach toward maintaining the airworthiness of an aircraft during the operating phase starts from the design, development and certification of a new aircraft, and continues throughout the aircraft's operating life. This approach requires a continuing dialogue between the operator of the aircraft, the relevant regulatory authority and the aircraft manufacturer [King, 1986].

There are two separate main documents concerning the maintenance program during the delivery of an aircraft, i.e. the Maintenance Planning Data (MPD) document and the Maintenance Review Board (MRB) document. Implementation of all items of the MRB document is mandatory, prior to the changes of the items based on the operating experience of relevant items. Experience from other operators (MRO's, alliance partners) may also be used to justify the initiative to change the maintenance program by the airline. However, some of the items are not allowed to be changed. This will be discussed later.

Operators are allowed to developed their own maintenance program based on the MPD document, including all items of MRB document, depending on the aircraft version

[20] Maintenance Program Revision is an optimisation of the airlines maintenance program, mostly based on the maintenance data (maintenance reports, pilot reports).

(option/type/model), type of operation and own experiences. This maintenance program is referred to as the "customised maintenance program". The development of a "customised maintenance program" requires a reliability program which monitors the aircraft reliability level, as a measure of the maintenance effectiveness (achieve the objectives as mentioned earlier). This reliability program must be approved by the local authority, and is executed consistently by the operator.

The customised maintenance program, which is sometimes called Maintenance Requirements (MR) or Maintenance Specifications (MainSpec), contains descriptions of the task (or process) conducted at a particular item (called Maintenance Requirement Item, MRI) with a specified period (interval). Maintenance tasks having a comparable intervals, will be carried out together in a maintenance package or letter check. Typical names are the A-check, B-check, C-check and D-check. Maintenance tasks having an interval smaller than the A-check interval, are normally conducted during pre-flight, daily, overnight, 90 or 180 flight hours checks. The Maintenance Requirements describes also programs related to maintenance, e.g. engine life limit program, structural inspection program, zonal inspections and the unscheduled maintenance [Garuda Maintenance Specifications]. Special inspections will be conducted after certain events, like hard landing or lightning strike.

Optimisation of the maintenance program in this thesis deals with the evaluation and adjustment (escalation) of the interval of a maintenance program package (letter check). The adjusted (escalated) letter check interval is a basis for revision of the Maintenance Requirements. Evaluation of the performance (effectiveness) of a maintenance program package must be conducted through evaluation of each maintenance task for the MRI's within the package. The evaluation result can lead to escalation, de-escalation (drop-out), deletion or addition of new maintenance tasks.

5.2 Development of an Initial Maintenance Program

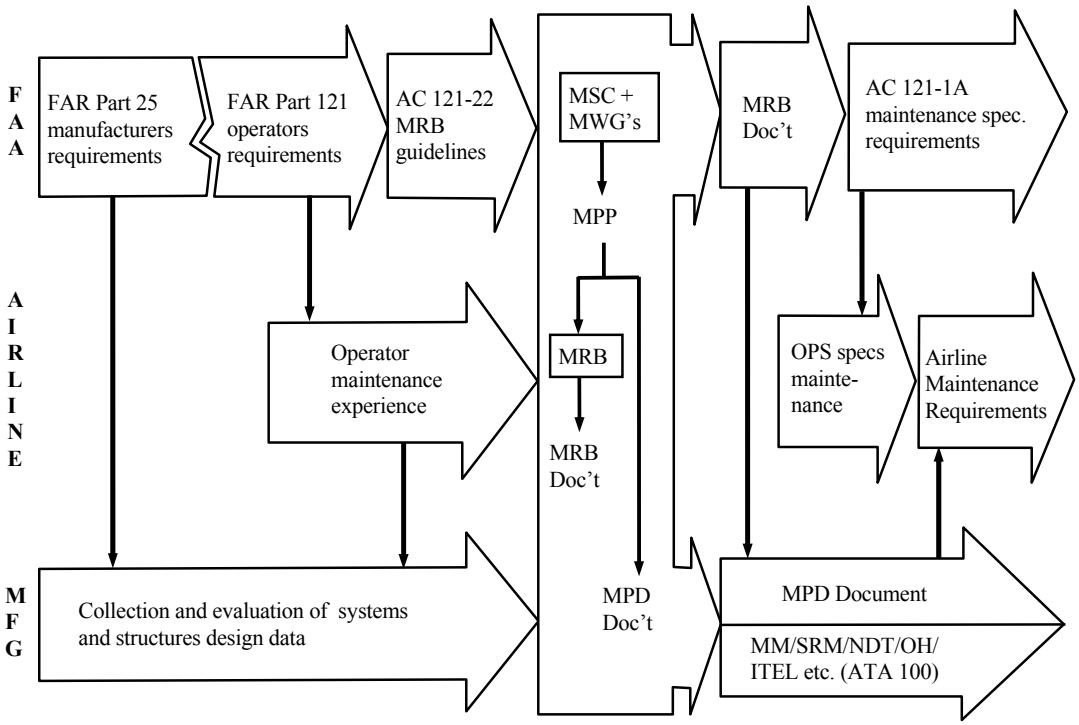
The development of an initial maintenance program for a new aircraft type/model involves the manufacturer (vendor), the Regulatory Authority and the lead (major future) operators. As noted in the Federal Aviation Regulations (FAR) Part 25.1529[21], aircraft manufacturer is obliged to provide the purchaser of an aircraft with information considered essential for proper maintenance. FAR Part 121 contains the specific requirements for preventive maintenance which must be complied by scheduled airlines registered at the United States of America [FAR 121 subpart L]. As a consequence of these requirements, the Advisory Circular (AC) 121-22 is issued to provide guidelines for developing and establishing a Maintenance Review Board (MRB) document for a new aircraft, power-plant or appliance (systems) to be used in airlines operation.

[21] **FAR § 25.1529 Instructions for Continued Airworthiness:**
The applicant must prepare Instructions for Continued Airworthiness in accordance with Appendix H to this part that are acceptable to the Administrator. The instruction may be incomplete at type certification if a program exists to ensure their completion prior to delivery of the first airplane or issuance of a standard certificate of airworthiness, whichever occurs later.

The initial maintenance program development is managed by a Maintenance Steering Committee (MSC) composed of aircraft and engine manufacturer, lead (future) operators and Regulatory Authority representatives. The steering committee is supported by several Maintenance Working Groups (MWG's) where each working group includes airline, manufacturer and FAA specialists as observer [Smit, 1993]. Figure 5.1 illustrates the development process of the initial maintenance program where the roles of each party are shown. Explanation of Fig. 5.1 is following.

The manufacturer's role in the development of an initial maintenance program begins with the collection and evaluation of data from systems and structures design. This is followed by a detailed analysis using MSG-3 decision logic which is initially developed by the Maintenance Steering Group (MSG)-3rd Task Force in 1980. Recent version of the MSG-3 logic is issued in 2002 (Appendix D describes this logic). The result of the detailed analysis is the required maintenance tasks for each item (system, sub-system or assembly) and their intervals. Required maintenance tasks with comparable time intervals are packaged into checks conforming to the airlines maintenance planning.

The MSC will evaluate the identified initial maintenance program by the manufacturer, with the support of MWG's, to develop the Maintenance Program Proposal (MPP) to be submitted



MSC= Maintenance Steering Committee MM = Maintenance Manual
MPP = Maintenance Program Proposal SRM = Structural Repair Manual
MPD = Maintenance Planning Data NDT = Non-Destructive Test Manual
MWG = Maintenance Working Group OH = Overhaul Manual
MRB = Maintenance Review Board ITEL = Illustrated Tools Equipment List
MFG = Manufacturer

Fig. 5.1 Initial maintenance program development [King, 1986]

to the Regulatory Authority. Airlines will support the manufacturer with their operating experience of previous generation aircraft (types/models) to finalise the MPP. The Regulatory Authority then appoints a Maintenance Review Board (MRB) to evaluate the MPP technically, especially an airworthiness task. Approval of this proposal leads to the release a MRB Document, containing all maintenance tasks mandatory to be carried by airlines, which are called MRB items. All MRB items and other additional information required to develop a customised maintenance program (Maintenance Requirements) for the airlines are described in the manufacturer's Maintenance Planning Data (MPD) document. MPD document is supplemented with other documents, i.e. Maintenance Manual (MM), Wiring Diagram, Illustrated Tools Equipment List (ITEL), Structural Repair Manual (SRM), Non Destructive Test (NDT), Overhaul Manual, Corrosion Prevention Manual, and Airline Maintenance Inspection Interval Report.

The Maintenance Requirements Document is prepared in accordance with FAA Advisory Circular 121-1A[22] and is then submitted to the local Regulatory Authority for approval (most of the local regulatory authorities are applying this AC, including Indonesian DGAC). The basis of the Maintenance Requirements document preparation are mandatory documents (the MRB Document, Certification Maintenance Requirements (CMR's)[23], Airworthiness Limitation Items (ALI's)[24]), MPD (including the Master Minimum Equipment List, MMEL), the airline's experience, route structure, flight segment lengths, operational environment, fleet size, facility and maintenance capabilities. Therefore, Maintenance Requirements are unique for each operator.

5.3 Ongoing Maintenance Requirements

During the life of the aircraft continuous improvements occur, to eliminate the problems that develop, improve safety, operational reliability and maintainability. This continuous process of improvement directly affects the Ongoing Maintenance Requirements, as shown in Fig. 5.2. The approval of changes made by the airline to in-service aircraft, as well as the related Maintenance Requirements and manuals, is the responsibility of the local Regulatory

[22] **AC 121-1A: Standard Operations Specifications Aircraft Maintenance Handbook (6/26/73)**
Provides procedures acceptable to the Federal Aviation Administration which may be used by operators when establishing inspection intervals and overhaul times.

[23] **A CMR** is a mandatory periodic task, required to maintain the safety of the aircraft, established during the design certification of the airplane as an operating limitation of the type certificate [SAE ARP4761, 1996]. **FAR 25.1309** mentions that the airplane systems and associated components, considered separately and in relation to other system, must be designed so that:
1. the occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable, and
2. the occurrence of any other failure conditions which would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable.

[24] An **ALI** is a structural member of the aircraft whose failure can result in injury to occupants or loss of aircraft based on safe life or damage tolerance analysis in accordance with FAR 25.571 and FAR 25 Appendix H [SR, 1995].

Authority where the aircraft is registered. The aircraft manufacturer can recommend, but has no authority to approve Maintenance Requirements and supporting data/ manual changes.

From the operations and maintenance data, especially inspection findings, the manufacturer can propose a revised MRB document. This is normally an extension of maintenance interval for letter checks. As shown in Fig. 5.2, this revised MRB document and probably issuance of Advisory Circular, or an Airworthiness Directive, can effect the Maintenance Requirements. The manufacturer may issue also a revised MPD document, Service Bulletins (SB), Service (Information) Letter (S(I)L) or other publications/documents to eliminate problems, or to improve the reliability and maintainability of the aircraft. The main driver of these improvement sources is the operating experience of the airlines which discover problems and the results of accident and incident investigation.

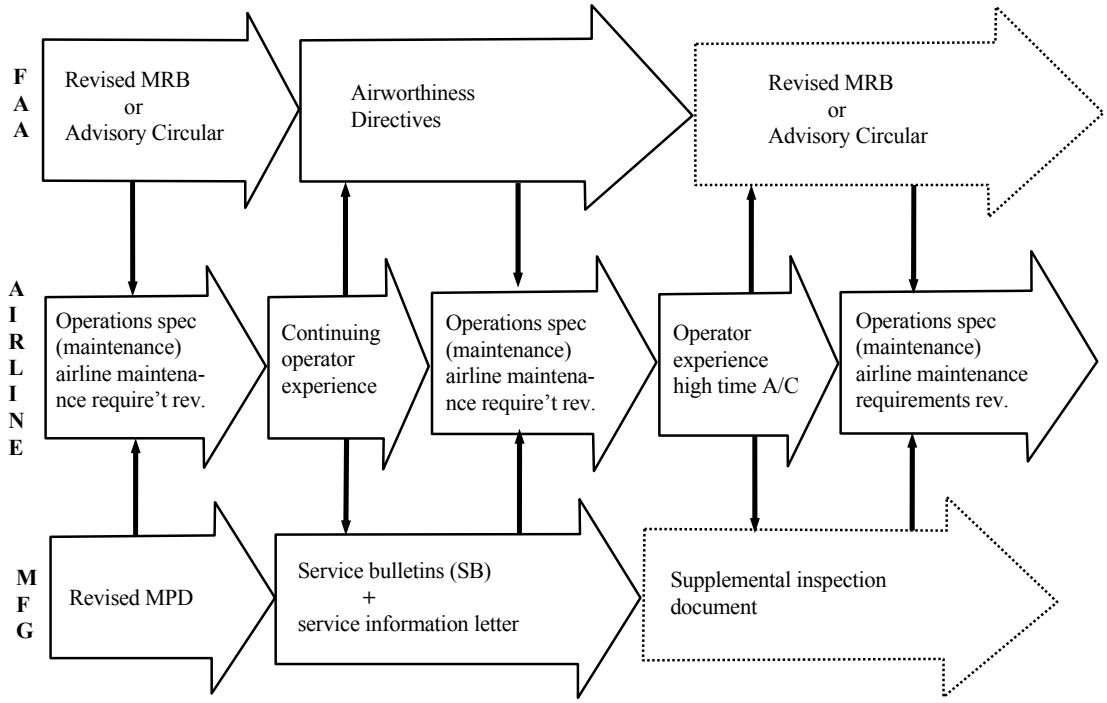


Fig. 5.2 Ongoing maintenance program [King, 1986]

5.4 AS-IS: Maintenance Requirements Development

This section presents the AS-IS situation for the development of Maintenance Requirements at Garuda Indonesia Airlines (GIA), to describe the 'real world' of the maintenance requirements development. This subject is beyond the investigation area of the research, because it is only a matter of following the Indonesian DGAC regulations. The regulations themselves are mostly derived from the FAA regulations. Therefore, no analysis and TO-BE situation are made for this subject. *The description of the AS-IS situation provides a basis to analyse the evaluation and adjustment process*, as introduced in section 5.3, which will be discussed further in Chapter 7.

The development of the Maintenance Requirements (MR) at Garuda principally follows the process described in section 5.2. Documents effective for the aircraft, which are issued *after* the first delivery of the aircraft model, are included as well during the development of the MR. These documents come from the Regulatory Authority (AD Notes, AC's) or the manufacturer /vendor (e.g. SB/SL).

Maintenance Requirements are developed based on mandatory documents (e.g. MRB, CMR, ALI, CPCP[25], SID documents), recommended documents (MPD and alike), Garuda policies and request from the Engineering and Maintenance Directorate for a specific maintenance task. During implementation of this maintenance program, some adjustments are made on the basis of Mandatory Engineering Orders (EO's) derived from AD Notes, EO's derived from manufacturer bulletins (SB/SL), which concerns Maintenance Requirements, and component specifications document (e.g. shop limits, shop tasks, storage limits) [TPM 08-20-01].

The rules for maintenance requirements development are following [GIA Reliability Control Program (RCP) Manual]:

a. All maintenance and servicing tasks in the Maintenance Review Board (MRB) document will be included within the specified intervals.

b. All on going maintenance or servicing tasks arising from applicable Civil Aviation Safety Regulation (CASR) or AD Notes will be included within the specified intervals.

c. Tasks included in the manufacturer Maintenance Planning Data (MPD) will be reviewed for inclusion if considered necessary for the proper maintenance of the aircraft.

d. The total maintenance program will be reviewed and where desirable tasks peculiar to the requirements of Garuda Indonesia will be included.

Figure 5.3 shows the process for development of Maintenance Requirements at Garuda organisation. The process is numbered as E0, because it is before (beyond) the process of Maintenance Program Optimisation (E1) shown in Fig. 5.4. The description of the process is following.

a. Prepare the Draft of Maintenance Requirements (E0-1)

The activity of this box is to prepare the draft Maintenance Requirements conducted by the Maintenance Program Management section (see Fig. 2.1). The input of the activity are Mandatory documents, i.e. MRB, CASR, Type Certificate Data Sheet (TCDS), CMR, ALI, EO derived from AD. Other sources are Maintenance Planning Data (MPD) Document, Garuda policies and requirements from Engineering and Maintenance based on own experiences. All items in the MPD Documents are included in the Maintenance Requirements, due to insufficiency of information (experience) from similar aircraft types/models, within GIA, to judge the MPD items. The output of this process are draft Maintenance Requirements to be evaluated further by the Aircraft Engineering unit.

[25] CPCP = Corrosion Prevention and Control Program

b. Evaluate/Review the Draft of Maintenance Requirements Technically (E0-2)

The activity of this box is to perform an engineering evaluation of the MR draft which is conducted by the Aircraft Engineering unit. The input of this activity is the MR draft prepared by the Maintenance Program Management section. Each section of the Aircraft Engineering unit will evaluate whether the MRB items of each area are included as well as the airlines maintenance experience in each area. The output of this activity is an evaluated MR draft to be forwarded to the Regulatory Authority.

c. Submit Maintenance Specification for Approval (E0-3)

The activity of this box is to submit the evaluated draft of MR to the National Regulatory Authority (the Directorate General Air Communication, DGAC) for evaluation and approval. The input of this process is the evaluated draft of MR, while the output is an approved MR. Unapproved MR will be returned to Aircraft Engineering unit for further analysis and adjustment. This activity is conducted by the Maintenance Program Manager.

5.5 AS-IS: Letter Check Interval Escalation

Description of the AS-IS situation in this section is a basis for the development and application of the LCC-OPS model for maintenance program optimisation (Chapter 6) and the maintenance optimisation process (Chapter 7) for the TO-BE situation. This description is derived from the existing procedure and the reports on escalation of the A-check interval of Airbus 300-B4 of Garuda. The procedure were followed, as shown in the reports. The reports on escalation of D-check of the Garuda B747-400 done by Garuda will be used as well, as far as relevant.

The AS-IS process of letter check escalation is shown in Fig. 5.4 and explained below.

a. Prepare the required data for escalation (E1-1)

The activity of this box is *to prepare* the required data for evaluating the feasibility of a particular letter check interval escalation. This activity is carried out by the Garuda Staff under supervision of the Maintenance Program Manager. The input is the request from management to escalate the letter check interval. This request normally comes from the Vice President of Technical Services, but may come also from the Director of Maintenance and Engineering. The output is the accomplishment data of relevant Maintenance Requirement Items (MRI) and supporting data for detailed evaluation, i.e. Pilot Reports (PIREPS[26]), Maintenance Reports (MAREPS[27]) and Shop data.

[26] PIREP is a report that presents pilot or cabin crew complaint and its rectification showing continuous operational monitoring.
[27] MAREP is a report that presents technical (functional) failure and its rectification found during line or hangar maintenance.

b. Evaluate all MRI's with respect to MDR, PIREPS and MAREPS (E1-2)

This activity box is to evaluate all Maintenance Requirement Items covered in the letter check whether there were findings during previous checks accomplishment (described in the Maintenance Discrepancy Reports, MDR[28], for each finding). If there were findings, it will be further evaluated whether the findings are:

- significant
- repetitive, following a 'normal' distribution (consistent or age related)
- correlated with PIREPS and/or MAREPS (related to unscheduled maintenance), and
- ratio between number of findings and number of inspection is higher than 0.5 (no argument mentioning this 0.5).

Findings or non-routine maintenance on items are considered significant when the functional failure (with the same failure mode with the findings) of the item could have safety effects, operational effects or major economic effects. The criteria used to determine these categories are following the MSG-3 logic (discussed in Appendix D).

The input of MRI evaluations are the findings from previous (past) checks described in MDR and data of PIREPS and MAREPS. The output is an evaluated Maintenance Requirement Item covered by the letter check. This activity is conducted by the relevant Aircraft Engineers. As mentioned earlier, the controls of this activity are:

- the significance[29] of the findings
- repetition of findings with the same failure mode (see also Appendix C)
- correlation[30] of the findings to PIREPS or MAREPS (unscheduled maintenance)
- ratio between number of findings and number of inspections[31].

c. Summarise the evaluation results (E1-3)

The activity of this box is to make a summary of the evaluation results and to judge whether the intended escalation is feasible. The judgement requires a review of the results of all MRI's evaluated. It is continued by development of a draft of the interval escalation proposal. The input of this activity is the result of all MRI's evaluated. The output are a judgement on the feasibility to escalate the interval and the draft of the interval escalation proposal. This activity is conducted by the Maintenance Program Manager.

Figure 5.5 shows an example of the result of MRI's evaluation. In this example, for MS-Item number 2760010100 the task is General Visual Check (GVC) with interval 1A (A=200FH). After conducting 128 times of inspection, number of findings is 1 and actually a false

[28] MDR is a report that provides detailed information concerning finding and its rectification during maintenance at maintenance base. **If not specifically mentioned, findings mean base maintenance inspection findings.**

[29] A finding is considered significant if the functional failure of the item, with failure mode as indicated by the finding, is significant according to MSI classification of MSG-3 (see Appendix D).

[30] Correlation means the findings are concerning items as indicated also by the PIREPS or MAREPS.

[31] Garuda uses a value of 0.5 for the threshold of this ratio. When the ratio is less than 0.5, the respective MRI can be escalated. If the ratio is above 0.5 **and** the failure effect of the item is not category of 5 or 8 (safety evident or safety hidden) of MSG-3 logic (see Appendix D), then modification might be preferred, if economical (see the corrective action decision diagram, Fig. 2.11)

finding. For MS-Item number 2915070100 the task is Special Check (SPC) with interval 1A (A=200FH). After conducting 117 times of inspection, number of findings is 3 and actually 1 finding is false. Because the Actual Ratio (number of findings divided by number of inspections) is far from 0.5 for these two MS-Items, then the interval of these two MS-Items is justified for escalation. Information concerning unscheduled maintenance of the MS-Item will be used if the Actual Ratio is close to 0.5.

d. Review escalation proposal (E1-4)

The activity of this box is to review the draft of the letter check interval escalation proposal prepared by the Maintenance Program Manager. For this purpose, the Maintenance Program Manager normally gives a presentation to the Maintenance Review Committee (MRC, see also Fig. 2.2). Unapproved proposals will be returned to Aircraft Engineering for re-evaluation and adjustment (activity box no. E1-2).

The input of this activity is a draft of the letter check interval escalation proposal, and the output is an approved escalation proposal by the MRC. The MRC will conduct this review.

e. Submit the proposal to escalate check interval to the Regulatory Authority (E1-5)

The activity of this box is to submit the proposal to escalate the check interval based on the result of all MR-Item evaluations, to the Regulatory Authority. MR-Items having an interval which cannot be escalated, are also mentioned. Normally these items will be dropped-out[32], except when the manufacturer/vendor allows its escalation. In most cases the dropped-out items are MRB items. Modifications to improve the items reliability require an approval from the Regulatory Authority.

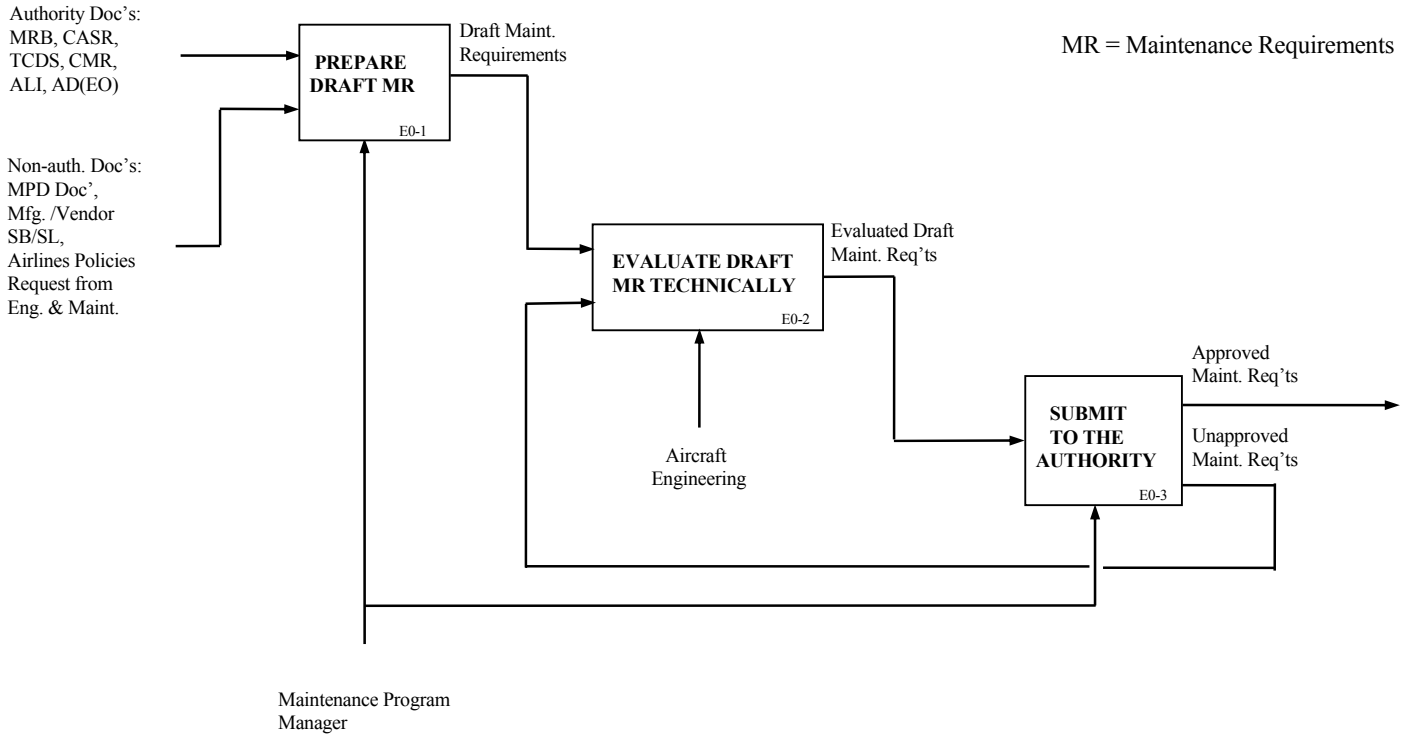
The input of this activity is the judgement on the proposal to escalate check, that the proposed escalation is feasible. The output is an approved escalated (new) check interval. The Vice President of Technical Services conducted this activity.

Observations:

a. **No** explicit cost consideration has been made in the AS-IS situation. The activities toward maintenance program optimisation are very limited.
b. The results of the Reliability Control Program are not (limited) applied for the analysis of findings (non-routine maintenance).
c. The number of escalations ever conducted is only two, i.e. A-check of AB300-B4 and D-check of B747-400. This number is very small, as compared to other airlines (e.g. KLM).

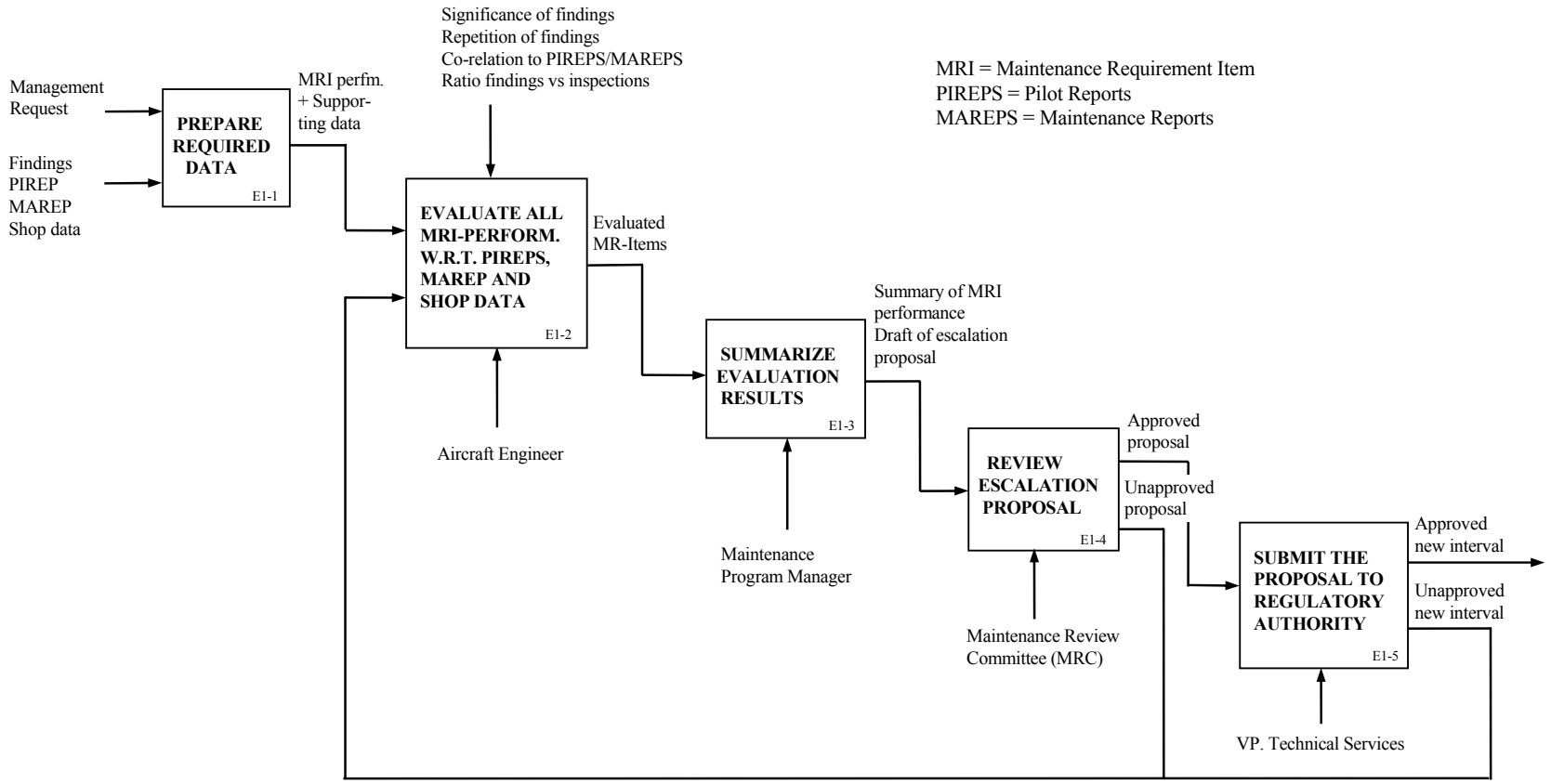
[32] Taken out from the package being escalated and put it into another package with higher frequency.

Development of Maintenance Requirements



NUMBER: E0	NODE: A1 CONTEXT: E0	TITLE: FIG. 5.3 DEVELOP MAINTENANCE REQUIREMENTS [WIMER01; RCP]	AUTHOR: E. SUWONDO DATE : 9 FEB. 2006

AS-IS: LETTER CHECK INTERVAL ESCALATION



NUMBER: E1-1	NODE: A1 CONTEXT: E0	TITLE: FIG. 5.4 **AS-IS**: CHECK INT. ESCALA. [AB-4 A-CHECK ESCAL.; VARIOUS GIA DOC'S]	AUTHOR: E. SUWONDO DATE : 9 FEB. 2006

MSI PERFORMANCE DATA
B737-SERIES

MS-ITEM NUMBER : 2760010100 ITEM :

MS-ITEM DESCR. : WING LEADING EDGE FLAPS SLATS, SPOILERS AND VISIBLE ACTUATING MECHANISMS.

INTERVAL : 1 A MPD # : B27-60-00-A

TASKCODE : GVC

NBR OF ACCOMP. : 128 RATIO LIMIT UPR : 0,5
NBR OF FINDING : 1 RATIO LIMIT LWR : 0
ACTUAL RATIO : 0.008

LIST OF FINDING

REG	TYPE	DATE	AHBC	USAGE	FINDING
GGF	A	04-01-99	126	63.00%	G.V.C CHECK

MS-ITEM NUMBER : 2915070100 ITEM :

MS-ITEM DESCR. : HYDRAULIC SYSTEM RETURN FILTER DIFFERENT PRESSURE INDICATOR

INTERVAL : 1 A MPD # : B29-15-61-A

TASKCODE : SPC

NBR OF ACCOMP. : 117 RATIO LIMIT UPR : 0,5
NBR OF FINDING : 3 RATIO LIMIT LWR : 0
ACTUAL RATIO : 0.03

LIST OF FINDING

REG	TYPE	DATE	AHBC	USAGE	FINDING
GGF	A	04-01-99	126	63.00%	RETURN FILTER CHECK
GWN	A	21-05-98	120	60.00%	IND NOT CLOSSING
GWN	A	21-05-98	120	60.00%	IND NOT CLOSSING

ISSUED BY : MER
ISSUED DATE : 07/09/99

AHBC = ACTUAL HOURS BETWEEN CHECK
PAGE : 3 OF 5

Fig. 5.5 Maintenance Specification (=Requirement) Item (MSI) evaluation results

Chapter 6

LCC-OPS for Maintenance Program Optimisation

This chapter describes the LCC-OPS model for maintenance program optimisation. It covers the framework of the model, the methods of cost components estimation, the required data inputs as well as their source. The delay time model will be used to evaluate the existing methods to develop an interval escalation proposal.

6.1 Framework of LCC-OPS for Maintenance Program Optimisation

This section describes the framework of LCC-OPS for maintenance program optimisation (called LCC-MOPS). As mentioned in sub-section 1.1.3, LCC-OPS is an LCC model applied in the operation phase which takes into account the impact of performance changes as an opportunity revenue. The opportunity revenue is added to the LCC savings. As mentioned in sub-section 1.3.2, *the application* of the LCC-OPS model for maintenance program optimisation in this thesis is limited to letter check interval escalation. But, principally the model is applicable for all types of maintenance package which are described in section 5.1. *LCC-MOPS does not cover the statistical analysis to judge the interval escalation.* The statistical analysis, like the Garuda method and the Boeing method, must be carried out before application of the LCC-MOPS.

Escalation of maintenance package intervals requires evaluation of the execution results of each MRI in the package. The MRI can fall under the following categories:

a. clean, means no findings or discrepancies during the evaluation period (e.g. two years)
b. with findings or unscheduled removals, it requires further technical investigation which can lead to a modification of hardware or changes/addition of maintenance tasks
c. drop out, when the task interval of the MRI cannot be escalated (e.g. ALI list, CMR list).

The LCC-MOPS consists of four main components, i.e.:

a. Investment costs
b. changes of maintenance costs (routine, non-routine and unscheduled)

c. changes of (opportunity) revenue
d. life cycle (period of evaluation).

These four components are similar to the top level LCC-OPS model shown in Fig. 1.3 as well as LCC-OPS model for aircraft modifications (LCC-MODS) in Fig. 3.1, except fuel and oil costs. The framework of LCC-MOPS is shown in Fig. 6.1. Explanations of these four components are following. Table 6.1 described the detail of these cost components.

Ad a). Investment costs consist of the engineering costs and the modification cost to increase reliability. The engineering costs consist of the required engineering hours to collect maintenance data, to analyse the discovered problems, as well as the efforts to develop the escalation proposal and the supporting staff costs. Engineering costs are considered as investment because the activities are sometimes sub-contracted to a third party, under supervision of the airline's engineers.

Ad b). Changes of operating costs are resulted by the maintenance program optimisation. They normally include the reduction of maintenance cost and depreciation cost. Maintenance cost changes are due to the changes of the routine maintenance interval, elimination or reduction of non-routine and unscheduled maintenance. Maintenance dependent costs and spares cost are influenced also by the changes of maintenance interval. Reduction of depreciation cost is assumed to come from the increase of resale value due to a lower required downtime for scheduled maintenance. However, this assumption is not proven yet, therefore the reduction of depreciation is assumed zero.

Ad c). Changes of gained (opportunity) revenues due to changes of aircraft availability. Changes of aircraft availability comes from the changes of the routine maintenance (down) time, non-routine maintenance time and unscheduled maintenance time. However, the changes of revenue depends on the utilisation of the aircraft, therefore it is considered as an 'opportunity' revenue.

Ad d). Life cycle is the evaluation period, within the operating phase.

Similar to the LCC-OPS model for aircraft modifications, the users can develop their own Cost Breakdown Structure and to select a more appropriate Cost Estimation Method. Further analysis of the results of the LCC-MOPS model can be conducted as well through:
a. sensitivity analysis
b. cost drivers identification
c. LCC profile development
d. (cost) risk analysis.

6.2 Cost Component Estimation Methods

The methods for cost component calculation/estimation are shown in Table 6.1, from 6.1a until 6.1f. Most of the methods are just calculation, for instance labour cost is equal to the

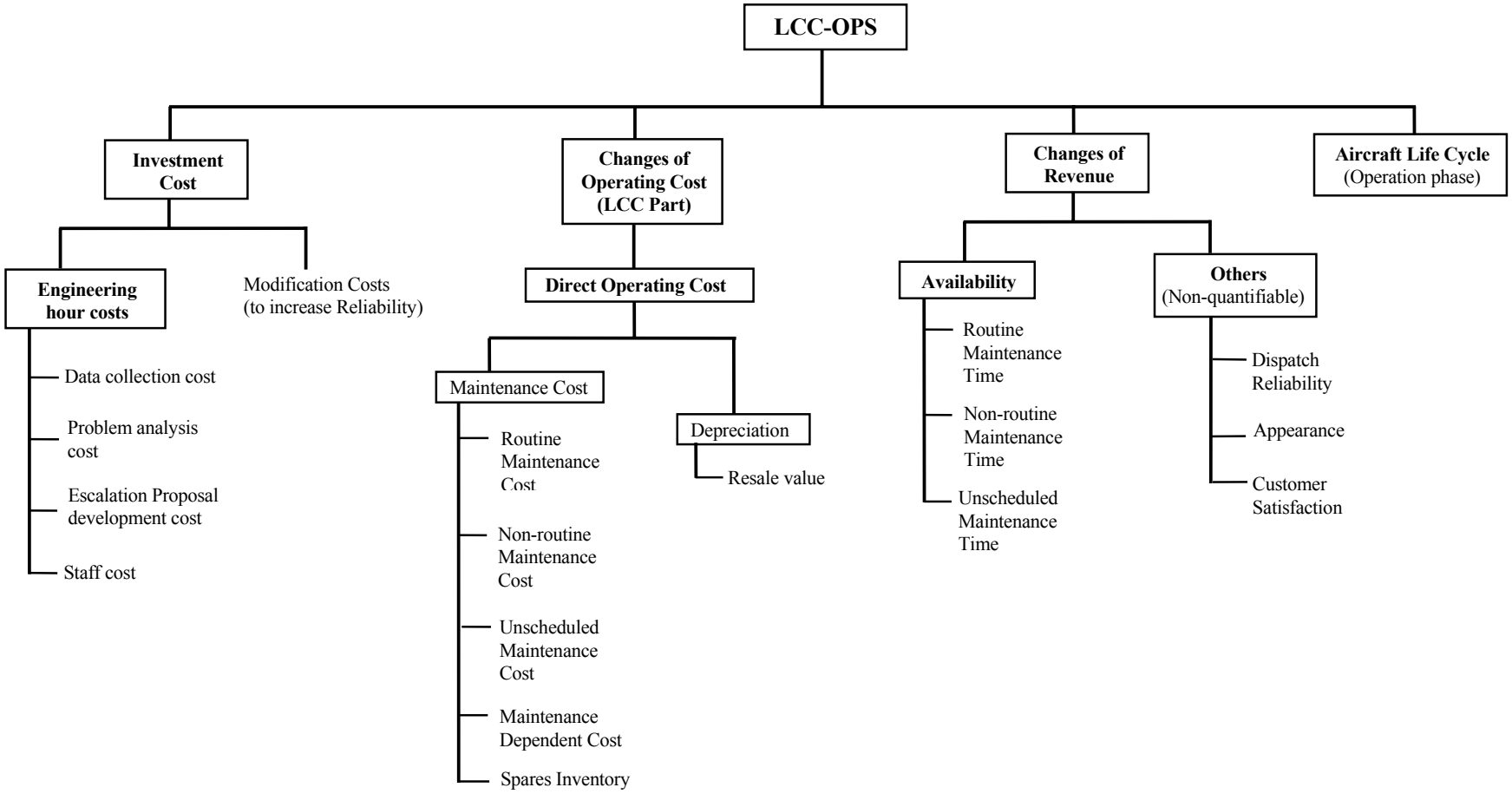


Fig. 6.1 The LCC-OPS model for maintenance program optimisation

number of required labour hour times the labour rate. However, selection of the cost estimation method being used depends on the availability of data. Appendix G provides an overview of methods of cost component estimation which were considered for application in LCC-OPS model.

For systems which have major economic consequences of their failures, inspection is frequently used for minimising total maintenance cost, if applicable. The total maintenance cost consists of inspection cost, repair cost of findings (non-routine maintenance) and the corrective (unscheduled) maintenance cost, excluding the maintenance dependent costs. *Delay time*[33] *model determines the distance of first indication of defect and failure occurrence*. By knowing the delay time function, an optimum inspection interval of an individual maintenance task can be found which gives the minimum of total maintenance cost. This is the reason the delay time model is chosen for maintenance intervals optimisation.

6.3 Application of Delay Time Model

This section presents the application of a delay time model to determine the optimum inspection interval of an *individual maintenance task* within a maintenance package (see also Chapter 5), which provides the minimum of total maintenance cost. The delay time models provide the analytical basis for interval optimisation of a maintenance task.. In the Reliability-Centered Maintenance (RCM) methodology this activity is referred to as age exploration [Nowlan, S.F., 1978]. Age exploration is based primarily on the monitoring and analysis of failure data to determine the effectiveness of the proposed tasks [Nowlan, S.F., 1978, p.109]. However, if the tasks are not aimed to prevent safety consequences, they should be evaluated on the basis of cost-effectiveness.

This section is structured as follows (see also Fig. 6.2). The existing methods are described shortly, then the relevant delay time models are discussed. This model will be applied to

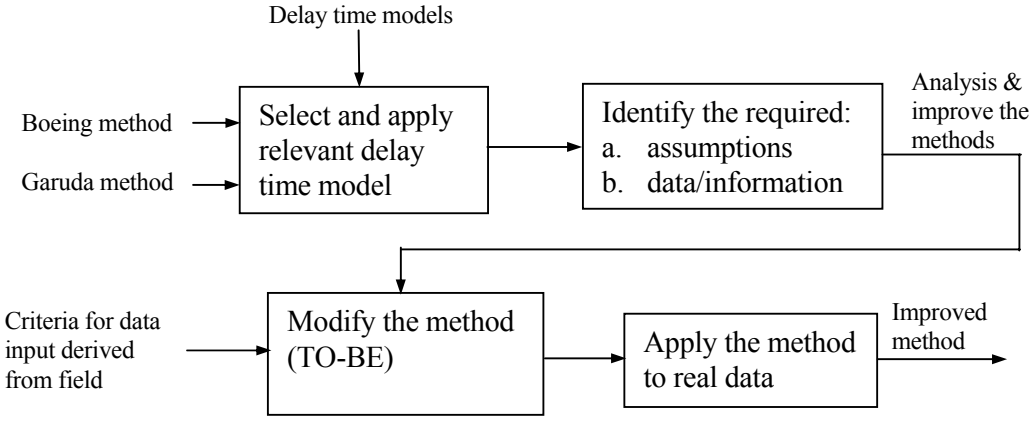


Fig. 6.2 The process of the delay time model application.

[33] Delay time in this context is nothing to do with the 'time delayed' model of condition degradation for maintenance policy determination and also nothing to do with aircraft delays during operation, except for the data of unscheduled maintenance.

analyse the method developed by Boeing [CSD Boeing, 2000] and the existing method of Garuda [GIA RCP]. The results of the analysis lead to modification of the existing methods, and this modified method will be applied on real data from an A-check interval of Garuda B737-series (section 6.4). From this application, improvement will be made to the modified method, if necessary. Data and information for the modified method will be described as well.

This section should enable to answer the following questions.

a. What is the effects of the utilisation of the interval?

b. What is the effects of the ratio between findings and number of inspections?

c. What is the effects of the percentage of interval escalation?

d. What is the use of unscheduled maintenance data?

Most airlines perform inspections before the aircraft's flight hours/cycle reaches the approved inspection intervals. This makes *the utilisation of the interval*[34] less than 100% (about 60%-95% at GIA). Because the escalation proposal is based on the results of the inspection with the actual intervals, then the calculation of the escalated intervals must be based on the actual inspection intervals, not the approved inspection intervals. An analysis using the delay time model results in the allowable escalated inspection intervals, based on the actual inspection interval. However, the escalated intervals are normally stated as a percentage of the approved intervals. The escalated intervals must be lower than or equal to the allowable escalated intervals determined by using the actual intervals (where the utilisation is less than 100%).

From the ratio of findings and inspections, the potential failure probability distribution should be derived. The probability to discover finding during a scheduled inspection is derived from this distribution.

6.3.1 Summary of the Delay Time Model

The delay time, h, of a defect[35] (see Fig. 6.3), is defined as the time lapse from when a defect could first be noticed (C) until the time when its repair no longer can be delayed (D) because of unacceptable consequences [Christer, A.H., JORS, Vol. 35, No. 5, 1984]. In other words, the delay time of a defect is a time interval between the defect is detectable and functional failure. A repair can be carried out any time within the delay time.

At the moment of inspection and/or repair, the following questions can be asked.

a. How Long Ago could the defect have first been noticed by inspection or the operator (=HLA)?
b. If the repair was not carried out, How Much Longer could it be delayed (=HML)?

The delay time for each defect is estimated by h=HML+HLA, as shown in Fig. 6.3. By observing the degradation of the system condition and its cause(s), or component defects, a

[34] **The utilisation of the interval** is the ratio of the actual interval to the approved interval.
[35] **Defect** is a potential failure for a particular failure mode.

prior distribution for *f(h)* may be obtained. It is assumed that the defects are independent of each other. If a dependence of the defects are found in the analysis, the delay time model should be modified according to the nature of the dependence.

A defect is noticed when the system fails (unscheduled maintenance) or during an inspection (findings, repaired with non-routine maintenance). When the defect is initiated before the initiation of the delay time (between point A and B in Fig. 6.3), it will fail before the scheduled inspection T. The failure is rectified by unscheduled maintenance, *b(T)*[36]. But, if the defect is initiated within the delay time (between B and T), it will reach the inspection time *T*. It will be rectified by non-routine maintenance, where the repair is carried out together with the inspection. If the inspection period (interval) *T* increases, the probability of unscheduled maintenance, *b(T)*, increases. In general, *it may be assumed that the total costs due to unscheduled maintenance is higher than inspection cost*. For this reason, it is important to estimate *b(T)*. The delay time model will be used to analyse the interval escalation methods developed by GIA and by Boeing.

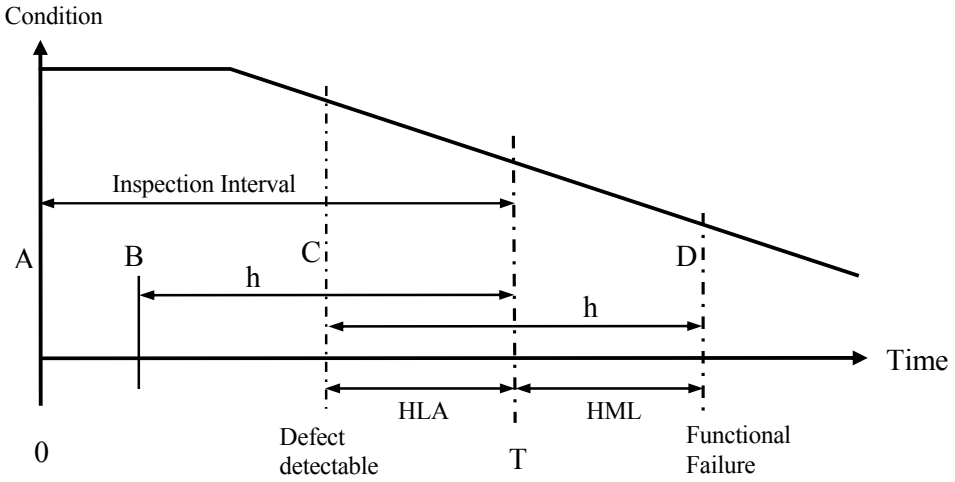


Fig. 6.3 The delay time model illustration

6.3.2 Summary of The Existing Interval Escalation Methods

Two methods of maintenance task interval escalation can be identified, i.e. the method with provisional check interval (using sample aircraft) like the Boeing method [CSD Boeing, 2000] and the method without sample aircraft like the Garuda method [GIA RCP]. The Boeing method can be considered as conservative, because the proposed interval will be tested first on sample aircraft before it is applied to the whole fleet. As it will be shown later, the findings discovered during inspection are very limited and therefore it is difficult to determine the probability distribution functions of the delay time. Therefore, the use of sample aircraft with the proposed inspection interval will provide a confidence estimate of the delay time. The followings present those two methods.

[36] *b(T)* has a probabilistic character because the defect initiation and the delay time have a probabilistic character as well.

The Garuda method:

The Garuda method uses two criteria to judge an escalation proposal, i.e.:
a. ratio between number of findings and number of inspections
b. the utilisation of the interval for each finding.

An escalation proposal can be justified when the ratio of number of findings and number of inspections is less than 0.5, and *the utilisation of interval for the findings is more than 80%.* The Garuda method does not mention the number of inspections required for the interval escalation. These two conditions will be analysed in sub-section 6.3.3. Information on delays and cancellations (unscheduled maintenance), and PIREPS are used only when the ratio of number of findings and number of inspections is nearly to 0.5, to investigate the failure cause. In general, this information is not used because the ratio of number of findings and number of inspections is very low (far from 0.5).

As mentioned in point b above, the interval utilisation of the findings is used for the evaluation. The findings data show that most of the findings have an interval utilisation far below 100% (see Fig. 5.5). It means that the inspections which discover findings are conducted at lower interval than the approved interval. In other words, the findings are *not* as result of overdue inspections. The analysis of the Garuda method in sub-section 6.3.3 below uses information on the interval utilisation of all inspections, as a basis to estimate the number of findings and unscheduled maintenance of the escalated intervals.

The Boeing method:

Boeing described a method to escalate a check interval by applying a provisional escalated check interval for sample aircraft and use the results from these sample aircraft to judge the proposed check interval [CSD Boeing, 2000]. A sample of two aircraft are with a check interval increment of half of the proposed interval increment and a sample of three aircraft are with full proposed interval increment will be sufficient (Boeing does not mention the confidence level of these provisional check intervals). Three to five checks per sample aircraft will be sufficient for the evaluation. However, according to this method, it depends on the type of the check. For checks with a high flight hours (e.g. D-Check), the escalation evaluations do not require three or more checks per sample aircraft (Boeing does not mention the reason of this dispensation).

6.3.3 Analysis of the Garuda Method

This sub-section presents an analysis of the Garuda method by using the delay time model discussed earlier in this section. The aim of this sub-section is to discover a rationale theoretical backgrounds and the assumptions used in the Garuda method. The applicants of the method must be aware to the assumptions used and how far these assumptions are valid for their cases.

The author's observation of A-check interval escalation for B737 series at Garuda Maintenance Facility shows that very limited types of data are recorded which are required to

judge the escalation proposal. So far, only the number of accomplished inspections, the number of findings and the failure modes of the findings are recorded. Delay and cancellation reports, Pilot Reports and other maintenance reports do not contain any information concerning the *MRI's being analysed for interval escalation*. It is expected to use this information for estimating the unscheduled maintenance probability of the MRI's. These unscheduled maintenance reports should indicate the same failure modes as the findings, in order to be useable for estimation of the unscheduled maintenance probability. For this reason, some assumptions must be introduced.

As discussed in sections H.1 and H.2 of Appendix H, inspection intervals are determined based on the time distance between potential failure and functional. *The ratio of number of findings and number of inspections cannot be used to determine inspection intervals*, because it only indicates the lapse time to potential failures from zero time (TSN or TSO). However, for the purpose of analysis of methods, the ratio of number of findings and number of inspections is evaluated in this section.

According to the Garuda method, maximum acceptable ratio between number of findings and number of inspection is 0.5. Assume the highest value 0.5 occurs and the interval utilisation of the findings is 80%. If the *inspection is perfect*[37], in order to have unscheduled maintenance (breakdown repair), then the value of delay time must be $0<h\leq T$, where T is the actual inspection interval. Assume the *defect initiation is uniformly* distributed[38], *then the proportion of unscheduled maintenance and findings indicates the proportion of (T-h) and h*. h=T when no unscheduled maintenance is discovered.

The following discuss possible situations.

a. Consider h=T, with an *interval utilisation of 80%. Assume the inspection is perfect.* The existing approved interval becomes T/0.8. By escalating 20% of the existing approved interval, it results in (T/0.8)*1.20=1.5T. Because the ratio of the number of findings and the number of inspection is 0.5 at interval T, then the *probability density* of defect initiation distribution is k=0.5/T. Figure 6.4 illustrates this situation. For the same *probability density* of the defect initiation distribution, the number of defects detected during inspection (findings) for the escalated interval will be the same as at the existing approved interval. This is because the number of defects detected is equal to the defect

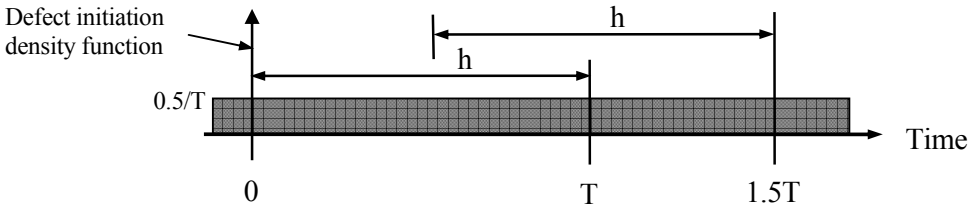


Fig. 6.4 The situation when h=T and the findings to inspections ratio = 0.5

[37] An inspection is perfect if any defect initiated will be detected during inspection.

[38] This assumption is applied by Christer and Redmond to optimise their inspection problems [7]. A more sophisticated model of the defect initiation distribution can be applied by using the description in section H.5 of Appendix H.

initiation *density* distribution times the length of delay time h. The probability of unscheduled maintenance given the defect has been initiated is (1.5T –h)/1.5T=0.333. This is a significant amount for the unscheduled maintenance probability, as compared to the existing interval. The probability of a defect detected during inspection, given the defect has been initiated, is h/1.5T = T/1.5T =0.667.

b. Consider h=0.6T, with an interval utilisation of 80%. *Assume the inspection is perfect.* For the ratio of number of findings and number of inspections 0.5, the probability distribution of defect initiation k for interval T (*assumed uniformly distributed*) is determined by:

$$\frac{h}{T}kT = \frac{0.6T}{T}kT = 0.5 \rightarrow k = 0.833/T$$

This value is higher as compared with the case of h=T.

If the inspection interval is escalated 20% of the existing interval, then the new interval is 1.5T (see also a). The (expected) number of defects detected during inspection is still the same. The probability of unscheduled maintenance, given the defect has been initiated, is (1.5T-0.6T)/1.5T=0.60. In the existing interval this probability is 0.40 (=(T-h)/T). It means the escalation will result in 50% increase of unscheduled maintenance.

c. Consider h>T for perfect inspection. If h<1.5T, escalation will result in the occurrence of unscheduled maintenance, which does not occur in the existing interval. If 1.5T<h, escalation will increase the number of findings, without having unscheduled maintenance.

d. Consider when h>T, specifically T<h<2T and the escalated interval is T'<h. For T'>h use the method described in situation b above. For *imperfect inspection*[39], this situation is shown in Fig. 6.5. Inspection at interval T results in the ratio of number of findings and number inspections 0.5. Concentrate on point F for the existing interval and point G for the escalated interval, where all contribution of h is taken into account. In order to obtain the ratio of 0.5, the probability density function of defect initiation (*assumed uniformly distributed*) for the existing interval is calculated as follows.
At point F:

$$0.5 = kT\left(\frac{BC}{T}p + \frac{CF}{T}\right)(1-p), \text{ where } p \text{ is the imperfection of the inspection.}$$

Where: $\frac{BC}{T}p$ is due to the imperfection of inspection at T (or point C)

$\frac{CF}{T}$ is the result of inspection at 2T (or point F)

Equation above leads to k=0.631/T for the inspection interval T. The probability of unscheduled maintenance is:

$$\Pr(corr.maint.) = kT\left(\frac{AB}{T} + \frac{BC}{T}p\right)p = 0.631*(0.2 + 0.8*0.4)0.4 = 0.1312$$

[39] **Imperfect inspection** means that there is a probability that some defects arise but are not detected during inspection at T. Imperfection of an inspection, p, means the probability of defects to be undetected at inspection T, given the defect have been initiated.

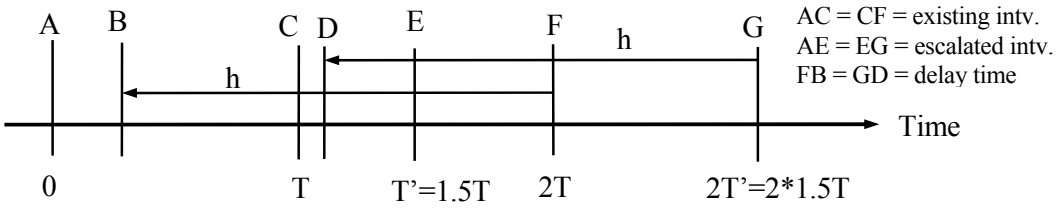


Fig. 6.5 Imperfect inspection with T<h<2T, where h>1.5T.

Assume p=0.4 and h=1.8T or BC=0.8T. If the escalated inspection interval T'=1.5T, then the probability of findings and unscheduled maintenance at this interval are following:

$$\Pr(findings) = kT'\left(\frac{DE}{T'}p + \frac{EG}{T'}\right)(1-p) = 0.9465*(0.3/1.5*0.4+1)*0.6 = 0.6360$$

$$\Pr(corr.maint.) = kT'\left(\frac{AD}{T'} + \frac{DE}{T'}p\right)p = 0.9465*(1.2/1.5+.3/1.5*0.4)*0.4 = 0.3332$$

The expected number of findings will be 27.2% more than the existing interval and the expected number of unscheduled maintenance will be 154.6% more than the existing interval.

Conclusions:

a. Information on the length of delay time (h) determines significantly the justification of an escalation proposal. It means the time period since a defect initiation and the functional failure of an item, for a particular failure mode, determines the allowable escalation interval.

b. The ratio of the number of findings and the number of inspections and the interval utilisation only are not enough to justify an escalation proposal. It must be supplied also with unscheduled maintenance data of the MRI's, in order to estimate the length of delay time and the *imperfection of inspections*.

c. 80% interval utilisation is quite low. 20% increase of the existing intervals will be equal to 50% increase of the actual intervals. Therefore, this may result in a significant increase of unscheduled maintenance.

d. The utilisation of the interval should be used as a parameter for estimation of probabilities of findings and unscheduled maintenance.

e. If h<T, indicated by the appearance of unscheduled maintenance, how small the delay time h results in how bad the impact of escalation to the number of unscheduled maintenance.

f. Information on the distribution of defect initiation can improve the estimation results. This information can be gathered from the failure mode, failure cause and failure mechanism of each finding or functional failure.

6.3.4 Analysis of the Boeing Method

From the delay time model point of view, the problems encountered with the inspection interval escalation are the estimation of delay time function f(h) and the probability of defect initiation distribution g(y) (see Fig. 6.6 and section H.5 of Appendix H). In sub-section 6.3.3 g(y) is assumed uniformly distributed and f(h) is assumed equal to h. Estimation of g(y) involves the initial time, i.e. time where the item can be considered as good as new (zero hours). The initial time can be Time Since New (TSN), Time Since Overhaul (TSO) or Time Since Install (TSI). Selection of the most appropriate initial time is another subject of investigation. Since available data of inspection does not include the 'distance' between each inspection to any initial time, then estimation of g(y) is not relevant to be discussed further in this thesis.

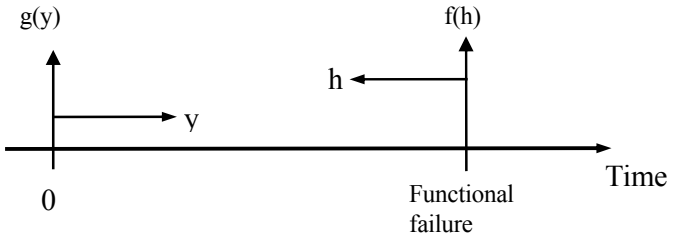


Fig. 6.6 The defect initiation distribution g(y) and the delay time distribution f(h)

If the existing approved interval is escalated (1+x) times, then by applying provisional intervals of (1+0.5*x) and (1+x) to sample aircraft, the changes of the number of unscheduled maintenance and the ratio of findings can be used to estimate f(h). Application of these intervals consecutively for several times (3-5 times) on the sample aircraft can be used to evaluated whether the position of the defect initiation concentration y>T' or y>2T' (see Fig. 6.7).

Estimate of f(h):

Estimate of f(h) can only be made if g(y) is known. *It is assumed*, as in the analysis of the Garuda method on sub-section 6.3.3, that *the defect initiation g(y) has a uniform distribution* with density of k. Let h is as the estimate of f(h), as the mean.

Consider an inspection with *interval utilisation of 80%. Assume the inspection is perfect.* The existing approved interval becomes T/0.8. By escalating 20% of the existing approved interval, the new interval will be (T/0.8)*1.20=1.5T. For 10% escalation, the new interval will be (T/0.8) * 1.1 = 1.375T.

When on the provisional intervals an escalation of 10% (=0.5*x) and 20% (=x) are applied, then monitoring on the number of unscheduled maintenance must be made. The following situations will be obtained:

a. If the number of unscheduled maintenance is still the same for those both intervals, then h>1.5T. Escalation of 20% is justified
b. If the number of unscheduled maintenance increases for the 20% interval escalation and not for the 10% interval escalation, then 1.375T<h<1.5T. Therefore, escalation is

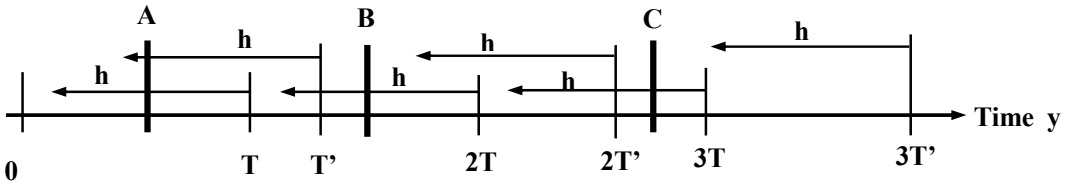
justified only for 10%

c. If the number of unscheduled maintenance increases for both the 10% and 20% escalation, then 1.2T<h<1.375T. Therefore, escalation is not justified.

Information gained due to consecutive interval:

The assumption used in the application of consecutive interval is that *the inspection is perfect.* From the delay time point of view, a rationale of applying the escalated interval several times consecutively is to detect possibility of having a concentrated defect initiation with defect initiation y longer T'. However, it is not the intention to estimate defect initiation distribution g(y), as mentioned earlier, due to unavailability of data.

A defect is normally detected as a potential failure or inspection repair (non-routine maintenance) when the inspection interval is T. But, when the inspection interval is escalated and becomes T', a defect may arise before the delay time. As a result, it leads to an unscheduled maintenance. Point B of Fig. 6.7 shows this situation. A defect initiation can occur at y longer than 2T', as shown by point C of Fig. 6.7. Therefore, the third application of the escalated interval on sample aircraft is to detect possibility of having defect initiation longer than 2T'. Points A, B and C indicate a possible position in time of defect initiation from an initial time 0. With the existing interval, defect due to B and C are detected during inspection at 2T and 3T, respectively. But, with the escalated interval T', B and C lead to unscheduled maintenance. An increase of unscheduled maintenance indicates that h>T and the escalation **is not** justified.



A, B, C = defect initiation position **T** = existing interval **T'** = escalated interval
h = the length of delay time

Fig. 6.7 Rationale to apply the escalated interval several times

Conclusions:

a. The form of the defect initiation distribution (also other than a uniform distribution) determines the justification of interval escalation

b. The length of delay time h determines the interval escalation justification

c. If the unscheduled maintenance increases, than the escalation **is not** justified.

d. The Boeing method is more reliable to estimate the probability of defect initiation and delay time

e. The Boeing method requires another method to estimate the escalated interval and the

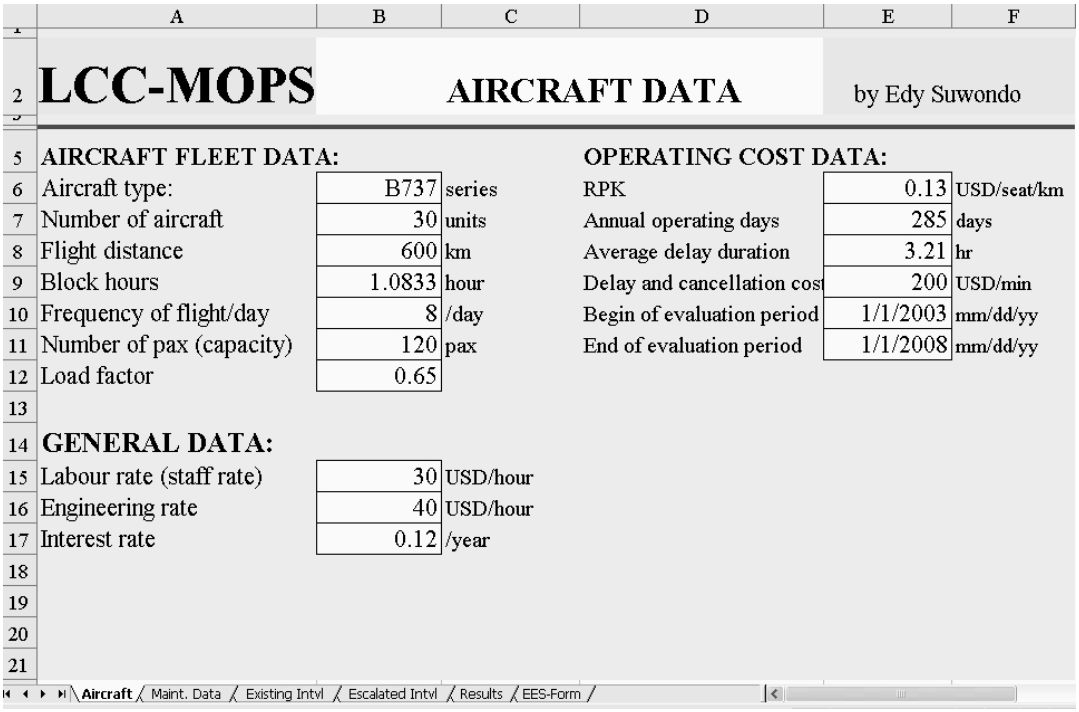
method discussed in section 6.4, the LCC-MOPS, is applicable by making use of the information of relevant unscheduled maintenance and findings.

6.4 Input for the LCC-MOPS

Table 6.2a until 6.2d show the input for the LCC-MOPS. The input are divided into groups according to the level of hierarchy of maintenance program (aircraft, package, MRI).

a. aircraft level: aircraft fleet data, general data and operating cost data
b. maintenance package level: package title, escalation costs per aircraft and the required aircraft modification costs
c. maintenance activities level: the current maintenance package interval (routine, non-routine and unscheduled maintenance) and the projected maintenance package interval (routine, non-routine and unscheduled maintenance)
d. Individual MRI data which is required for aircraft engineering analysis:
   - the time (FH, date or cycles) when inspections are conducted
   - number of inspections
   - the time (FH, date or cycles) when a finding is discovered
   - findings, failure modes and causes
   - number of findings
   - the time (FH, date or cycles) when the functional failure occurs
   - unscheduled maintenance, failure mode and causes.

Figures 6.8a, b, c and d show the input displays of the LCC-MOPS. The entries in Fig's. 6.8a, b, c and d are hypothetical because the real data is not available. Data sources will be identified during the discussion of the TO-BE situations (section 7.5 of Chapter 7). This is because the data sources are strongly related to the evaluation process.



LCC-MOPS — **AIRCRAFT DATA** — by Edy Suwondo

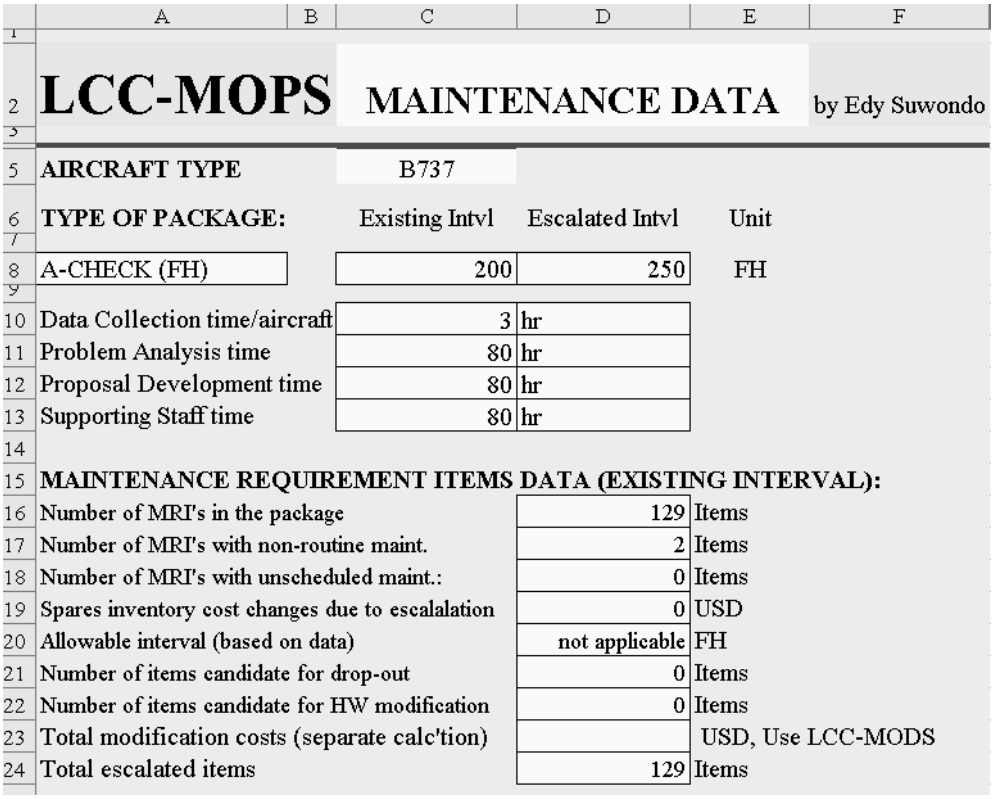
AIRCRAFT FLEET DATA:			OPERATING COST DATA:		
Aircraft type:	B737	series	RPK	0.13	USD/seat/km
Number of aircraft	30	units	Annual operating days	285	days
Flight distance	600	km	Average delay duration	3.21	hr
Block hours	1.0833	hour	Delay and cancellation cost	200	USD/min
Frequency of flight/day	8	/day	Begin of evaluation period	1/1/2003	mm/dd/yy
Number of pax (capacity)	120	pax	End of evaluation period	1/1/2008	mm/dd/yy
Load factor	0.65				

GENERAL DATA:

Labour rate (staff rate)	30	USD/hour
Engineering rate	40	USD/hour
Interest rate	0.12	/year

Aircraft / Maint. Data / Existing Intvl / Escalated Intvl / Results / EES-Form

Fig. 6.8a Aircraft level input for the LCC-MOPS



LCC-MOPS — **MAINTENANCE DATA** — by Edy Suwondo

AIRCRAFT TYPE B737

TYPE OF PACKAGE:	Existing Intvl	Escalated Intvl	Unit
A-CHECK (FH)	200	250	FH

Data Collection time/aircraft	3	hr
Problem Analysis time	80	hr
Proposal Development time	80	hr
Supporting Staff time	80	hr

MAINTENANCE REQUIREMENT ITEMS DATA (EXISTING INTERVAL):

Number of MRI's in the package	129	Items
Number of MRI's with non-routine maint.	2	Items
Number of MRI's with unscheduled maint.:	0	Items
Spares inventory cost changes due to escalalation	0	USD
Allowable interval (based on data)	not applicable	FH
Number of items candidate for drop-out	0	Items
Number of items candidate for HW modification	0	Items
Total modification costs (separate calc'tion)		USD, Use LCC-MODS
Total escalated items	129	Items

Fig. 6.8b Maintenance package level input for the LCC-MOPS

	A	B	C	D	E	F	G
2	**LCC-MOPS**	**EXISTING INTERVAL**				by Edy Suwondo	
5	Routine maint. name	Labour hour	Material cost	Downtime	Interval (FH)	Total Cost	Total Time
6	A-check package	29	200	3	200	13214.1	37.0
10							
11				TOTAL =		13214.1	37.0
12	Non-routine maint. name:	Labour hour	Material cost	Downtime	Nr./year	Total Cost	Total Time
13	Return filter indicator fails	0.25	100	0	2	215.0	0.00
17						0.0	0.00
18				TOTAL =		215.0	0.00
19	Unscheduled maint. name:	Labour hour	Material cost	Downtime	Nr./year	Total Cost	Total Time
20	XYZ (hypothetical)	2	200	1	1	260.0	1.00
24						0.0	0.00
25				TOTAL =		260.0	1.00
26	Total 'direct' maintenance cost:	13,689	Maint. Dependent cost:		12,000	Opport. rev.	213,689

Fig. 6.8c MRI level input of the existing interval for the LCC-MOPS

	A	B	C	D	E	F	G
2	**LCC-MOPS**	**ESCALATED INTERVAL**				by Edy Suwondo	
5	Routine maint. name:	Labour hour	Material cost	Downtime	Interval	Total Cost	Total Time
6	A-check package	29	200	3	250	10,571	29.64
10							
11				TOTAL =		10,571	29.64
12	Non-routine maint. name:	Labour hour	Material cost	Downtime	Nr./year	Total Cost	Total Time
13	Return filter indicator fails	0.25	100	0	3	323	0.00
17						0	0.00
18				TOTAL =		323	0.00
19	Unscheduled maint. name:	Labour hour	Material cost	Downtime	Nr./year	Total Cost	Total Time
20	ABC (hypothetical)	2	200	1	2	520	2.00
24						0	0.00
25				TOTAL =		520	2.00
26	Total 'direct' maintenance cost:	11,414	Maint. Dependent cost:		24,000	Opport. rev.	177,691

Fig. 6.8d MRI level input of the escalated interval for the LCC-MOPS

6.5 Output of the LCC-MOPS

The final output of the LCC-MOPS is a completed LCC-MOPS Form. Before the result is displayed in the LCC-MOPS Form, it is shown in the 'RESULTS' worksheet. The result consists of:

k. Investment cost: Engineering hour costs and modification costs. The Engineering costs consist of a Data Collection cost, Problem Analysis cost, Proposal Development cost, Staff cost. The inspection interval escalation may require modifications to increase aircraft reliability, therefore modification costs are included.

l. Direct Maintenance Cost savings (DMC)
m. Maintenance Dependent Cost savings (MDC)
n. Inventory cost reduction
o. Resale value increase due to less maintenance frequency
p. Other cost reduction (to facilitate special cases)
q. Opportunity revenue
r. LCC-OPS per aircraft
s. LCC-OPS at fleet level.

The distribution of the expenses and the savings are shown in the form of a table (see Fig. 6.9). The total cost savings as a function of time is shown in a chart as well. Figure 6.10a and b show the LCC-MOPS Form.

As mentioned earlier the entries of the input in Fig. 6.8a through 6.8d are hypothetical, but it is made as close as possible to the real data (see also section J.5 of Appendix J, where the unscheduled maintenance does not exist in the real data). The LCC-MOPS of the hypothetical data input is 177,865.- for 5 years evaluation period, Net Present Value. The calculation of LCC-MOPS is based on the total LCC-MOPS of the fleet divided by the number of aircraft in the fleet. This is because the investment for escalation is for the fleet, not for an individual aircraft.

The LCC-MOPS savings are dominated by opportunity revenue coming from the reduction of aircraft downtime for routine maintenance. The non-routine and unscheduled maintenance may reduce the opportunity revenue, but this reduction is relatively small.

LCC-MOPS **RESULTS** by Edy Suwondo

Engineering hour costs :	11,500	USD	
Data Collection cost	2,700	USD	
Problem Analysis cost	3,200	USD	
Proposal Development cost	3,200	USD	
Supporting staff costs	2,400		
Modification Costs (fleet)	0	USD	
Resale value increase	0	USD	
Direct maintenance cost savings/yr	2,275	USD	
Maint. Dependent cost savings/yr	-12,000	USD	
Inventory cost reduction/yr	0	USD	
Other cost reduction/yr	0.0	USD	
Opportunity revenue/yr	35,998	USD	
LCC-OPS per aircraft	105,693	USD	
Period of evaluation	5	years	
LCC-OPS at fleet level	3,170,784	USD	
ADDITIONAL CRITERIA:			
Payback Period (with interest)	0.0146	years	
Return On Investment (ROI)	6,854.0	%	
Internal Rate of Return (IRR)	Not applicable	%	

Fleet level calculation

Year	Expenses	Savings (USD)	Total (USD)
1	11,500	788,211	776,711
2		788,211	703,760
3		788,211	628,357
4		788,211	561,033
5		788,211	500,922

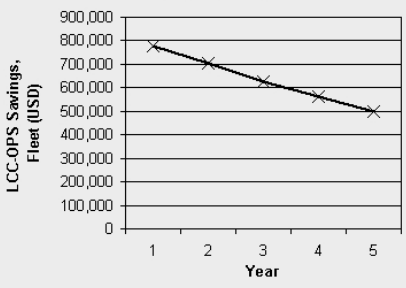


Fig. 6.9 The 'RESULTS' worksheet of the LCC-MOPS

LCC-MOPS FORM

Designed by Edy Suwondo

page 1/2

No: Date: 14-Apr-03 A/C Type: B737

ATA: SUB-ATA: Part No.:

TITLE: **Escalation of A-check interval form 200 FH to 250 FH**

REF: None DATE:

TARGETS SUMMARY:

LCC-OPS SAVINGS **177,865** USD/Aircraft Number of A/C: 30

INVESTMENT REQ. **11,500** USD/Fleet

Performance improv.

Other Benefits: Increase aircraft availability

Priority: [ ] Mandatory [ ] Recommended [ ] Pending

Prepared by: Checked by: Approved by:

Date:

ENGINEERING VERIFICATION:

Result: [ ] Feasible [ ] Not feasible [ ] Pending

Justifications:

Reference: Engineering Analysis Report: AER/xx/yy/zz

Prepared by: Checked by: Approved by:

Date:

DEMONSTRATION SUMMARY (see page 2/2 for detail):

Investment req. (USD): Operating cost (USD):

LCC-OPS SAVINGS: USD

Performance: Improvement is not measurable/noticed

Negative impacts:

Reference: Operation Report: OR/xx/yy/zz

Prepared by: Checked by:

Date:

Fig. 6.10a The LCC-MOPS Form (1/2)

LCC-MOPS FORM

Designed by Edy Suwondo

page 2/2

PROJECTED SAVINGS (Annual):

Maintenance Dependent Costs:		Numbers	Projected (USD)	Realised (USD)
Delay:		0	0	
Cancellation :				
Others :				
Direct Maintenance:		Numbers or hours	Projected (USD)	Realised (USD)
Routine Maintenance :	DMC:		2,643	
	Down time:	7.4	41,615	
Non-routine Maint.:	DMC:		-108	
	Down time:	0.0	0	
Unsched. Maint.:	DMC:		0	
	Down time:	0.00	0	
Spares:			0	
Subtotal (A):			44,150	
Life Cycle (Evaluation Period):		5.00 years		
IMPLEMENTATION :		Units	Projected (USD)	Realised (USD)
Engineering hours				
	Data collection	90	2,700	
	Supporting Staff	80	2,400	
	Engineering man-hours:	160	6,400	
Modification costs (incl. revenue lost)		None		
	Ground time (from LCC-MODS)	None		
Others :		None		
Sub-total (B):			11,500	
Increase resale value (C):		None		
LCC-OPS (A*Life Cycle - B + C), PV:			**177,865**	

OTHER BENEFITS:

Increase aircraft availability:	[ ] Yes	[ ] No
Passenger satisfaction:	[ ] Yes	[ ] No
Crews convenience:	[ ] Yes	[ ] No

NOTES :

Fig. 6.10b The LCC-MOPS Form (2/2)

6.6 Application of the LCC-MOPS

This section describes shortly the application of the LCC-MOPS. The details of the application and the results can be seen in Appendix J. The objective of the application is to evaluate the feasibility to escalate the interval of A-check of B737-300/400/500 from 200 flight hours (FH) to 250 flight hours (FH).

6.6.1 Description of the problem

Current A-check interval of B737-300/400/500 is 200 FH, it is still the same with the MRB document. At this interval, the ratio of number of findings and number of inspections is very small (less than 1% in average). Some airlines in Europe have their A-check interval of B737-300/400/500 is more than 250 FH. Without having experience with A-check interval of 250 FH, is it impossible to escalate the A-Check interval for higher than 250 FH.

6.6.2 The process of the LCC-MOPS application

First of all, relevant cost components and elements are identified for the existing interval and the escalated interval. A Cost Breakdown Structure (CBS) is developed to support this activity (Fig. J.1 of Appendix J). The existing interval is considered as the baseline, where all cost components of the CBS are relative to this baseline. Estimation (calculation) of these cost components is then carried out. The labour and supporting staff rate used is USD 30/hour, while engineering rate is USD 40/hour. Estimation is done for 5 years basis, namely for the period of beginning of 2003 until beginning of 2008. No modification is required because the failure data indicate that the items in the A-check package have a high reliability. This is shown by no unscheduled maintenance and a very low ratio of the number of findings and the number of inspections.

6.6.3 The results of the LCC-MOPS application

The total annual operating costs savings at fleet level is:

USD (6,645,060 - 5,320,560) = USD 1,324,500.-

The investment required for the escalation is USD 11,500.-

Total LCC-MOPS savings at fleet level is USD 5,335,969.- (Present Value). At aircraft level the LCC-MOPS is USD 177,865.- for five years of evaluation period.

Increase of 25% of the existing interval results in 55% increase of the findings probability, if the defect initiation is assumed uniformly distributed. However, the absolute value of the probability of defects detected is only 2.65%. *For this reason, 25% escalation of the existing interval* ***is justified.***

6.6.4 The discovered problems by applying the LCC-MOPS

Two main problems of the application of the LCC-MOPS for A-check escalation of B737 series are:

a. unscheduled maintenance data does not exist. This data is used to estimate the length of delay time
b. number of findings is very limited, even with 117 inspections only two findings were discovered. This information is used to predict the number of findings if the escalated interval is applied.

With data limitations above, the escalation becomes until the maximum allowable increase of inspection interval. In this situation, the role of the maximum limit of the increase of inspection interval is very vital, if the Garuda method (without a provisional check interval) is applied. For this reason the author recommends to use the Boeing method to reduce the risk of having an un-expected length of delay time, as discussed in sub-section 6.3.4. However, a change of the escalation method will take sometime due the requirement of approval from the Regulatory Authority.

Table 6.1a Cost component estimation method

Cost component	Estimation method
Investment costs (C_I)	$C_I = C_{IE} + C_{IM}$ Where: C_{IE} = Engineering hour costs C_{IM} = Modification costs to increase reliability
Engineering hour costs (C_{IE})	$C_{IE} = C_{IEC} + C_{IEA} + C_{IEE} + C_{IES}$ Where: C_{IEC} = Data collection cost C_{IEA} = Data analysis cost C_{IEE} = Escalation proposal development cost C_{IES} = Supporting staff cost
Data collection costs (C_{IEC})	C_{IEC} = NRAC * DCTM * LABRT Where: NRAC = Number of aircraft DCTM = Data collection time per aircraft LABRT = Labour rate (assumed equal to mechanic labour rate).
Problem analysis costs (C_{IEA})	C_{IEA} = PATM*ENGRT = NRPRO * RTPPR * ENGRT Where: PATM = Problems analysis time NRPRO = Number of problems to be analysed RTPPR = Required time per problem (average) ENGRT = Engineering hour rate
Escalation proposal development costs (C_{IEE})	C_{IEE} = PRDTM * ENGRT Where: PRDTM = Escalation proposal development time ENGRT = Engineering hour rate
Supporting staff costs (C_{IES})	C_{IES} = STFTM * LABRT = NRSTF * NRDIN * LABRT Where: STFTM = Supporting staff time required (total) NRSTF = Number of staff involved HRSTF = Number of hours per staff LABRT = Labour rate (assumed equal to mechanic labour rate).
Modification costs (C_{IM})	C_{IM} = MODCOS = Modification cost to increase the reliability of MRI's with low reliability (use LCC-MODS to estimate these costs)
Changes of operating cost *per trip* (C_O)	$C_O = C_{OM} + C_{OD}$ Where: C_{OM} = Changes of maintenance cost C_{OD} = Changes of depreciation cost

Table 6.1b Cost component estimation method (continued)

Cost component	Estimation method
Changes of maintenance cost (C_{OM})	$C_{OM} = C_{OMS} + C_{OMN} + C_{OMU} + C_{OMD} + C_{OMP}$ Where: C_{OMS} = due to scheduled maintenance changes C_{OMN} = due to non-routine maintenance changes C_{OMU} = due to unscheduled maintenance changes C_{OMD} = due to maintenance dependent cost changes C_{OMP} = due to required spares changes
Changes of routine maintenance cost (C_{OMS})	C_{OMS} = ((CRLBHR*LABRT+CRMAT)*(FLFRE *BLHR*ANUTL)/CRINT) - ((PRLBHR*LABRT+PRMAT))*(FLFRE *BLHR*ANUTL)/PRINT) Where: CRLBHR = current labour hours for each check LABRT = labour rate CRMAT = required material/spares for each check, for the current check interval FLFREQ = daily flight frequency BLHR = block hour of each flight ANUTL = annual utilisation of the aircraft CRINT = current length of check interval. PRLBHR = projected labour hour for each check PRMAT = required material for each check, for the projected check interval PRINT = projected length of check interval.
Changes of non-routine Maintenance cost (C_{OMN})	C_{OMN} = (B12*LABRT+C12)*E12 $\sum(CRNMNR_i*(CRNMLAB_i * LABRT+ CRNMMT_i)) - \sum(PRNMNR_i * (PRNMLB_i *LABRT+PRNMMT_i))$ Where: $CRNMNR_i$ = number of non-routine maintenance i per year at the current check interval. $CRNMLB_i$ = required man hour for each non-routine maintenance i at the current check interval. $CRNMMT_i$ = material cost of each non-routine maintenance i at the current check interval. LABRT = labour rate. $PRNMNR_i$ = number of non-routine maintenance i per year at the projected check interval. $PRNMLB_i$ = required man hour for each non-routine maintenance i at the projected check interval.

Table 6.1c Cost component estimation method (continued)

Cost component	Estimation method
	$PRNMMT_i$ = material cost of each non-routine maintenance i at the projected check interval.
Changes of unscheduled maintenance cost (C_{OMU})	$C_{OMU} = \sum(CRUMNR_i*(CRUMLB_i *LABRT + CRUMMT_i)) – \sum(PRUMNR_i * (PRUMLB_i *LABRT + PRUMMT_i))$ Where: $CRUMNR_i$ = number of unscheduled maintenance i per year at the current check interval. $CRUMLB_i$ = required man hour for each unscheduled maintenance i at the current check interval. $CRUMMT_i$ = material cost of each unscheduled maintenance i at the current check interval. LABRT = labour rate. $PRUMNR_i$ = number of unscheduled maintenance i per year at the projected check interval. $PRUMLB_i$ = required man hour for each unscheduled maintenance i at the projected check interval. $PRUMMT_i$ = material cost of each unscheduled maintenance i at the projected check interval.
Changes of maintenance Dependent cost (C_{OMD})	$C_{OMD} = (\sum PRUMDT_i – \sum CRUMDT_i)* 60 * DACC$ Or (depends on availability of data) $C_{OMD} = (\sum PRUMNR_i – \sum CRUMNR_i)* AVDEL*60 * DACC$ Where: $CRUMNR_i$, $PRUMNR_i$ are as earlier DACC = delay and cancellation cost per minute AVDEL = average delay duration in hours $CRUMDT_i$ = annual downtime of unscheduled maintenance i at the current check interval. PRUMDT = annual downtime of unscheduled maintenance i at the projected check interval.
Changes of the required spares inventory (C_{OMP})	C_{OMP} = SPCCHG Where: SPCCHG = changes of the required annual spares inventory.
Annual changes of depreciation cost (C_{OD})	C_{OD} = 0 (assumed)

Table 6.1d Cost component estimation method (continued)

Cost component	Estimation method
Changes of revenue (R)	$R = R_A$ Where: R_A = changes of revenue due to changes of availability in the life cycle
Changes of revenue due to Availability changes (R_A)	$R_A = R_{AS} + R_{AN} + R_{AU}$ Where: R_{AS} = changes of revenue due to changes of scheduled maintenance time in the life cycle R_{AN} = changes of revenue due to changes of non-routine maintenance time in the life cycle. R_{AU} = changes of revenue due to changes of unscheduled maintenance time in the life cycle R_A = (PRSMDT/CRINT-CRSMDT/PRINT + $\sum PRNRDT_i$ – $\sum CRNRDT_I$ + $\sum PRUMDT_i$ – $\sum CRUMDT_i$) *(FLFRE* BLHR *ANUTL) *RVPH Where: CRSMDT = downtime of scheduled maintenance of the current check interval. CRINT = current interval (FH) PRSMDT = downtime of scheduled maintenance of of the projected check interval. PRINT = projected interval (FH) FLFRE = flight frequency BLHR = block hour ANUTL = annual utilisation (days) RVPH = revenue per hour = LF * NRPAX * FLDIS * RPK / BLHR LF = load factor NRPAX = number of passengers (capacity) FLDIS = Flight distance RPK = revenue passenger kilometre (USD) $PRNRDT_i$, $CRNRDT_i$, $PRUMDT_i$, $CRUMDT_i$ are as earlier.

Table 6.2a Input for the LCC-MOPS based on Table 6.1 (continued).

Input name (following LCC-MOPS model)	Input variable	Input unit	Estimated cost component(s)
a.1. AIRCRAFT FLEET DATA:			
Aircraft type (string variable)	ACTYP	None	None
Number of aircraft	NRAC	None	Total fleet LCC-OPS
Flight distance	FLDIS	km	Revenue
Block hour	BLHR	hour	Downtime cost
Frequency of flight (daily)	FLFRE	times/day	Revenue, downtime cost
Number of passenger (capacity)	NRPAX	None	Revenue, downtime cost
Load factor (average)	LF	None	Revenue, downtime cost
a.2. GENERAL DATA:			
Labour rate	LABRT	USD/hour	Labour cost (mod.)
Engineering rate	ENGRT	USD/hour	Engineering cost
Interest rate	INTRT	/year	LCC-OPS profile
a.3. OPERATING COST DATA:			
RPK (Revenue Passenger Kilometre)	RPK	USD/(seat. km)	Revenue, downtime cost
Annual operating days (days)	ANUTL	days/year	Revenue, downtime cost
Average delay duration	AVDEL	hours	Maintenance dependent cost
Delay and cancellation cost	DACC	USD/minute	Maintenance dependent cost
Begin of evaluation period	BEVAL	(date)	LCC-OPS
End of evaluation period	EEVAL	(date)	LCC-OPS

Table 6.2b Input for the LCC-MOPS based on Table 6.1 (continued).

Input name (following LCC-MOPS model)	Input variable	Input unit	Estimated cost component(s)
b.1. CHECK PACKAGE TITLE:			
Type of package	CHECNM	String	Escalation attributes
Current Interval	CRINT	FH	Current maintenance costs
Projected Interval	PRINT	FH	Current maintenance costs
Unit	CHECUN	String	None
b.2. ESCALATION COSTS PER AIRCRAFT:			
Data Collection time/aircraft	DCTM	Hours	Escalation costs
Problems Analysis time	PATM	Hours	Escalation costs
Proposal Development time	PRDTM	Hours	Escalation costs
Supporting Staff time	STFTM	Hours	Escalation costs
b.3. AIRCRAFT CHANGES			
Number of items in the package	NRICHE	Integer	Changes of sched. Maint. Costs
Number of items with non-routine maintenance	NRINM	Integer	Changes of non-routine maint. Costs
Number of items with unscheduled maintenance	NRIUM	Integer	Changes of unsched. Maint. Costs
Spares cost changes due to escalation	SPCCHG	USD	Changes of spares costs
Allowable interval (based on data)	ALLINT	FH or years	Changes of sched. Maint. Costs
Number of items candidate for drop-out	NRIDRP	Integer	Changes of sched. Maint. Costs
Number of items candidate for HW modification	NRIMOD	Integer	Escalation costs
Total modification costs (separate calculation)	MODCOS	USD	Escalation costs
Total escalated items	NRIESC	Integer	Projected scheduled maint. costs.

Table 6.2c Input for the LCC-MOPS based on Table 6.1 (continued).

Input name (following LCC-MOPS model)	Input variable	Input unit	Estimated cost component(s)
c.1. CURRENT MAINTENANCE INTERVAL			Maintenance cost, opportunity revenue.
Scheduled maintenance name	CRSMNM	String	CRSMTDM (Total Direct Maintenance Cost
Labour hour	CRSMLB	Hours	due to Scheduled Maintenance at the Current
Material cost	CRSMMT	USD	interval), CRSMTDT (Total Down Time due
Downtime	CRSMDT	Hours	to Scheduled Maintenance at the Current
Interval	CRINT	FH	interval)
Non-routine maintenance name	CRNMNM	String	CRNMTDM (similar, for Non-routine
Labour hour	CRNMLB	Hours	Maintenance)
Material cost	CRNMMT	USD	CRNMTDT (similar, for Non-routine
Downtime	CRNMDT	Hours	Maintenance)
Annual frequency	CRNMNR	Times/year	
Unscheduled maintenance name	CRUMNM	String	CRUMTDM (similar, for Unscheduled
Labour hour	CRUMLB	Hours	Maintenance)
Material cost	CRUMMT	USD	CRUMTDT (similar, for Unscheduled
Downtime	CRUMDT	Hours	Maintenance)
Annual frequency	CRUMNR	Times/year	

Table 6.2d Input for the LCC-MOPS based on Table 6.1 (continued).

Input name (following LCC-MOPS model)	Input variable	Input unit	Estimated cost component(s)
c.2. PROJECTED MAINTENANCE INTERVAL			Maintenance cost, opportunity revenue
Scheduled maintenance name	PRSMNM	String	PRSMTDM (Total Direct Maintenance Cost
Labour hour	PRSMLB	Hours	due to Scheduled Maintenance at the
Material cost	PRSMMT	USD	Projected interval), PRSMTDT (Total Down
Downtime	PRSMDT	Hours	Time due to Scheduled Maintenance at the
Interval	PSMNR	FH	Projected interval)
Non-routine maintenance name	PRNMNM	String	PRNMTDM (similar, for Non-routine
Labour hour	PRNMLB	Hours	Maintenance)
Material cost	PRNMMT	USD	PRNMTDT (similar, for Non-routine
Downtime	PRNMDT	Hours	Maintenance)
Annual frequency	PRNMNR	Times/year	
Unscheduled maintenance name	PRUMNM	String	PRUMTDM (similar, for Unscheduled
Labour hour	PRUMLB	Hours	Maintenance)
Material cost	PRUMMT	USD	PRUMTDT (similar, for Unscheduled
Downtime	PRUMDT	Hours	Maintenance)
Annual frequency	PRUMNR	Times/year	

Chapter 7

TO-BE Situation of Maintenance Program Optimisation

This chapter describes the TO-BE situation of the Maintenance Program Optimisation process, where the LCC-MOPS model is part of. This chapter begins with the analyses of the AS-IS situation and it is followed by a description of the proposed LCC-MOPS Form. Interval escalation of a maintenance program requires evaluation of each Maintenance Requirement Item (MRI) performance (findings) of the previous checks. For this reason, a decision diagram to find the most appropriate treatment for each MRI is required. The Escalation Decision Diagram is proposed for this purpose. This chapter is closed with discussion of the sources of the required data input to implement the TO-BE situation. Discussion on organisational aspect is considered as not necessary because the AS-IS situation is sufficient.

7.1 Analysis of the AS-IS situation

Section 5.5 describes the AS-IS process of Letter Check Interval Escalation. Sub-process E1-1 (Prepare the required data for escalation) indicates that the driver or the initiator of the process is the request from management (Vice President of Technical Services or the Director of Maintenance and Engineering). In this request there is no explicit cost consideration. Therefore, it is expected that the unit of Maintenance Program Management will be active in collecting MRI's performance data, without waiting for the request from the management. MRI's performance data can be used to evaluate the performance of the existing Maintenance Program as well as to evaluate the feasibility of an attempt to escalate the maintenance interval.

Sub-process E1-2 (Evaluate all MRI’s with respect to MDR, PIREPS and MAREPS) of section 5.5 describes the four criteria to judge whether an MRI's interval is justifiable to be escalated. These criteria are the significance of the findings, repetition, correlation with PIREPS and finding/inspection ratio. To make this sub-process more simple, the author developed an "Escalation Decision Diagram" to be applied in the TO-BE Situation. This diagram will be further discussed in section 7.4.

Field research of the author at the Garuda Maintenance Facility shows that almost no data from PIREPS and MAREPS can be used to support analysing MRI's performance. PIREPS and MAREPS data is presented in ATA two or four digits (system or sub-system level). This is not enough to correlate the PIREPS and MAREPS data with the discovered findings. In some cases the reported findings are not relevant, e.g. oil check, filter check, seal replaced, etc. The recordings need to be standardised on what should be recorded and how. In other words, the role of the Reliability Control Program must be stronger in supporting necessary data and information to analyse the findings.

Section 6.3 discussed comprehensively that the use of the ratio of the number of findings to the number of inspections only is not enough to evaluate escalation feasibility. The most important parameter is the estimation of the probability of defect and the probability of failure at the escalated interval. This estimate can be made by using the utilisation of the existing interval, the ratio of number of findings and number of inspections, number of corrective maintenance. After the defect probability estimate is available, the LCC-MOPS can be used to estimate the benefits of the interval escalation.

The points above are the most important issues which need to be improved. The TO-BE situations, in section 7.3, is intended to fulfil these needs.

7.2 The LCC-MOPS Form

Based on the discussion in section 7.1 above, the specifications of the LCC-MOPS Form for Maintenance Program Optimisation are following. The proposed LCC-MOPS Form is shown in Fig. 6.10a and 6.10b of Chapter 6.

a. It shows the economical assessment of the attempt to escalate Maintenance Program interval and contains the report summary on the effectiveness evaluation of the escalation. Escalation is effective when the targeted performance improvements, benefits and cost savings are achieved

b. It supports the implementation of the three phases of the modification process described in section 1.1.2, i.e. target establishment, verification and demonstration

c. The projected performance improvement or benefits, cost savings and implementation costs need to put side by side with the demonstrated ones, in order to be compared easily

d. It supports long term evaluation to obtain:
e. an indication of the amount of cost savings and increase of aircraft availability can be expected by escalating a Maintenance Program interval
f. an indication of the performance of the engineers in terms of the number of escalations made during a certain period of time (years).

g. It records the conclusions and recommendations of Maintenance Program Management section for each project of Maintenance Program escalation, as a ‘lesson learned’, which can be used for the next analysis by engineers and evaluation by managers on similar cases.

7.3 TO-BE: Maintenance Program Optimisation Process

This section discusses the TO-BE situation for letter check interval escalation based on available literature and the results of implementing the proposed TO-BE situation by the author for A-check interval escalation of Garuda B737 series. The TO-BE situation process of letter check escalation is shown in Fig. 7.2 and described below. Comparison with the AS-IS process will be made and when there is a difference between the TO-BE and the AS-IS process, it will be described and improvements motivated.

Letter check escalation, or generally Maintenance Requirements changes, must be done periodically in order to take the benefit of operation and maintenance experiences. However, the process of Maintenance Requirements changes must include safety considerations and must be economically justifiable. The proposed TO-BE situation of letter the check escalation process is derived from the process of target establishment, engineering verification and demonstration (see sub-section 1.1.2 of Chapter 1).

Based on the explanations above, the process of letter check escalation consists of four sub-processes. Each of these sub-processes will be explained further below.

a. Investigate the technical feasibility to escalate a check interval (preliminary estimate, LCC savings target establishment). This can be done periodically depending on the interval of the check, the results of the inspections and the unscheduled maintenance
b. Review the inspection interval of ALI's and CMR's (first approval)
c. Perform engineering analysis of each MRI (engineering verification) on the basis of maintenance history
d. Develop escalation proposal (for the final approval by the Regulatory Authority).

Additional sub-process, i.e. *demonstration* of the LCC savings target, during the production period (in hangar) and operation period, are considered as routine task of Reliability Management and Cost Management (see Fig. 4.2). The results of this demonstration sub-process are reported to the Maintenance Program Manager for final evaluation of the letter check escalation.

Some airlines apply a provisional interval (as a verification sub-process, see also the Boeing method in sub-section 6.3.2 of Chapter 6) before establishing the final letter check escalation proposal. The results of the application of provisional interval on sample aircraft are to judge the proposed interval. When the results of the sample aircraft satisfy the established requirements, then the provisional interval is justified to become the final escalation proposal. In some cases, the airlines are allowed to establish a new interval (normally higher than the provisional interval) based on the results of sample aircraft, where the new interval is justifiable to become the final interval.

The author considers the application of a provisional interval is conservative, because the proposed interval will be tested first on sample aircraft before it is applied to the whole fleet. However, the author considers the application of a provisional interval is necessary in situations:

a. the fleet data is limited due to new aircraft
b. no operator has experience with the length of the interval. It means that the airlines will be leading in the length of inspection intervals

c. a high ratio of the number of findings and the number of inspections. For this situation, an interval escalation may lead to an increase of unscheduled maintenance.

The author's field research shows that the number of findings is very small and the unscheduled maintenance is very limited (frequently none), therefore the author does not recommend to apply a provisional check for the proposed TO-BE situation. The delay time model is sufficient to determine the allowable increase of inspection interval based on the operation and maintenance data, assuming these are available. The delay time method is discussed in Appendix H.

a. Investigate the technical feasibility to escalate check interval (E2-1-1)

The activity of this box is to investigate the technical possibility to escalate check interval based on available information (data). Modifications can be required for items, under particular MRI's, which do not satisfy the required reliability level for escalation. The ratio of the number of findings and the number of inspections and the amount unscheduled maintenance are the parameters to determine the level of reliability. The Performance Improvement Decision Diagram, as discussed in sub-section 4.3.1, can be applied for selection of the most cost-effective corrective action. The input of this activity are the findings and the unscheduled maintenance related to each MRI in the package. The output is a preliminary estimate of the technical possibility to escalate check interval and the benefits to be gained (LCC savings).

This activity is conducted by the Maintenance Program unit. The investigation should consider the failure effect category of each Maintenance Requirement Item (MRI) in order **not** to overlook MRI with failure effect category of 5 (evident safety) and 8 (hidden safety) (see also Fig. D.1 of Appendix D).

Appendix H discusses the delay time models to be used as a method for optimisation of inspection interval. This method considers the effect of interval utilisation, the ratio of the number of findings and inspections (assumed uniformly distributed defect initiation), and the number of unscheduled maintenance. Actually, the determination of inspection interval cannot be based in the ratio of number of findings and number of inspections, because inspection intervals are originally determined based on the time distance between potential failure and functional failure. Therefore, the prime objective is to estimate the delay time using information on findings and unscheduled maintenance. The confidence level of the estimate depends on the number of findings and unscheduled maintenance (discussed also in Appendix H).

b. Review the inspection interval of ALI's and CMR's (E2-1-2)

The activity of this box is to review the preliminary estimate made by the maintenance program engineer with respect to the maximum inspection interval of ALI's (Airworthiness Limitation Items) and CMR's (Certification Maintenance Requirements). If the escalated

interval is greater than the maximum inspection interval of ALI's and/or CMR's, then the ALI's or CMR's will be dropped out. The review covers also items which have failure effect category of 5 (evident safety) or 8 (hidden safety) and the projected LCC savings. The input of this activity is the preliminary estimate of the technical feasibility and LCC savings.

The output of this activity is a 'Go ahead' statement, if the preliminary estimate is justified. This activity is carried out by the Maintenance Review Committee (MRC).

c. Make engineering analysis for each MRI (E2-1-3)

The activity of this box is to perform an engineering analysis for each MRI which has findings or a relation with PIREPS, MAREPS or technical delays. In order to escalate a maintenance package, all MRI's in the proposed package must be feasible to be escalated. Feasibility evaluation uses the proposed Escalation Decision Diagram shown in Fig. 7.3 (see also description in section 7.4). MRI's which are not feasible to be escalated must be dropped-out.

The input of this activity is the preliminary estimate made by Maintenance Program Engineer and the relevant operation and maintenance data, accompanied with the 'Go ahead' statement from the Maintenance Review Committee (MRC). The output is an evaluated and approved new Maintenance Requirements by the MRC. This activity will be carried out by Aircraft Engineer (specialist).

d. Develop escalation proposal (E2-1-4)

The activity of this box is to develop a proposal to escalate letter check interval to be submitted to the Regulatory Authority for approval. This activity can be done when the earlier activity shows significant LCC savings by escalating the letter check interval.

The input of this activity is the results of MRI performance evaluation, while the output is an evaluated and approved new Maintenance Requirements proposal. This activity will be carried out by the Maintenance Program Manager.

7.4 TO-BE: Escalation Decision Diagram

The Maintenance Requirement Item (MRI) performance data, prepared by Maintenance Program unit (in activity box E2-1-1) should contain all findings and related PIREPS, MAREPS and technical delays for each MRI. After the failure modes of the findings are identified, an analysis is conducted to find the most appropriate (cost-effective) decision/improvement action for each MRI by using the proposed Escalation Decision Diagram. The logic of the proposed Escalation Decision diagram is shown in Fig. 7.3. In fact, this diagram is similar to the proposed Performance Improvement Decision Diagram

discussed sub-section 4.3.1 of Chapter 4, except that the goal of this diagram is to increase failure resistance up to the required level by the proposed new check interval.

Evaluation begins on the performance of the MRI: "1. Are there findings for the MRI?". When there are **no** findings for the MRI under evaluation, then it will check with question "2. Are there PIREPS, MAREPS or technical delays related to the task(s) of the MRI?". Task interval of the MRI can be escalated directly if **no** PIREPS, MAREPS or technical delays related to the maintenance task. But, if there are PIREPS, MAREPS or technical delays related to the maintenance task for the MRI being evaluated, further question is "4. Does LCC indicate savings by escalating the task interval?". The LCC concept is applied to evaluate whether significant savings can be obtained by escalating the interval of the task. LCC evaluation must include the cost of each PIREP, MAREP or technical delay, for both the existing interval and the proposed escalation interval. When significant savings are identified, interval escalation is justified. Otherwise, task revision or modification implementation is required, in question "6. Does LCC indicate savings by revising maintenance task or/and implementing modification at increased interval, taking account also the PIREPS, MAREPS and technical delays?". A "No" answer to question 6 leads to drop-out of the MRI to the lower interval (or higher frequency).

If LCC shows that revision of maintenance task or modification still provide savings, then it will be evaluated which one give the highest savings with question of "7. Does modification give more LCC savings?". A "Yes" (implement modification) or "No" (maintenance task revision) answer will lead to an escalation of the maintenance task interval.

Back to question 1. If there is finding for the MRI, then it will be evaluated further with question "3. Is the failure mode of the finding of airworthiness significance?". If it is **not** of airworthiness significance, then question 4 (mentioned earlier) is posed. A "Yes" answer to question 4 means escalation is justified with Nil Action, while a "No" answer results in evaluation by equation 6 (mentioned earlier). A "Yes" answer for question 6 leads to escalation after task revision and/or modification, but a "No" answer results in drop-out.

If the answer of question 3 is "Yes", then it will be evaluated further with question "5. Will revision of maintenance task or modification improve failure resistance at increased interval?". Because the failure mode is of airworthiness significance, revision of maintenance task or modification requires approval from the Regulatory Authority. Even though the revision of maintenance task or modification is effective to increase failure resistance, decision to implement those action must be based on the economic reason as well, i.e. the LCC savings, including the cost to obtain approval. *Special attention must be given when the functional failure of the item is category of 5 (evident safety) or 8 (hidden safety), especially for CMR and ALI items*. This is evaluated with question 6. Drop-out to higher check frequency is recommended when the LCC evaluation, does not show significant savings.

In summary, escalation of maintenance task interval can be made when:

a. there are no findings during previous checks **and** there are no PIREPS, MAREPS or technical delays related to the maintenance task of the MRI

b. there are no findings during previous checks, there are PIREPS, MAREPS or technical delays related to the maintenance task of the MRI, but LCC evaluation (which takes into

account the PIREPS, MAREPS and technical delays) directly indicates savings by escalating the maintenance task interval

c. there are no findings during previous checks, there are PIREPS, MAREPS or technical delays related to the maintenance task of the MRI, LCC does not directly indicate savings by escalating the maintenance task interval, but after revising the task or/and modify the item, LCC still indicates significant savings

d. there are findings during previous checks, but the failure mode of the findings is not of airworthiness significance **and** LCC evaluation(which takes into account the PIREPS, MAREPS and technical delays) directly indicates savings by escalating the maintenance task interval

e. there are findings during previous checks, but the failure mode of the findings is not of airworthiness significance, LCC evaluation does not directly indicate savings by escalating the maintenance task interval, but after revising the maintenance task or/and modifying the item, LCC still indicates significant savings

f. there are findings during previous checks and the failure mode of the findings is of airworthiness significance, revision of the maintenance task or/and modification of the item will improve the failure resistance of the item at increased interval, and LCC evaluation still indicates significant savings.

Drop-out is necessary for the case of:

a. there are findings for the MRI, the failure mode of the findings is of airworthiness significance and revision of maintenance task or modification of the item does not improve the failure resistance of the item (not effective)

b. revision of the maintenance task or/and modification of the item will improve the failure resistance, but LCC evaluation indicates no significant savings if the maintenance task is revised or/and the item is modified to improve failure resistance (question 6).

The relevance for applying the LCC concept is indicated in questions 4, 6 and 7. A method to apply the LCC concept for this purpose is by using the LCC-MOPS form, as discussed earlier in section 7.2.

7.5 Input Data Sources

Observations at GMF shows that data of inspection findings is readily available, at ATA 6 digits and indication of the failure mode. The main problem is the detail of the unscheduled maintenance data, so that it is useable for analysis of the maintenance task under escalation evaluation. Although the reliability program based on AC120-17A has been approved and implemented, it is not enough to support Maintenance Program Optimisation.

The sources of the required data for the LCC-OPS for Maintenance Program Optimisation are mostly similar to the data sources for Aircraft Modifications (see Table 4.1). These sources are shown in Table 7.1.

For the purpose of delay time estimation, it is recommended in the report of findings to indicate HLA (How Long Ago could the defect have first been noticed) and HML (if the repair was not carried out, How Much Longer could it be delayed). For unscheduled maintenance (functional failures) HLA is applicable. Delay time estimates are the main basis to judge the appropriateness of the inspection intervals. Appendix H discusses this subject in detail.

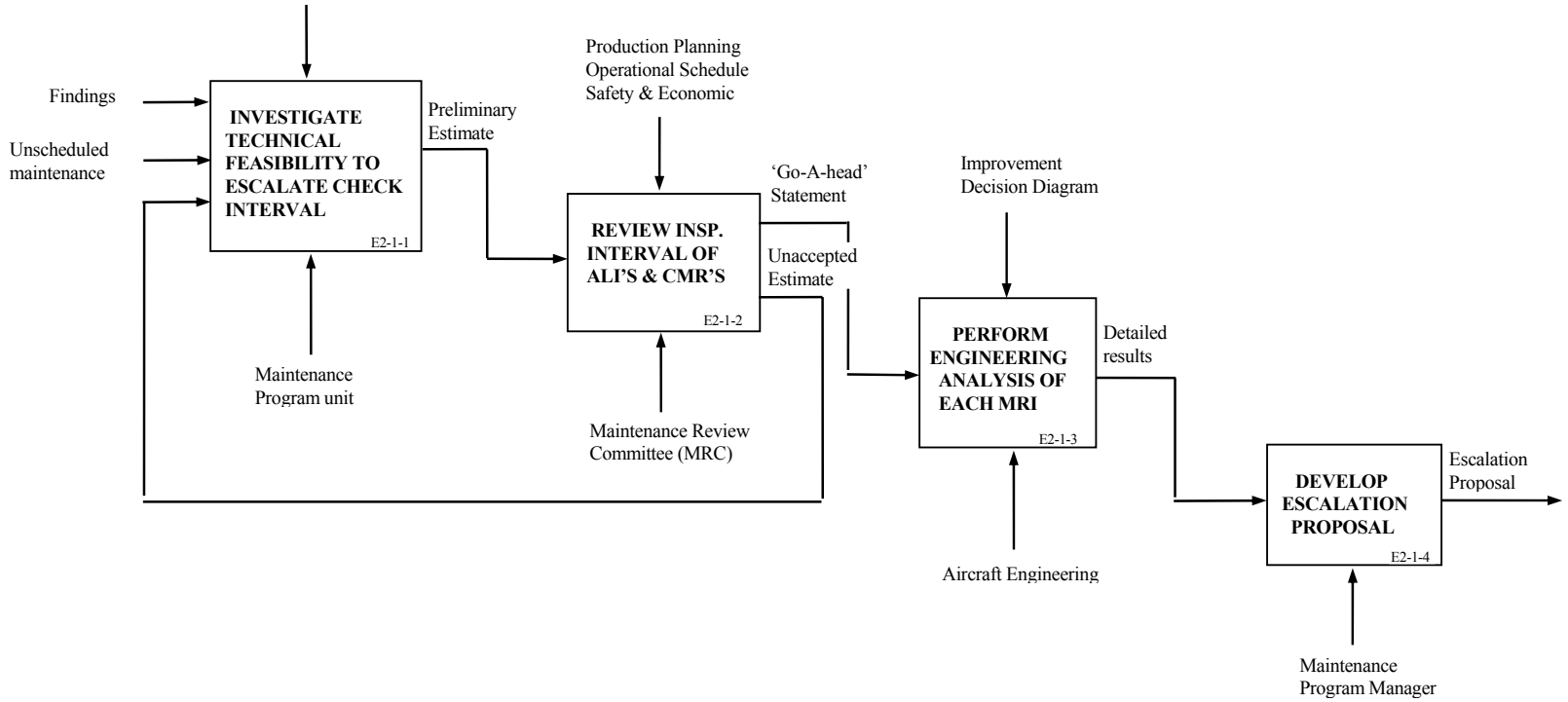
Table 7.1a Source of the input of the LCC-MOPS model (see also Table 6.1)

Input variable	Meaning	Source of information	Current availability
ACTYP	Aircraft type	Reliability report	Yes
NRAC	Number of aircraft	Reliability report	Yes
FLDIS	Flight distance	Operation data	Yes
BLHR	Block hour	Operation data	Yes
FLFRE	Flight frequency	Reliability report	Yes
NRPAX	Number of passengers	Operation data	Yes
LF	Load factor	Marketing data	Yes*
LABRT	Labour rate	Finance data	Yes
ENGRT	Engineering rate	Finance data	Yes
INTRT	Interest rate	Finance data	No
RPK	Revenue passenger kilometre	Marketing/WFA	Yes*
ANUTL	Annual utilisation	Reliability report	Yes
AVDEL	Average delay duration	Reliability report	Yes
DACC	Delay and cancellation cost	Finance data	Yes*
BEVAL	Begin evaluation time	Input of analyst	Yes
EEVAL	End evaluation time	Input of analyst	Yes
CHECNM	Check name	Input of analyst	Yes
CRINT	Current interval	Maintenance Program	Yes
PRINT	Projected interval	Input of analyst	Yes
CHECUN	Check interval unit	Maintenance Program	Yes
DCTM	Data collection time	Analyst estimate	No
PATM	Problem analysis time	Analyst estimate	No
PRDTM	Proposal development time	Analyst estimate	No
SSTM	Supporting staff time	Analyst estimate	No
NRICHE	Number of item in check	Maintenance Program	Yes
NRINM	Number of non-routine maint.	MDR	Yes
NRIUM	Number of unscheduled maint	MCDR	No
SPCCHG	Spare cost changes	Material record	No
ALLINT	Allowable interval	Engineering Analysis	No
NRIDRP	Number of drop-outs	Engineering Analysis	No
NRIMOD	Number of HW modification	Engineering Analysis	No
MODCOS	Total modification cost	Engineering Analysis	No
NRIESC	Total escalated items	Engineering Analysis	No

Yes* = Currently available but limited and not well documented.

Table 7.1b Source of the input of the LCC-MOPS model (see also Table 6.1).

Input variable	Estimated cost component(s)	Source of information	Current availability
CR …	Current interval …		
CRSMNM	Scheduled maintenance name	Maintenance Program	Yes
CRSMLB	Sched. maint. labour hour	Job card accomplishment	Yes
CRSMMT	Sched. maint material cost	Job card accomplishment	Yes
CRSMDT	Sched. maint. downtime	Job card accomplishment	Yes
CRNMNM	Non-routine maint. name	MDR	Yes
CRNMLB	N-routine maint. labour hour	Job card accomplishment	Yes
CRNMMT	N-routine maint. material cost	Job card accomplishment	Yes
CRNMDT	N-routine maint. downtime	Job card accomplishment	Yes
CRNMNR	N-routine maint. annual frequency	MDR	Yes
CRUMNM	Unscheduled maintenance name	MCDR	Yes
CRUMLB	Unsched. maint. labour hour	Job card accomplishment	Yes
CRUMMT	Unsched. maint. material cost	Job card accomplishment	Yes
CRUMDT	Unsched. maint. downtime	Job card accomplishment	Yes
CRUMNR	Unsched. maint. annual frequency	MCDR	Yes
PR …	Projected interval …	Will be:	Will be:
PRSMNM	Scheduled maintenance name	Maintenance Program	Yes
PRSMLB	Sched. maint. labour hour	Job card accomplishment	Yes
PRSMMT	Sched. maint material cost	Job card accomplishment	Yes
PRSMDT	Sched. maint. downtime	Job card accomplishment	Yes
PSMNR	Sched. maint. interval	MDR	Yes
PRNMNM	Non-routine maint. name	MDR	Yes
PRNMLB	N-routine maint. labour hour	Job card accomplishment	Yes
PRNMMT	N-routine maint. material cost	Job card accomplishment	Yes
PRNMDT	N-routine maint. downtime	Job card accomplishment	Yes
PRNMNR	N-routine maint. annual frequency	MDR	Yes
PRUMNM	Unscheduled maintenance name	MCDR	Yes
PRUMLB	Unsched. maint. labour hour	Job card accomplishment	Yes
PRUMMT	Unsched. maint. material cost	Job card accomplishment	Yes
PRUMDT	Unsched. maint. downtime	Job card accomplishment	Yes
PRUMNR	Unsched. maint. annual frequency	MCDR	Yes



NUMBER: E1-1	NODE: A1 CONTEXT: E0	TITLE: FIG. 7.2 **TO-BE**: CHECK INT. ESCALA. [B737 A-CHECK ESCAL.; VARIOUS DOC'S]	AUTHOR: E. SUWONDO DATE : 18 AUGT. 2006

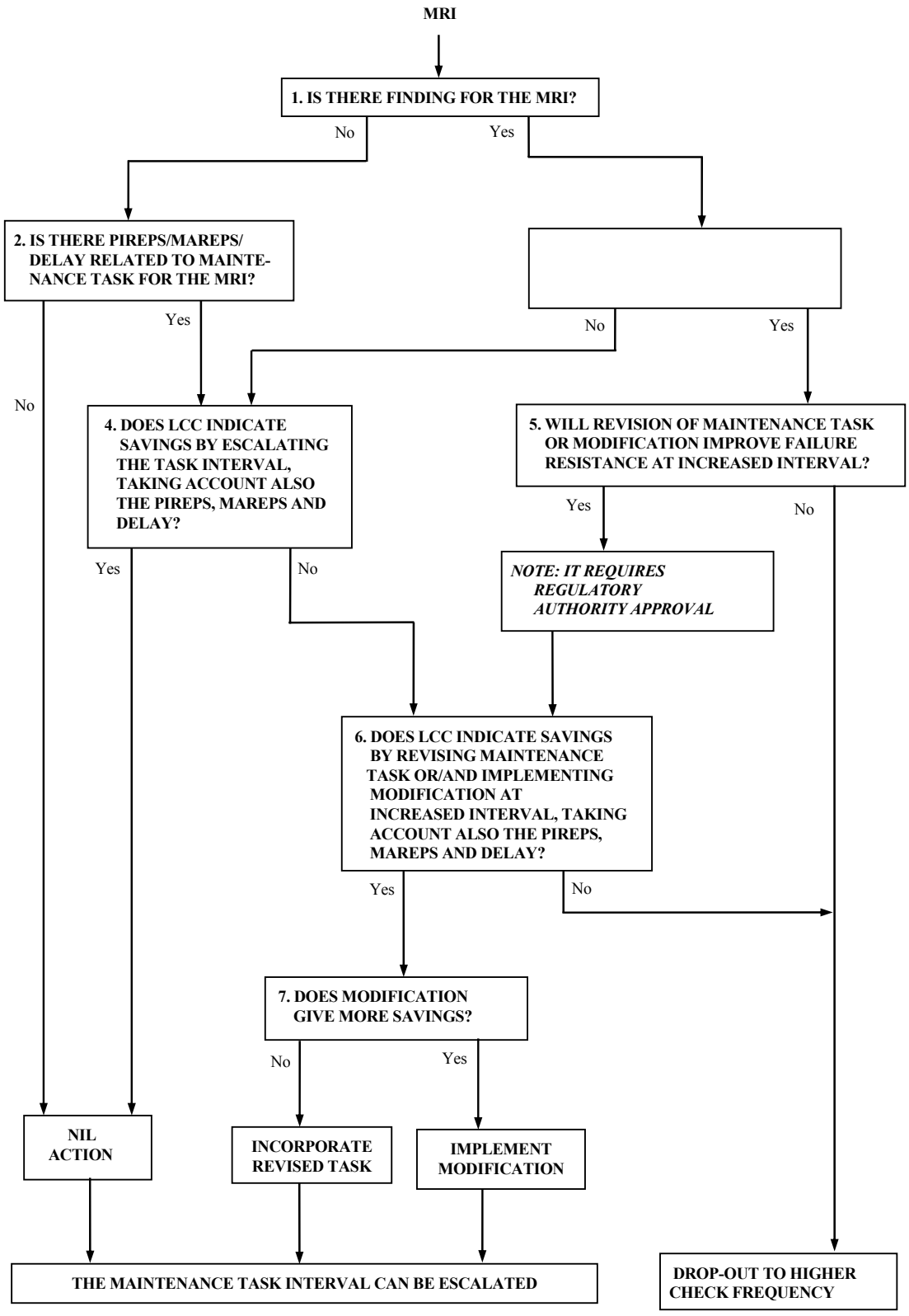


Fig. 7.3 **TO-BE:** ESCALATION DECISION DIAGRAM

PART IV
AIRCRAFT SELECTION

Chapter 8

Aircraft Selection

This chapter describes the AS-IS and the TO-BE situation of aircraft selection. The TO-BE situation concentrates on the application of the LCC concept on this subject. It begins with an introduction describing factors/parameters which influence aircraft selection. Then it continues with discussion on the AS-IS situation of aircraft selection, analysis of the AS-IS situation and the recommendations for improvement. The aspects to be considered are the process, organisation and information required.

8.1 Introduction

Airline fleet planning and aircraft selection includes assessment of the current fleet and projection of the future aircraft needs based on market analysis, i.e. transportation demand and available aircraft. Assessment of the current fleet is applied on systems, engines, airframe, and ground support equipment. It includes the assessment of aircraft performance, operating objectives, schedules, route structure and the airline competitive position.

Selection of an appropriate fleet composition is one of the most difficult tasks for an airline and the process involves to find an optimal balance among operations (aircraft), marketing (demand) and financial (resources) [Banfe, C.H., 1992]. Figure 8.1 shows the interactions of the groups involved in aircraft selection, i.e. the marketing, operation and finance group. The Engineering and Maintenance unit (E&M) is included in the operation group. A more detailed description is shown in Fig. 8.2 (on page 184). By comparing Fig. 8.1 and Fig. 8.2, it can be concluded that aircraft selection process primarily comprises of aircraft technical analysis (S1-2 of Fig. 8.2) and economic analysis (S1-4 of Fig. 8.2), while the three responsibilities mentioned earlier will support the required information.

The marketing group has to identify the customer demands in terms of required quantity and the quality of services and to define the market strategy. The input of the market analysis is the growth of Gross National Product (GNP), populations, industry, airline traffic, segment traffic and market share (S1-1 of Fig. 8.2). Other factors which need to be considered are the situation of politics, effective rights, new routes and pooling in flights and maintenance. The competitive factors, the types of service and routes are the input from the airline itself. The output of the market analysis is the traffic forecast, origin and destination of passenger, cargo and mail, the load factor objective and the seasonal factors. The detail of the market analysis is beyond the discussion in this research.

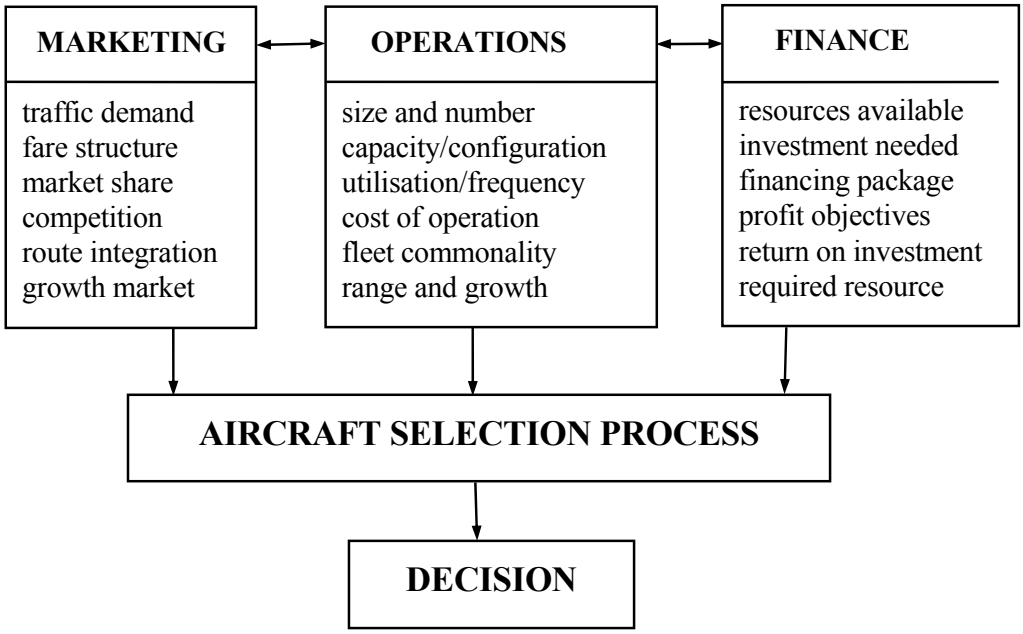


Fig. 8.1 Aircraft selection process and factors [Banfe, C.H., 1992]

The technical analysis determines the required block time and block fuel for certain amount of payload (S1-2 of Fig. 8.2). The input of the technical analysis is the data of the currently owned aircraft and aircraft candidates, the conditions of airport to be flown, the environment of the related sectors and the data of reserve airports. The detail of the technical analysis is beyond the discussion in this research.

Based on the information from the marketing group and specifications of aircraft candidates, the operations group will provide information on the size and number of aircraft, or the capacity (load factors) and configuration, or the utilisation and frequency, and the cost of operation by considering also the fleet commonality[40] (S1-3 of Fig. 8.2). This information is the basis for economical analysis to transform it into an aircraft recommendation. Finally, the financial group will make a final evaluation on the profitability of each aircraft candidate, by considering also the investment needed, finance package and required resources.

The factors to be considered during aircraft selection are the range, block speed, fuel consumption, number of flight crews and the maintenance cost to be anticipated [O'Connor, W. E., 1995]. The take-off and landing performance need to be considered as well to satisfy the airport conditions, as it is shown as a sub-process number S1-2 in Fig. 8.2. Other aspects which need to be included are the fleet mix, aircraft capacity, configuration (seat, cargo), growth potential of subsequent models[41], spare parts support, airport facilities and the required ground support equipment [Banfe, C. H., 1992].

[40] **Commonality** means the use of the same part numbers, operator qualifications or mechanic skills.
[41] It means the predicted number of aircraft flying in the future.

As shown in Fig. 8.3, economic analysis contains cost and revenue analysis. The cost analysis takes into account the Direct Operating Cost (DOC), Indirect Operating Cost (IOC) and required capital introduction costs. The revenue analysis includes current yields from first class, economic class, charters, cargo and mail. Figure 1.1 in Chapter 1 shows the composition of DOC and IOC, where DOC contributes 42.3% to the total operating cost [IATA, 1999]. The research will be concentrated on DOC, because it can be influenced by engineering and maintenance characteristics. More specifically, *the influence of maintenance on aircraft selection, which covers the reliability performance of the aircraft and the maintenance cost*. It will assess the (inherent) maintainability of the aircraft candidates, based on the existing information and projections. The following sections will discuss these factors into more detail.

Due to the important role of maintenance for the reliability performance of aircraft, maintenance cost should be considered appropriately during aircraft selection and determination of the most appropriate time for aircraft replacement. As a consequence, the research is focused on the application of the Life Cycle Cost (LCC) concept to handle the impact of maintenance cost to LCC and aircraft reliability performance, which is included in LCC. The impact of (un)reliability performance is quantified as the maintenance dependent cost, especially the costs of delays and cancellations. Figure 8.3 shows the scope of the research as indicated by the area bordered with dashed lines.

The research introduces the Life Cycle Cost Analysis (LCCA) as a final analysis after the 'normal' cost analysis (S1-41a top, Fig. 8.3) is carried out. The input of the whole process of the research are:

a. the output of operational analysis, i.e. fleet size, maintenance schedule and aircraft utilisation
b. aircraft data (existing fleet and aircraft candidates), and
c. the output of the aircraft analysis (S1-2 of Fig. 8.2), i.e. block time and block fuel.

The end result of the process is LCC information which contains:

a. total amount of LCC
b. the distribution of LCC in the course of aircraft life
c. the risk due to uncertainty of the input data.

This information is forwarded to the Finance Directorate for a final analysis which includes also the expected revenues. The research will exclude the revenue aspect, but concentrates on LCC only.

8.2 AS-IS: Aircraft Selection

Within Garuda Indonesia Airlines (GIA) organisation, aircraft selection is conducted by the Procurement Department. The process itself can be divided into two stages, as shown in Fig. 8.4. *The first stage* consists of market analysis, aircraft analysis and operational analysis (see also Fig. 8.2). The total process of the first stage can be considered as an operational analysis, because the process is aimed to deliver the Basic Production Planning (**BPP**) by conducting an operational analysis. BPP is the planned services to be delivered by the airline, as it is

shown by Annual Flight Schedule. The products of the first stage are the BPP and specifications of aircraft satisfying the projected demands, in terms of *range and capacity*. Aircraft satisfying these specifications are normally listed. The procedure for this stage can be considered general and can be found in open references, as discussed in section 8.1.

In *the second stage*, the listed aircraft will be further evaluated together by all directorates within GIA organisation. The requirements of each directorate will be involved in the decision making process. Section 8.2 concentrates on the requirements defined by the Engineering and Maintenance Directorate. The process of the second stage can be considered as an economical analysis, because it concerns of the maximisation of profit (revenue - cost) by considering the requirements from each directorate.

In most cases, the involvement of the government is inevitable. This is due the status of GIA as a national flag carrier. However, the role of the staff of GIA in determining the preferred (proposed) aircraft for GIA's fleet is very essential for the final decision. The involvement of other parties than GIA are excluded from the discussion. The following sub-sections discuss this procedure into more detail.

8.2.1 The First Stage of Evaluation

The first stage begins with a prediction of the world-wide and regional passenger and cargo demand encompassing a period of 10-20 years (box no.1 of Fig. 8.4). The changes of population, politics, economy and other factors are included in this prediction. The market share and load factor objectives for GIA are then estimated, both for domestic, regional and international flights.

Based on the estimated (forecast) of market share and load factor a Basic Production Planning (BPP) is developed (box no. 3 of Fig. 8.4) by applying the existing fleet. The existing fleet has to be analysed technically to be match with airport and other operational conditions (box no. 2 of Fig. 8.4). The Basic Production Planning contains the production objective in term of Available Seat Kilometre (ASK) and Available Ton Kilometre (ATK), the frequency of flights for each segment and the routes to be flown. When the market share and load factor objectives are not satisfied (box no. 4), then new aircraft may be required. However, technical evaluations will be made for aircraft candidates to fulfil the airport and other operational conditions (box no. 5 of Fig. 8.4), as it is applicable also for existing fleet.

If the market share and load factor objectives are met, the Basic Production Planning (**BPP**) can be produced and published. When new aircraft are required, then the detailed specifications, which include range and capacity, will be established. Some options (aircraft types) which satisfy these specifications can be identified, including the alternative engines for each aircraft type. When no new aircraft are required, the whole process is stopped.

8.2.2 The Seconds Stage of Evaluation

The results of the analysis of the first stage are distributed to all directorates for evaluation and as a basis for development of the requirements from each directorate (box no. 7 of Fig. 8.7). The requirements from the Directorate of *Engineering and Maintenance* are normally:

- commonality to the existing aircraft to include interchange-ability of maintenance and operating crews.
- economy of scale, to reduce inventory cost and learning curve of the maintenance crew (minimum of 8 aircraft begins to be economical)
- number of aircraft in the region to ensure the availability of spare parts.

The requirements from the *Operations Directorate* are normally the operational economic, e.g. fuel consumption and block time. Other requirements may come from the *Directorate of Finance* due to the limitation of financial resources (provided by financial institutions). After all specific requirements from each directorate are included, the next activity is to find an optimum aircraft model and type for these requirements (box no. 8 of Fig. 8.4). The criterion for optimisation is the maximum profit for the company.

Observations:

a. The AS-IS process of aircraft selection is good enough as compared with the theory described in section 8.1.
b. Consideration of maintenance aspects is conducted in qualitative way where maintainability and reliability are included.
c. The maintenance cost history (quantitative relationship between aircraft age and maintenance cost) of the existing fleet has not been utilised.

8.3 LCC-OPS for Aircraft Selection

This section describes the LCC-OPS model for aircraft selection (called LCC-SEL). It covers the framework of the model, the methods of cost components estimation, the required input data as well as the source. An example of application of the LCC-SEL model will be given as well.

LCC-SEL will provide information to support aircraft selection. When the candidates include also the existing aircraft owned by the airline, then it is a replacement problem. Optimum replacement time occurs when the existing aircraft are less economical as compared to replacement candidate(s).

The information supplied by the LCC-SEL, or the output, is the LCC and its distribution in the course of the evaluation period. Additional information is the risk due to uncertainty of the input data.

Evaluation of aircraft candidates must make use of long term information collected from similar type of aircraft, especially from the same manufacturer, as far as available. This is to investigate the relation between aircraft reliability performance, maintenance cost and aircraft age. The role of the number of aircraft within the fleet and the fleet commonality need to be quantified as far as possible. The relation above enables the management to determine the best time for replacing an aircraft type and to select the most appropriate one.

The maintenance and operational information systems must be able to support this evaluation process. Together with aircraft modification and maintenance program optimisation, the use of such an information system will be maximal. However, the quality of data entered must be complete and accurate in order to arrive at right decisions. However, this information systems is beyond the scope of discussion in this research.

8.3.1 Framework of LCC-OPS for Aircraft Selection

A LCC-SEL model consists of three main components, i.e.:
a. Investment (or lease) costs which consist of the depreciation cost and the financing cost. The depreciation is determined by the purchase price of the aircraft and the resale value estimate
b. Exploitation costs to operate the aircraft, consists of fuel cost, maintenance cost (Direct Maintenance Cost, DMC) and the cost of schedule interruptions (delays and cancellations and revenue losses)
c. The evaluation period for LCC evaluation.

These two main cost components are combined together to become Direct Operating Cost (DOC), if the schedule interruption cost is excluded. The investment costs are represented as depreciation cost in DOC. In this thesis, DOC includes also the schedule interruption cost, to make it more simple.

Those three main components are similar to the top level LCC-OPS model shown in Fig. 1.3 as well as LCC-MODS model shown in Fig. 3.1 and the LCC-MOPS model shown in Fig. 6.1. The Cost Breakdown Structure (CBS) of the LCC-SEL model is shown in Fig. 8.6. Table 8.1 describes the detail of the cost components.

Similar to the LCC-MODS model and the LCC-MOPS model, the users can develop their own Cost Breakdown Structure and to select a more appropriate Cost Estimation Method. Further analysis of the results of LCC-SEL model can be conducted as well through:
a. sensitivity analysis
b. cost drivers identification
c. LCC profile development
d. (cost) risk analysis.

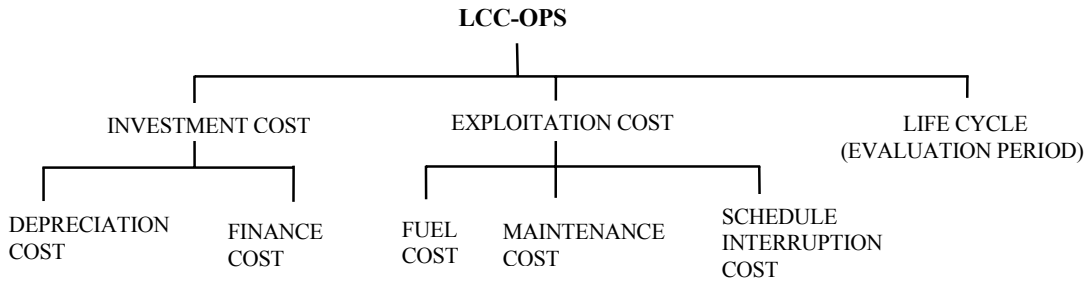


Fig. 8.6 The LCC-OPS model for aircraft selection.

8.3.2 Cost Component Estimation Methods

The methods for cost component estimation are shown in Tables 8.1.a and 8.1.b. Most of the methods are detailed engineering calculations. Care must be taken during application of these estimation methods by using current historical data, prediction data and the combination of these.

Selection of the cost estimation method being used depends on the availability of data. Appendix G provides other possible methods of cost component estimation.

8.3.3 Input of LCC-OPS for Aircraft Selection

Table 8.2 shows the input of the LCC-OPS for Aircraft Selection and the sources. The input data are divided into groups, i.e. the projected operation data and the aircraft candidate's data. Projected operation means the operational requirements to be satisfied by the aircraft candidates (the aircraft being evaluated). Table 8.2 shows the data sources of the input data. The Projected operation data is following:

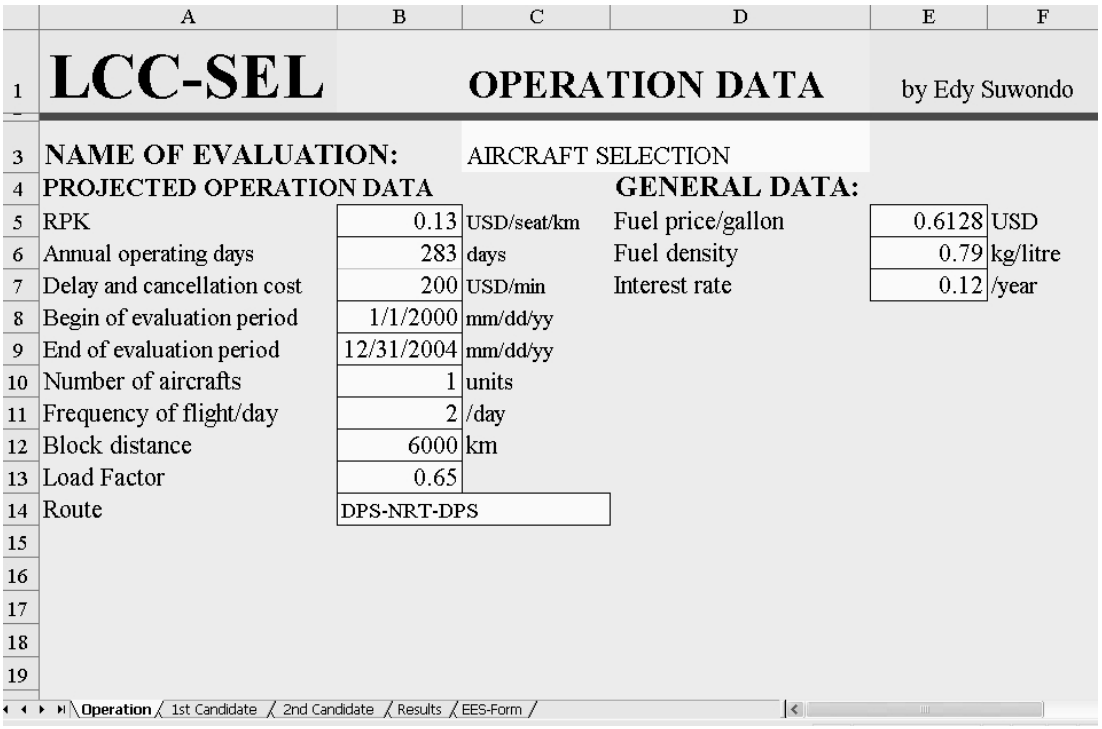
- Revenue passenger kilometre
- Annual operating days
- Delay cost per minute
- Begin evaluation period
- End evaluation period
- Number of aircraft
- Flight frequency per day
- Flight distance
- Load factor
- Flight route
- Fuel price per gallon
- Fuel density
- Interest rate

The aircraft candidate's data is following:

- Aircraft type
- Manufacturer

- Number of passengers (aircraft capacity)
- Market price (of aircraft) at initial period
- Current age
- Market price at end period
- Estimated operating life
- Finance cost
- Other cost (to facilitate special costs)
- Fleet utilisation
- Number of aircraft operated
- Annual utilisation per aircraft
- Total annual delay time
- Total annual cancellation
- Total annual departures
- Block hour average
- Fuel consumption per trip
- Maintenance cost per block hour

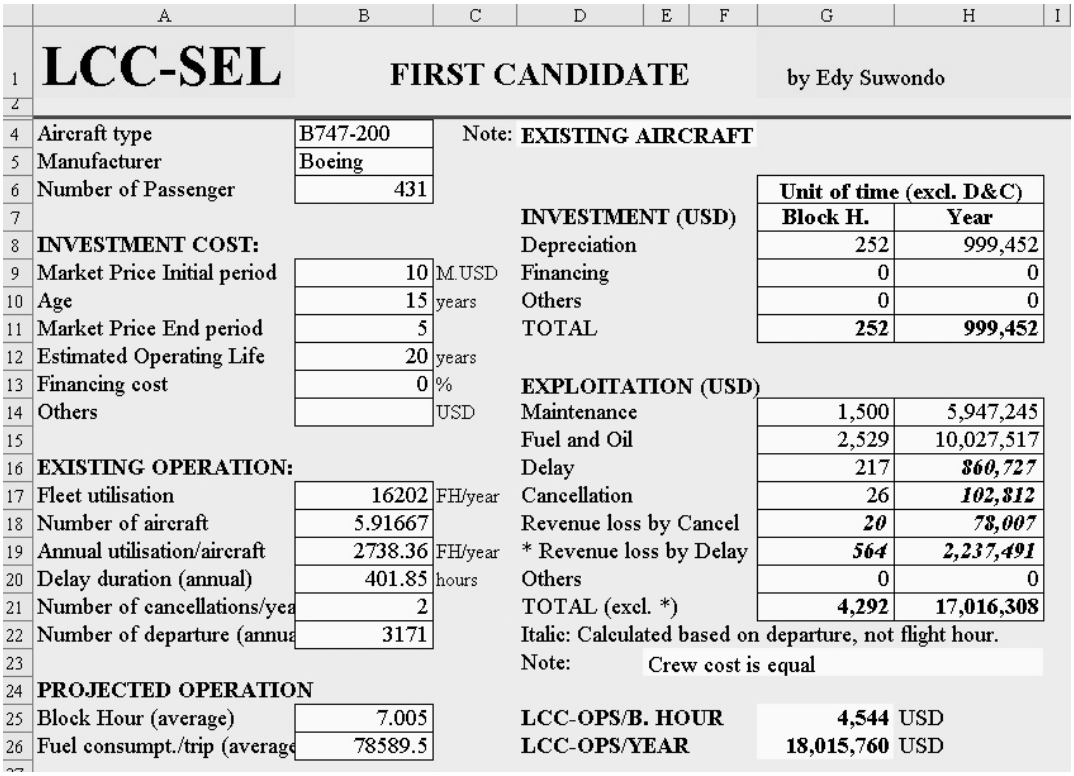
Figures 8.7a, b and c show the input displays of the LCC-OPS for Aircraft Selection. Figure 8.7b shows the first aircraft candidate while Fig. 8.7c shows the second aircraft candidate.



	A	B	C	D	E	F
1	**LCC-SEL**		**OPERATION DATA**		by Edy Suwondo	
3	**NAME OF EVALUATION:**		AIRCRAFT SELECTION			
4	**PROJECTED OPERATION DATA**			**GENERAL DATA:**		
5	RPK	0.13	USD/seat/km	Fuel price/gallon	0.6128	USD
6	Annual operating days	283	days	Fuel density	0.79	kg/litre
7	Delay and cancellation cost	200	USD/min	Interest rate	0.12	/year
8	Begin of evaluation period	1/1/2000	mm/dd/yy			
9	End of evaluation period	12/31/2004	mm/dd/yy			
10	Number of aircrafts	1	units			
11	Frequency of flight/day	2	/day			
12	Block distance	6000	km			
13	Load Factor	0.65				
14	Route	DPS-NRT-DPS				
15						
16						
17						
18						
19						

Operation | 1st Candidate | 2nd Candidate | Results | EES-Form

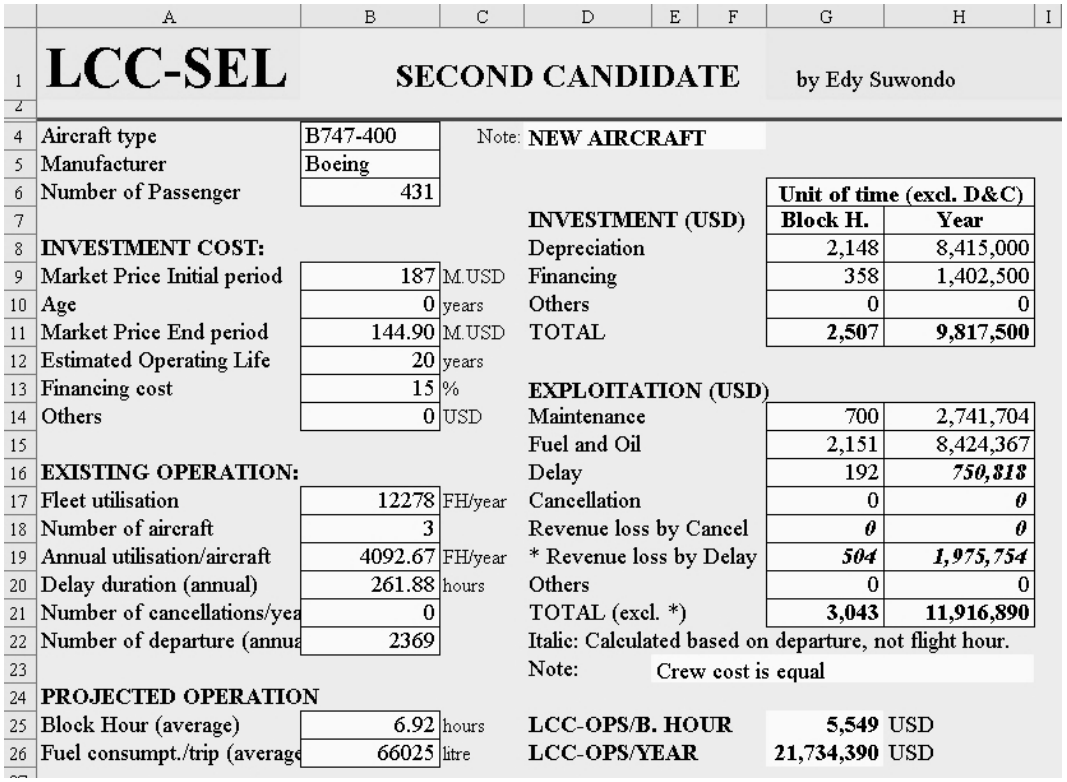
Fig. 8.7a The Operation Data input display of LCC-OPS for Aircraft Selection



LCC-SEL — **FIRST CANDIDATE** — by Edy Suwondo

Aircraft type	B747-200		Note:	**EXISTING AIRCRAFT**			
Manufacturer	Boeing						
Number of Passenger	431				**Unit of time (excl. D&C)**		
				INVESTMENT (USD)	**Block H.**	**Year**	
INVESTMENT COST:				Depreciation	252	999,452	
Market Price Initial period	10	M.USD		Financing	0	0	
Age	15	years		Others	0	0	
Market Price End period	5			TOTAL	**252**	**999,452**	
Estimated Operating Life	20	years					
Financing cost	0	%		**EXPLOITATION (USD)**			
Others		USD		Maintenance	1,500	5,947,245	
				Fuel and Oil	2,529	10,027,517	
EXISTING OPERATION:				Delay	217	***860,727***	
Fleet utilisation	16202	FH/year		Cancellation	26	***102,812***	
Number of aircraft	5.91667			Revenue loss by Cancel	***20***	***78,007***	
Annual utilisation/aircraft	2738.36	FH/year		* Revenue loss by Delay	***564***	***2,237,491***	
Delay duration (annual)	401.85	hours		Others	0	0	
Number of cancellations/yea	2			TOTAL (excl. *)	**4,292**	**17,016,308**	
Number of departure (annua	3171			Italic: Calculated based on departure, not flight hour.			
				Note: Crew cost is equal			
PROJECTED OPERATION							
Block Hour (average)	7.005			**LCC-OPS/B. HOUR**	**4,544**	USD	
Fuel consumpt./trip (average	78589.5			**LCC-OPS/YEAR**	**18,015,760**	USD	

Fig. 8.7b The First (Aircraft) Candidate input display of LCC-OPS for Aircraft Selection



LCC-SEL — **SECOND CANDIDATE** — by Edy Suwondo

Aircraft type	B747-400		Note:	**NEW AIRCRAFT**			
Manufacturer	Boeing						
Number of Passenger	431				**Unit of time (excl. D&C)**		
				INVESTMENT (USD)	**Block H.**	**Year**	
INVESTMENT COST:				Depreciation	2,148	8,415,000	
Market Price Initial period	187	M.USD		Financing	358	1,402,500	
Age	0	years		Others	0	0	
Market Price End period	144.90	M.USD		TOTAL	**2,507**	**9,817,500**	
Estimated Operating Life	20	years					
Financing cost	15	%		**EXPLOITATION (USD)**			
Others	0	USD		Maintenance	700	2,741,704	
				Fuel and Oil	2,151	8,424,367	
EXISTING OPERATION:				Delay	192	***750,818***	
Fleet utilisation	12278	FH/year		Cancellation	0	***0***	
Number of aircraft	3			Revenue loss by Cancel	***0***	***0***	
Annual utilisation/aircraft	4092.67	FH/year		* Revenue loss by Delay	***504***	***1,975,754***	
Delay duration (annual)	261.88	hours		Others	0	0	
Number of cancellations/yea	0			TOTAL (excl. *)	**3,043**	**11,916,890**	
Number of departure (annua	2369			Italic: Calculated based on departure, not flight hour.			
				Note: Crew cost is equal			
PROJECTED OPERATION							
Block Hour (average)	6.92	hours		**LCC-OPS/B. HOUR**	**5,549**	USD	
Fuel consumpt./trip (average	66025	litre		**LCC-OPS/YEAR**	**21,734,390**	USD	

Fig. 8.7c The Second (Aircraft) Candidate input display of LCC-OPS for Aircraft Selection

8.3.4 Output of LCC-OPS for Aircraft Selection

The final output of the LCC-OPS is a completed LCC-SEL Form (shown in Fig. 8.9). Before the result is put in the LCC-SEL Form, it is shown in the 'RESULTS' worksheet (shown in Fig. 8.8). The results consist of two groups, i.e. the annual investment costs and the exploitation costs. Breakdown of each group is following.

a. Investment costs:
   - depreciation cost
   - financing

b. Exploitation costs:
   - Maintenance (maintenance costs are assumed constant)
   - Fuel and Oil
   - Delay
   - Cancellation
   - Revenue loss by cancellations
   - (Revenue loss by delays)

Revenue loses due to delays are not included in the calculation of LCC-OPS because delays do not lead to loss of revenues. As shown in Fig. 8.8, the distribution of the expenses and the savings are shown in the form of a table. The total cost savings (with the current fleet as a reference) as a function of time is shown in a chart as well.

	A	B	C
1	**LCC-SEL**	**RESULTS**	by Edy Suwondo
2			
4	**INVESTMENT ANNUAL:**	**8,818,048**	
5	Depreciation	7,415,548	USD
6	Financing	1,402,500	USD
7	**EXPLOIT. COST SAVINGS:**	**5,099,418**	
8	Maintenance cost savings	3,205,541	USD
9	Fuel and Oil cost savings	1,603,150	USD
10	Delay cost savings	109,908	USD
11	Cancellation cost savings	102,812	USD
12	Revenue loss by Cancel	78,007	USD
13	* Revenue loss by Delay	261,737	USD
14	**LCC-OPS (excl. *)**	-15,013,406	USD
16	Period of evaluation	5.00	years
17	**ADDITIONAL CRITERIA:**		
18	Payback Period (with interest)	Not applicable	years
19	Return On Investment (ROI)	Not applicable	%
20	Internal Rate of Return (IRR)	Not applicable	%
21			

Year	Investment	Exploit. Saving	Total (USD)
0	8,818,048	5,099,418	-3,718,629
1	8,818,048	5,099,418	-3,320,205
2	8,818,048	5,099,418	-2,964,469
3	8,818,048	5,099,418	-2,646,847
4	8,818,048	5,099,418	-2,363,256

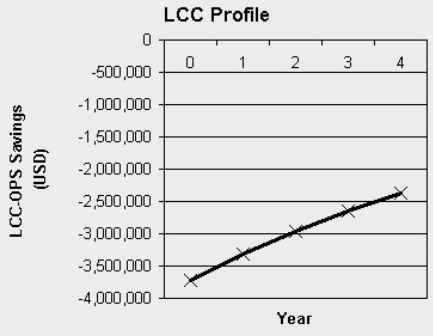


Fig. 8.8 The 'RESULTS' worksheet of LCC-OPS for Aircraft Selection

8.3.5 Application of LCC-OPS for Aircraft Selection

The LCC-OPS model for Aircraft Selection were applied for selecting between Boeing 747-200 and Boeing 747-400 for the route of Denpasar (Bali)-Narita (Japan)-Denpasar. Both types of aircraft have ever been operated by Garuda at this route. The B747-200 is currently available at Garuda fleet for this route, but a new B747-400 must be acquired if it is going to be operated at this route. The operational data of these aircraft is available from Garuda. Life cycle is the period of evaluation, i.e. 5 years, due to the age of the owned B747-200. Appendix K discusses this application in a more detail.

In this application, the investment (acquisition) cost consists of the purchase price, finance cost and resale value of the aircraft. Investment cost depends on the seat configuration, furnishing and the avionics applied. Investment cost is represented by the depreciation cost of the aircraft. The exploitation cost consists of the cost of fuel, maintenance and schedule interruptions (delays and cancellations). Fuel cost is influenced by the drag characteristics of aircraft, engine efficiency and aircraft weight. Maintenance cost is usually divided into the cost of line maintenance, base maintenance and maintenance by third parties. Schedule interruption cost is divided into delay and cancellation cost and revenue loss.

The results of the LCC-OPS application is following. The LCC-OPS, excluding the revenue losses due to delay, is USD 15,013,406,- (loss). This LCC-OPS is the relative value between B747-200 as a reference for B747-400. In other words, B747-200 is more beneficial than B747-400 for the case study above. Revenue losses due to delays are excluded because delays normally lead only to a postponement of the departure and the delay costs.

The investment cost consists of the depreciation cost and the financing cost. While the exploitation cost consists of the cost of maintenance, fuel and oil, delay and cancellation, and the lost of opportunity revenue. The value of those cost components are shown in the Table 8.3 below.

Table 8.3 The result of LCC-OPS application

Investment annual (A)	**8,818,048**
Depreciation	7,415,548
Financing	1,402,500
Exploitation cost savings (B)	**5,099,418**
Maintenance cost savings	3,205,541
Fuel and Oil cost savings	1,603,150
Delay cost savings	109,908
Cancellation cost savings	102,812
Opp. Revenue by Cancel	78,007
* Opp. Revenue by Delay	261,737
LCC-OPS (excl. *) = Present Value (B-A) for 5 years	**-15,013,406**

LCC-SEL FORM

Designed by Edy Suwondo

page 1/1

TITLE: **AIRCRAFT SELECTION** Date: 22-Jul-03

Route: DPS-NRT-DPS Daily Freq.: 2

Candidates: B747-200 B747-400 **Choice: B747-200**

Status	Existing (Baseline)	To be acquired	Relative
Investment Annual			
Depreciation	999,452	8,415,000	7,415,548
Financing	0	1,402,500	1,402,500
Exploitation Annual			
Maintenance	5,947,245	2,741,704	3,205,541
Fuel and Oil	10,027,517	8,424,367	1,603,150
Delay	860,727	750,818	109,908
Cancellation	102,812	0	102,812
Revenue loss by Cancel	78,007	0	78,007
* Revenue loss by Delay	2,237,491	1,975,754	261,737

LCC-OPS: -15,013,406 USD (excl. *) Period (years): 5.0

Other Benefits: None

Priority: [ ] Mandatory [ ] Recommended [ ] Pending

Prepared by: Checked by: Approved by:

Date:

ENGINEERING VERIFICATION:

Result: [ ] Feasible [ ] Not feasible [ ] Pending

Justifications:

Reference: Engineering Analysis Report: AER/xx/yy/zz

Prepared by: Checked by: Approved by:

Date:

DEMONSTRATION ANNUAL (USD):

Fuel and Oil cost: Delay hours

Maintenance cost: Cancellation times

Notes:

Prepared by: Checked by:

Date:

Fig. 8.9 The LCC-SEL Form of the LCC-OPS for Aircraft Selection

8.4 TO-BE: Aircraft Selection

As shown in Fig. 8.3, the author recommends to apply the Life Cycle Cost Analysis (LCCA) procedure to evaluate possible alternatives. The LCCA procedure was applied by the author to evaluate the feasibility to replace the existing Boeing 747-200 with Boeing 747-400 in the GIA fleet (see Appendix K). Generally, there is no need to change the existing GIA process. However, before the financial analysis (S1-5b) is conducted, it is necessary to perform a Life Cycle Costs Analysis (LCCA) (S1-5a in Fig. 8.3) in order to have the LCC-OPS of the candidates. As described in sub-section 1.3.3 the objective of having LCC-OPS information is to maximize profit through minimising the LCC-OPS, assuming that revenues are independent of the model (manufacturer) and type of aircraft being operated.

Figure 8.5 illustrates the procedure of LCCA for aircraft selection. Figure 8.5 is a standard LCC procedure, but the descriptions of each step in text are suited only for aircraft selection. The description of each step is following.

First of all, the objective of the evaluation must be identified. The objective of evaluation determines the cost elements to be included and the form of Cost Breakdown Structure (CBS), where only relevant cost components for the evaluation are taken into account. The objective of evaluation can be aircraft selection among available candidates or determination of the time to replace the existing aircraft in the fleet with a new one (by calculating the LCC-OPS for various evaluation periods and determine the evaluation period where the new aircraft provides a lower LCC-OPS than the existing one). Normally the objective of evaluation is given or determined by the board of directors. However, from the recorded data of aircraft reliability performance and costs, an initiative to make an aircraft LCC-OPS comparison can be done as well, to support the management in evaluating the existing fleet.

Define the scope of evaluation (S2-5a-1)

The objective of this step is to determine which costs elements need to be included in the evaluation. The included aspects must represent the problem to be solved as stated in the objective of the evaluation. Some aspects sometimes can be equalised when there is no significant different in the design feature. An illustration is during comparison of two aircraft with the same category of range, speed and passenger capacity, it is not relevant to include the landing fee, navigation cost and insurance cost. But, attention must be given to the acquisition cost, fuel consumption, maintenance cost, commonality and supportability of the aircraft in the routes of aircraft operation. Dispatch reliability can be the main point of attention, because it is related to revenue generation.

Make a Cost Breakdown Structure, CBS (S2-5a-2)

After the included costs elements are defined, a CBS can be made which represents the total cost resulting from the alternatives. Each alternative has typical characteristics for the costs elements included in the evaluation. The detail of a CBS depends on the scope and objective of evaluation. An example of CBS for aircraft selection is shown earlier in Fig. 8.6, which is applied for the case study discussed in sub-section 8.3.4.

Collect data and select cost estimation method (S2-5a-3)

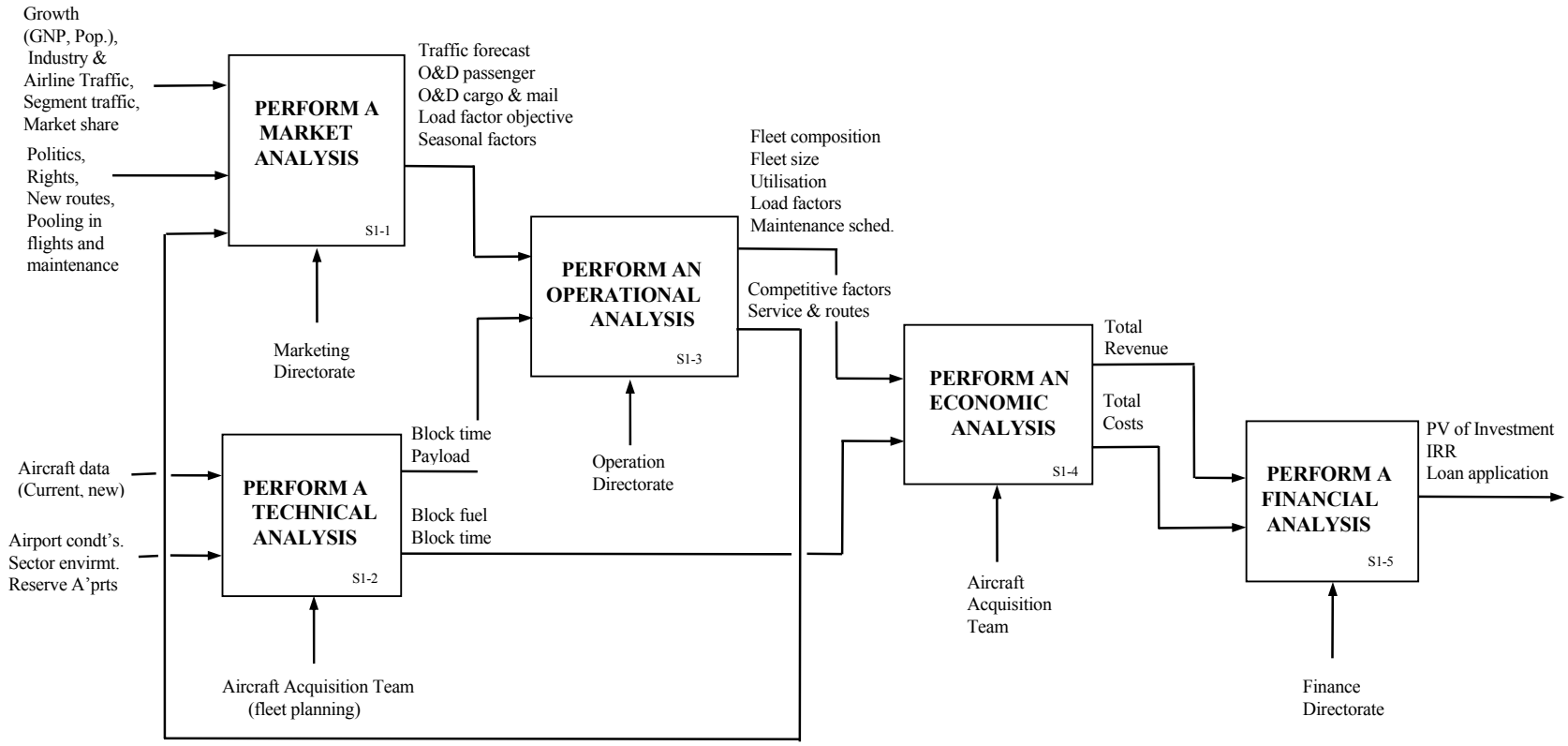
The aim of data collection is to find a basis for estimation of cost components identified in the CBS. In the beginning, the key parameters which determine the cost component must be identified. For estimation of fuel cost, for instance, the fuel burn for the route (trip), fuel price and fuel density are the key parameters.

The required data must be supplied by the Cost Management section. This section is recommended by the author as described in Chapter 2 sub-section 2.5.2. The recommended Engineering Evaluation Sheet (EES) is designed so that it can support data collection for evaluation of aircraft reliability performance and cost. Application of the recommended EES after a certain period of time will give an indication (summary) on the reliability performance and life cycle cost of the aircraft.

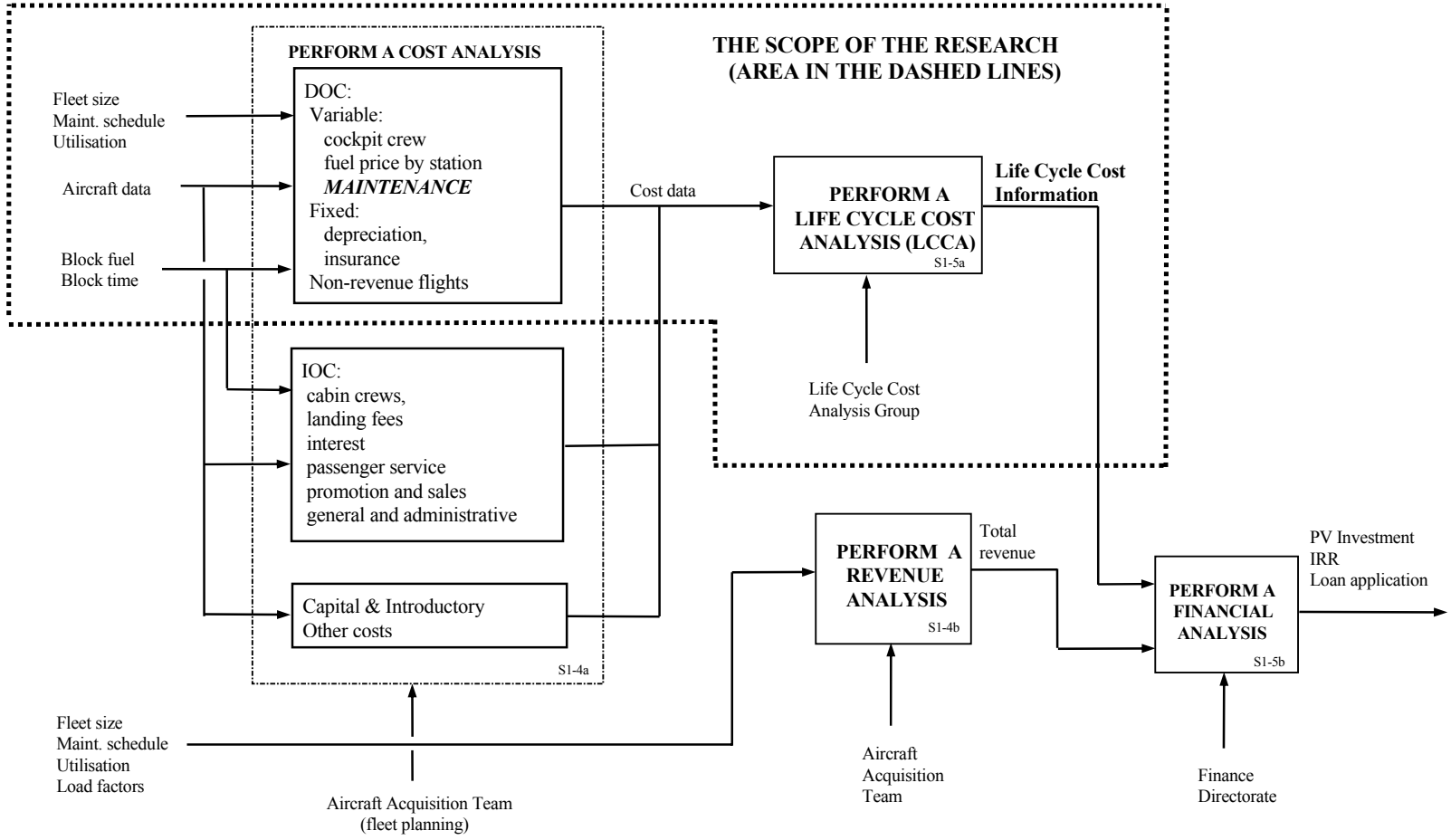
A further step is to select the most appropriate Cost Estimating Method for each cost component based on the identified key parameters and data available. If the data does not support the estimation by using the key parameters, other methods must be selected following the flowchart shown in Fig. F.2 of Appendix F. The CEM developed by Roskam [Roskam, 1991] for estimation of cost components of LCC-OPS can be used if a method using key parameters is not applicable.

Identify cost drivers, make sensitivity analysis and risk analysis (S2-5a-4)

Cost drivers identification results in indication of the aircraft parts which give the highest contribution to LCC-OPS. These can be hardware or software. Sensitivity analysis is aimed to identify parameters which the value changes of these parameter leads to a significant change of LCC-OPS. These are not necessarily the parameters of cost drivers. Although, generally they are. Risk analysis is aimed to estimate the maximum value of LCC-OPS and its probability when the parameters which determine LCC-OPS changes to their maximum (minimum) range. Appendix F describes this subject in sufficient detail. If the value of LCC-OPS is not sensitive to the key parameters, risk analysis is not necessary. Appendix K shows also the application of cost drivers identification and sensitivity analysis.



NUMBER: S0	NODE: A0 CONTEXT: TOP	TITLE:. FIG. 8.2 AIRLINE ANALYSIS [Banfe, C.H.; restructured]	AUTHOR: E. SUWONDO DATE : 28 AUGT. 2006



NUMBER: S0	NODE: A0	TITLE:. FIG. 8.3 THE SCOPE OF THE RESEARCH [Banfe, C.H.; Modified]	AUTHOR: E. SUWONDO
	CONTEXT: TOP		DATE : 28 AUGT. 2006

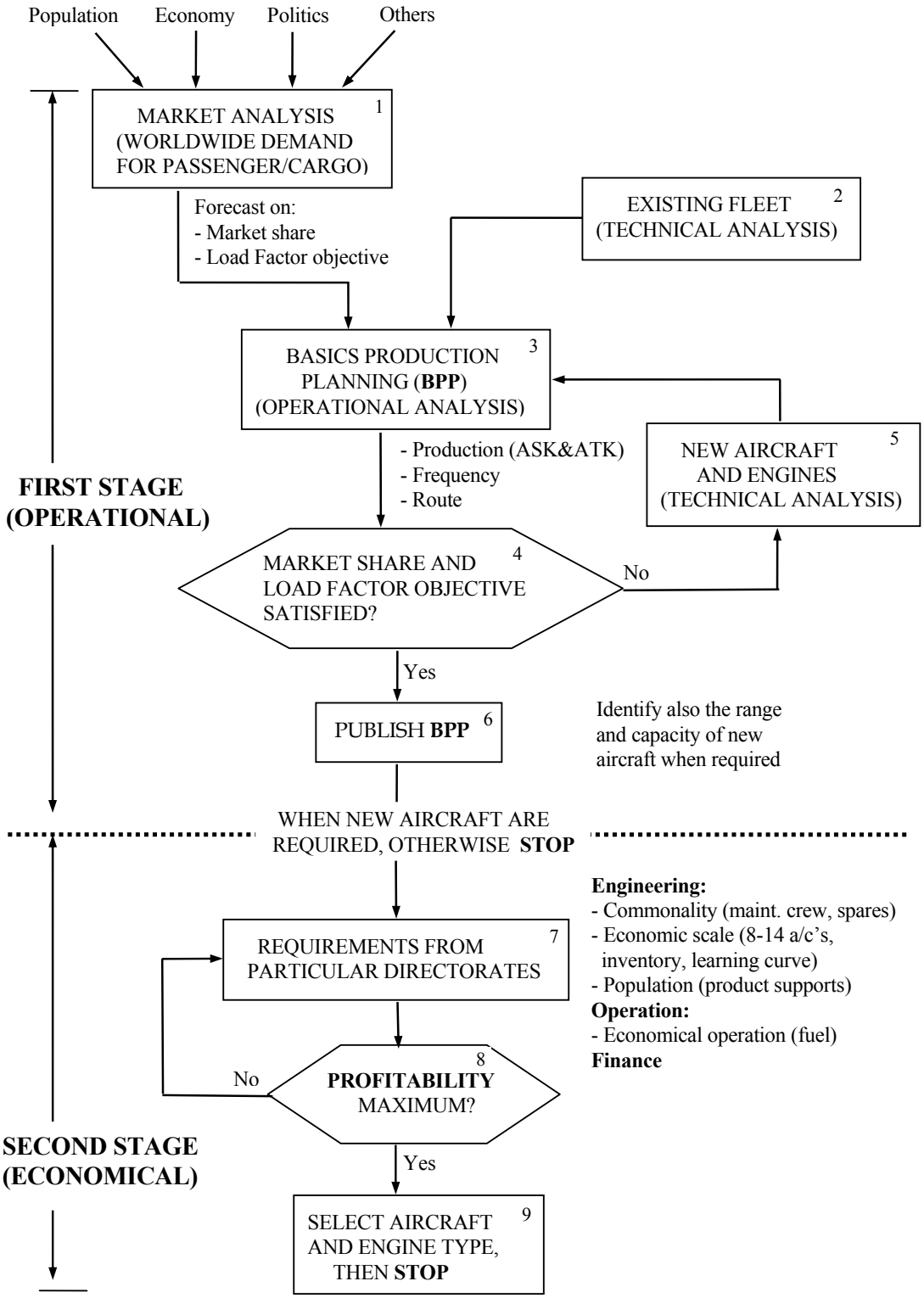
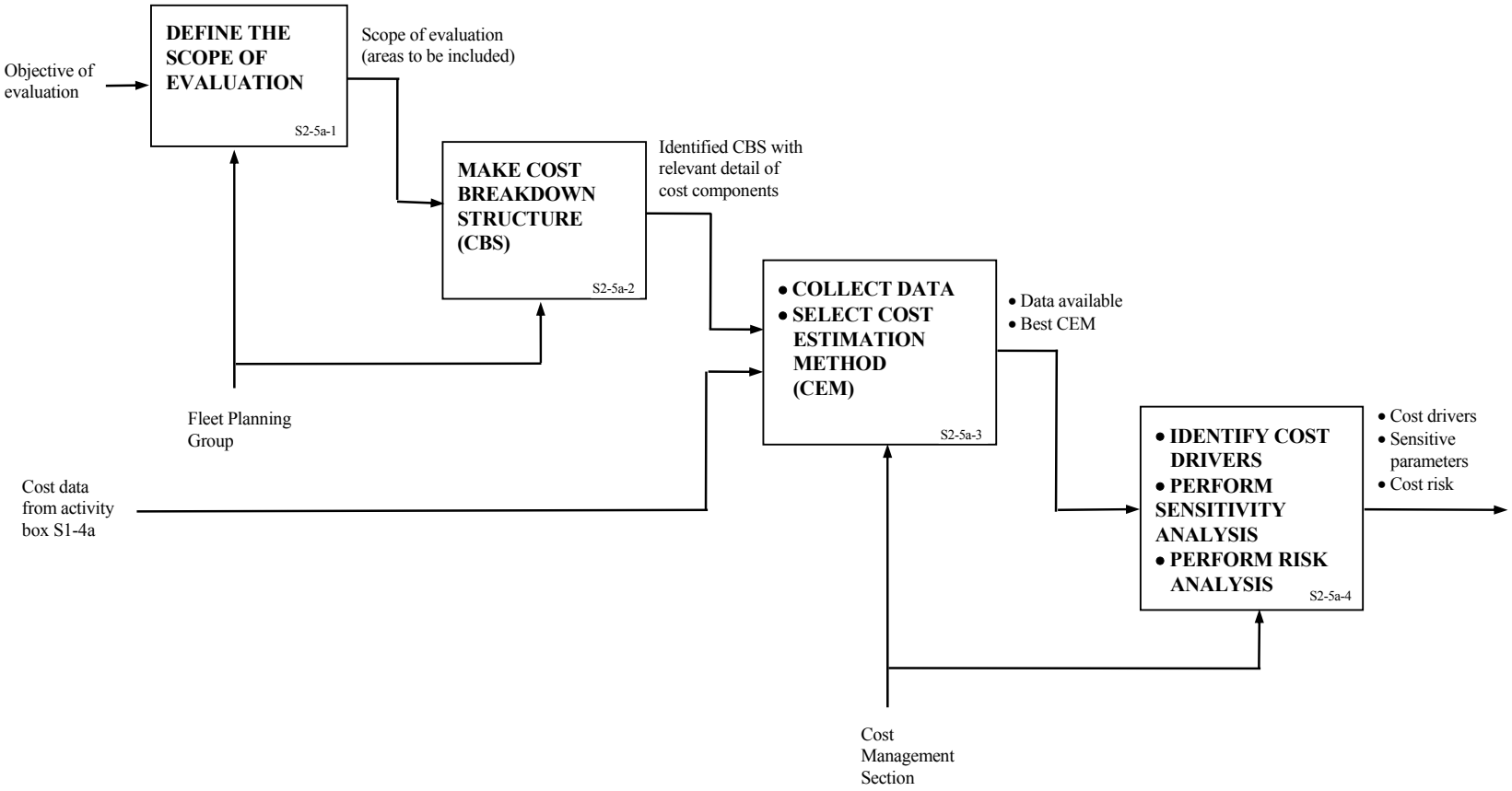


Fig. 8.4 The **AS-IS** process of aircraft selection (fleet planning)
[Interview with GIA Staffs]



NUMBER: S1-5a	NODE: A1	TITLE:. FIG. 8.5 **TO-BE:** ECONOMIC ANALYSIS	AUTHOR: E. SUWONDO
	CONTEXT: S0		DATE : 28 AUGT. 2006

Table 8.1a Cost component estimation method

Cost component	Estimation method
Investment costs (C_I)	$C_I = C_{ID} + C_{IF}$ Where: C_{ID} = Depreciation cost of the aircraft C_{IF} = Financing cost to acquire the aircraft
Depreciation cost (C_{ID})	$C_{ID} = (MPRIP - MPREP)/LC$ Where: MPRIP = Market price at the initial of evaluation period. MPREP = Market price at the end of evaluation period LC = Life cycle or evaluation period For new aircraft, the purchase price is available from the manufacturer, e.g. manufacturer's website or magazine. The price of 'second hand' aircraft mostly available in magazines, but the price range is normally very wide. Resale value is determined by using the assumption that the price of the aircraft at the end of life cycle is about 10% of the purchase price [Roskam, 1991]. The depreciation model applied in this thesis is the stright line model.
Financing cost (C_{IF})	This cost is required to borrow a cash from banks. Its value is 0.1-0.2 times the aircraft purchase price [Roskam, 1991]. The median value is used in this thesis, i.e. 0.15.
Exploitation costs (C_E)	$C_E = C_{EF} + C_{EM} + C_{ES}$ Where: C_{EF} = Fuel and Oil cost C_{EM} = Maintenance cost C_{ES} = Schedule interruption cost
Fuel and Oil costs (C_{EF})	$C_{ES} = 1.1*FUCON*FUPPG/FUDEN/3.785/BLHR$ Where: 1.1 = factor to take account the oil cost (10%) [Roskam, 1991]. FUCON = Fuel consumption FUPPG = Fuel price per gallon FUDEN = Fuel density (kg/lt) 3.785 = conversion from gallon to litre BLHR = Block hour

Table 8.1b Cost component estimation method (continued)

Cost component	Estimation method
Maintenance cost (C_{EM})	A figure is normally provided by airlines for C_{EM}. If not available: C_{EM} = TMC/BLHR Where: TMC = Total annual maintenance cost BLHR = Annual block hour
Cost of schedule interruption (C_{ES})	$C_{ES} = C_{ESD} + C_{ESC} + C_{ESO} + (C_{EST})$ Where: C_{ESD} = Cost of schedule interruption due to delays C_{ESC} = Cost of schedule interruption due to cancellation C_{ESO} = Revenue lost due to cancellation
Cost of schedule interruption due to delays (C_{ESD})	C_{ESD} = TDTM * 60* DELC / BLHR Where: TDTM = Total (annual) delay time, in hour 60 = conversion to minute DELC = Delay cost per minute, e.g. USD 200,- It is more appropriate to calculate delay cost per departure.
Cost of schedule interruption due to cancellations (C_{ESC})	C_{ESC} = TCANC * 24 * 60 * DELC / BLHR Where: TCANC = Total (annual) number of Cancellations 24 = conversion of cancellation to hour of delay. 60 = conversion to minute
Revenue lost due to cancellations, annual (C_{ESO})	C_{ESO} = NPAX*LF*FDIS*RPK*TCANC Where: NPAX = Number of passenger LF = Load factor estimate FDIS = Flight distance RPK = Revenue passenger kilometre This is annual lost of revenue. To calculate lost of revenue per block hour, divide with the projected flight hours.
Revenue lost due to total delay hours, annual (C_{EST})	C_{EST} = NPAX*LF*FDIS*RPK*TDTM/BLHR Where: TDTM = Total delay time, in hours This is annual lost of revenue. To calculate lost of revenue per block hour, divide with the projected flight hours.

Table 8.2 Input of the LCC-SEL model and the sources (see also Table 8.1)

Input variable	Meaning	Source of information	Current availability
Projected ops:			
RPK	Revenue passenger kilometre	Marketing/WFA	Yes
ANOPS	Annual operating days	Reliability report	Yes
DELC	Delay cost per minute	Finance data	Yes
BEVAL	Begin evaluation time	Input of analyst	
EEVAL	End evaluation time	Input of analyst	
NRAC	Number of aircraft	Input of analyst	
FLFRE	Flight frequency per day	Input of analyst	
FLDIS	Flight distance	Operation data	Yes
LF	Load factor	Marketing data	Yes
ROUT	Flight route	Input of analyst	
FUPPG	Fuel price per gallon	Operation data	Yes
FUDEN	Fuel density	Operation data	Yes
INTR	Interest rate	Finance data	Yes
A/C Candidate:			
ACTYP	Aircraft type		
MFG	Manufacturer		
NRPAX	Number of passengers	Marketing data	Yes
MPRIP	Market price initial period	Magazine/Expert	Yes*
AGE	Current age	Marketing data	Yes*
MPREP	Market price end period	Magazine/Expert	Yes*
OPSLF	Estimated operating life	Magazine/Expert	Yes*
FINC	Financing cost	Finance data	
OTHC	Other cost		
FLUTIL	Fleet utilisation	Reliability report	Yes
NRAC1	Number of aircraft operated	Reliability report	Yes
ANUTIL	Annual utilisation per aircraft	Reliability report	Yes
TDTM	Total annual delay time	Reliability report	Yes
TCANC	Total annual cancellation	Reliability report	Yes
TDEPA	Total annual departures	Reliability report	Yes
BLHR	Block hour average	Reliability report	Yes
FUCON	Fuel consumption per trip	Operation data	Yes
MCPFH	Maintenance cost per flight hour	Finance data	Yes

Yes* = Currently available but limited and not well documented

PART V
CONCLUSIONS AND RECOMMENDATIONS

Chapter 9

Conclusions and Recommendations

This chapter presents the conclusions and recommendations of this thesis. The conclusions are derived from LCC-OPS developments and implementations as the answer of the research goals stated in section 1.3. The developments and implementations of LCC-OPS are discussed in parts II until IV in this thesis. The conclusions cover also the summary of decision criteria, analysis process, the cost data recording and information systems and the organisational aspect required to implement LCC-OPS. This chapter describes also recommendations for future research.

9.1 LCC-OPS Model

Observation of current practices in aircraft operations and maintenance shows limited consideration of cost savings applied by aircraft modifications, maintenance program optimisation and aircraft selection. This is due to hidden (maintenance dependent) costs and difficulties in quantifying the utilisation of a higher availability or revenue losses. Hidden costs can be a significant portion of operating costs and can be reduced by a better aircraft reliability. LCC-OPS is developed in this thesis to visualise the hidden costs and to quantify opportunity revenue resulted by a higher availability.

LCC-OPS is a Life Cycle Cost model to evaluate alternatives for aircraft modifications, maintenance interval escalation and aircraft selection, in order to reduce aircraft LCC during the exploitation phase. LCC-OPS is tested on several case studied and evaluated by some relevant managers and engineers at Garuda Indonesia Airlines organisation and Indonesian DGAC. Based on these evaluation, LCC-OPS is considered as a good method for evaluation of alternatives.

LCC-OPS consists of three models, i.e.:

a. LCC-MODS: LCC-OPS for aircraft modifications (Chapter 3)
b. LCC-MOPS: LCC-OPS for maintenance program optimisation (Chapter 6)
c. LCC-SEL : LCC-OPS for aircraft selection (section 8.3 of Chapter 8)

ad a. The framework of LCC-MODS is shown in Fig. 3.1. This framework is applicable for any type of systems. For non-moving systems, the influence of weight and drag on Fuel and Oil Cost is not relevant. The Excel model of LCC-MODS (Fig's 3.2a, b, c and Fig. 3.3) is applicable only for aircraft, because the cost element calculation methods are typical for aircraft operations. Extension of LCC-MODS applications for other types of system requires adjustment of the cost element calculations methods, especially the maintenance dependent cost and the revenue changes due to an increase of availability. The adjustment might be only on the values of the input data.

ad b. The Excel model of LCC-MOPS is based on the framework shown in Fig. 6.1. This framework is applicable for any type of scheduled maintenance, a maintenance package or an individual maintenance task, subjected to any type of system. If a modification is required to increase the reliability of an item in the maintenance package being analysed, LCC-MODS can be used to evaluate the advantage of the modification. The Excel model of LCC-MOPS (Fig's 6.8a, b, c, d and Fig. 6.9) is applicable only for aircraft. Similar with LCC-MODS, extension of LCC-MOPS applications for other types of system requires adjustment of the cost element calculations methods.

ad c. The framework of LCC-SEL is shown in Fig. 8.6. This framework is applicable for any type of systems. The Excel model of LCC-SEL (Fig's 8.7a, b, c and Fig. 8.8) is applicable only for aircraft selection. Extension of LCC-SEL applications for other types of system requires adjustment of the cost element calculations methods, similar with LCC-MODS and LCC-MOPS.

9.2 Decision Criteria

In practice, a modification proposal will be approved for implementation when it is mandatory and close to the due date, it may have a safety impact, it is an alert item, it is a request from the Operations or Commercial function, or if the modification kit is free of charge. *Implementation of aircraft modifications due to total cost savings are very limited*. This is due to limited modification budgets or engineering staff shortages. With respect to Service Bulletins, there is not sufficient information (on cost savings and reliability improvements) to judge SB's, especially information supplied by the SB's themselves. *This situation can be improved by a better quantification of the modification costs and the savings and by a proper evaluation of the implemented modifications (demonstration process). These will provide an objective evaluation of the current and projected situations.*

Current process of maintenance program optimisation indicates that the driver or the initiator of the process is a request from management (Vice President of Technical Services or the Director of Maintenance and Engineering). In this request there is no explicit cost consideration. Therefore, it is expected that the Maintenance Program Management Unit will be active in collecting Maintenance Requirement Items (MRI's) performance data, without waiting for the request from management. MRI's performance data can be used to evaluate the effectiveness of the existing Maintenance Program as well as to evaluate the feasibility and potential *financial benefit* of an attempt to escalate the maintenance intervals.

In most cases, the involvement of the government and other parties during aircraft selection is inevitable. This is due the status of GIA as a national flag carrier. However, the role of the GIA staff in determining the preferred (proposed) aircraft for GIA's fleet is very essential for the final decision. The most important role of GIA staff is providing quantitative estimates of the future revenues and costs as well as the reliability performance of aircraft candidates.

9.3 Analysis Process

In order to apply the decision criteria described in section 9.2 an additional process is required, i.e. the Cost Analysis route. In the AS-IS situation this route does not exist. The idea of the Cost Analysis route is taken from the Alert type analysis method, where it records, evaluates and analyses operations and maintenance cost data.

The process of the Cost Analysis route begins with recording, reporting and evaluation of the operation and maintenance cost data, continued by *investigation of the identified (cost) drivers*. The next activities are to find a solution for the identified problems through engineering analysis or selecting a relevant SB/SL. Subsequently to develop an Engineering Order (EO) when a solution is discovered, or to issue a Follow-On report when the problem is not solved.

Recommendations for improvement of the process of aircraft modifications due to Manufacturer Bulletins (MB's) are following:

a. perform an initial assessment on LCC-OPS savings
b. *verify (technical feasibility) the targeted LCC-OPS savings and performance improvement* before the Engineering Orders for the MB's are implemented
c. collect cost data for cost monitoring (demonstration) and future cost predictions. This requires establishment of a "Cost Database" system.

The process of letter check escalation should consist of five sub-processes:

a. Investigate the technical feasibility to escalate a check interval (preliminary estimate, LCC savings target establishment). This can be done periodically depending on the interval of the check, the results of the inspections and the unscheduled maintenance
b. Review the inspection interval of ALI's and CMR's (first approval)
c. Perform engineering analysis of each MRI (engineering verification) on the basis of maintenance history
d. Develop escalation proposal (for final approval by the Regulatory Authority).
e. Demonstration of the LCC-OPS savings target.

The author considers the application of a provisional interval as conservative, because the proposed interval will be tested first on sample aircraft, before it is applied to the whole fleet. However, the author considers the application of a provisional interval is necessary in the following situations:

a. the fleet data is limited due to new introduced aircraft
b. there is no operator experience with the escalated interval
c. a high ratio of the number of findings over the number of inspections. For this situation, interval escalation may lead to an increase of unscheduled maintenance.

There are no recommendations for the process of aircraft selection. The existing process is satisfactory.

9.4 Cost Data Recording and Information Systems

Long term evaluation on (potential) cost savings for the (TO-BE) implemented manufacturer/vendor bulletins need to be done, to evaluate how far the airline has followed the manufacturer suggestions and how much total cost saving has been achieved. This is to measure the effectiveness of the bulletins in solving the problems and to estimate potential cost savings.

In the existing situation, the material and man-hours used for modifications are recorded. However, information about the used material and man-hours is not evaluated against the projected costs mentioned in the EES form. A database record on realised material and man-hours for modifications is necessary for evaluation of the effectiveness of modifications to reduce cost and/or improve performance and also to estimate the required man-hours and material for the next modifications. The record is already available, but not used by the Reliability Engineering Unit, due to a high workload of the engineers.

Information from manufacturer/vendor bulletins is frequently not sufficient to decide to implement proposed modifications. Information like estimated improved MTBF, implementation cost and projected savings are rarely shown in such bulletins. *To make SB's more attractive, the manufacturers have to indicate the required data to enable estimation of reliability improvements and operating cost savings.*

Field research of the author at the Garuda Maintenance Facility shows that almost no data from PIREPS and MAREPS can be used to perform root cause analysis and to support analysis of MRI's performance. PIREPS and MAREPS data is presented in ATA two or four digits (system or sub-system level). This is not enough to correlate the PIREPS and MAREPS data with the inspection findings. In some cases the reported findings are not relevant, e.g. oil check, filter check, seal replaced, etc. The recordings need to be standardised on what should be recorded and how. In other words, the role of the Reliability Control Program must be stronger in supporting necessary data and information to analyse the findings.

The use of the ratio of the number of findings over the number of inspections only is not enough to evaluate escalation feasibility. The most important parameter is the estimation of the probability of a defect and the probability of a failure at the escalated interval. This estimate can be made by using the utilisation of the existing interval, the ratio of the number of findings over the number of inspections, and the number of corrective maintenance. After the defect probability estimate is available, LCC-MOPS can be used to estimate the benefits of interval escalation.

For the purpose of delay time estimation, it is recommended to indicate in the report of findings HLA (How Long Ago could the defect have first been noticed) and HML (if the repair was not carried out, How Much Longer could it be delayed). For unscheduled

maintenance (functional failures) HLA is applicable. Delay time estimates are the main basis to judge the appropriateness of the inspection intervals.

The maintenance cost history (quantitative relationship between aircraft age and maintenance cost) of the existing fleet has not been utilised. Evaluation of aircraft candidates must make use of long term information collected from similar type of aircraft, especially from the same manufacturer, as far as available. This is to investigate the relation between aircraft reliability performance, maintenance cost and aircraft age. The role of the number of aircraft within the fleet and fleet commonality need to be quantified as far as possible. The relation above enables the management to determine the best time for replacing an aircraft type and to select the most appropriate one.

The maintenance and operational information systems must be able to support this evaluation process. Together with aircraft modification and maintenance program optimisation, the use of such an information system will be maximal. However, the quality of data entered must be complete and accurate in order to arrive at right decisions.

9.5 Organisational Aspects

As it has become clear in the observations, from the subject of aircraft modifications, maintenance program optimisation and aircraft selection, the role of cost consideration, is very limited in all three processes. An improvement is by introducing a new unit called "Cost Management", i.e. a unit in the Engineering and Maintenance department which concerns with Operation and Maintenance costs related to aircraft reliability performance. By introducing a Cost Management Unit, the activities of the Engineering and Maintenance department becomes to manage and change the aircraft configuration, as carried out by the section of Configuration Change Management, and to control the configuration of the aircraft by monitoring and evaluating aircraft reliability and cost, as carried out by the Reliability Management and the Cost Management sections.

9.6 Recommendation for Future Research

There are three decision diagrams used for the TO-BE situation, i.e.: the Reliability Improvement Decision Diagram (sub-section 4.3.1 and Fig. 4.4), the Manufacturer Bulletins Evaluation Diagram(sub-section 4.3.2 and Fig. 4.5), and the Cost Evaluation Decision Diagram (sub-section 4.3.3 and Fig. 4.6). The Reliability Improvement Decision Diagram is used in the Alert Type Analysis route and intended to replace the Corrective Action Decision Diagram in the AS-IS situation. The Manufacturer Bulletin Evaluation Diagram is used to evaluate the in-coming Manufacturer Bulletins. The Cost Evaluation Decision Diagram is used in the Cost Analysis route. Research is aimed to determine the effectiveness of the decision diagram in achieving the goals.

New Performance Indicators for Engineering are proposed, i.e. LCC-OPS savings per year and percentage error for estimating the preliminary LCC-OPS savings. Therefore an analysis need to be made by maintenance organisations on the number of aircraft modifications per year, verification of preliminary LCC-OPS estimates and the realisation of the LCC-OPS and

reliability improvement estimates (demonstration) in base maintenance, line maintenance and operation. This is to evaluate how far the potential cost savings can be realised and how accurate maintenance engineers in making estimates.

Delay time estimates are the main basis to judge the appropriateness of the inspection intervals. For the purpose of delay time estimation, it is recommended to indicate in the report of findings HLA (How Long Ago could the defect have first been noticed) and HML (if the repair was not carried out, How Much Longer could it be delayed). For unscheduled maintenance (functional failures) only HLA is applicable. It is recommended to conduct a research to identify methods to detect HLA and HML. This research can be done by aircraft manufacturers who know the aircraft condition degradation.

The detail of the maintenance and operation data is hardly sufficient to make root cause analysis. It is recommended to maintenance organisations to conduct a research to improve the form for data recording of PIREPS and MAREPS and to identify additional training for the mechanics on data recording. The data must support also the estimation of LCC-OPS savings.

PART VI
APPENDICES

Appendix A

The Structured Analysis And Design Technique

This appendix contains a short description of the Structured Analysis and Design Technique (SADT). SADT, which is developed by D.A. Marca [Marca, D. A., et al, 1988], is selected to describe the processes in this research. This is because SADT is relatively simple and includes the components of a process completely, i.e. the input, control, output and mechanism (ICOM).

SADT is a technique to describe a complex system through graphical modelling. Therefore, SADT presentation of a system or a process is called a model. An SADT model of a system or a process is a system description that has a single subject (called activity), a purpose, and a viewpoint. A purpose is the set of questions to be answered by the model, while a viewpoint is the perspective from where the system is being described.

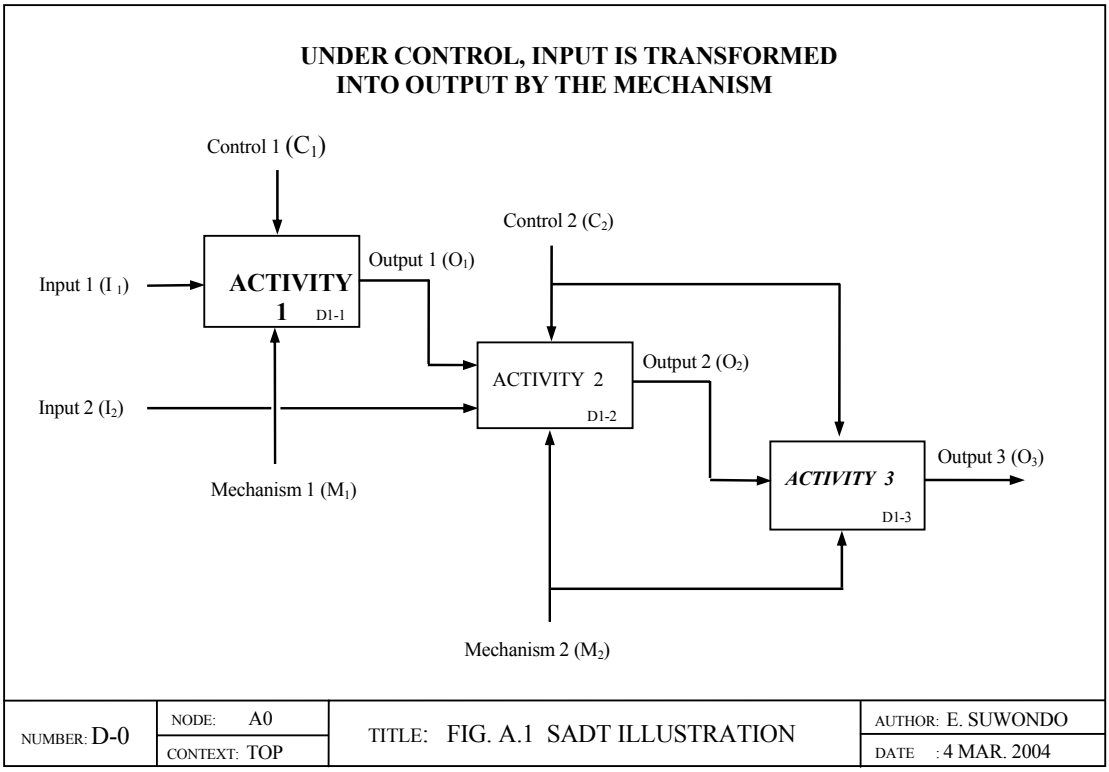
The components of SADT model/diagram are the activities/subjects plus input, control, output and mechanism (ICOM). A process described by an SADT diagram can be mentioned as 'Under control, input is transformed into output by the mechanism'. The inputs are transformed into output, controls constraint or dictate under what conditions transformation occurs, and mechanisms describe how (by whom) the function is accomplished.

To make the diagram, SADT uses boxes (three to six) which represent activities, and arrows which represent things, like plans, data, tool, machine, etc. Arrows may represent also interconnections between boxes. Figure A.1 shows an example of SADT diagram, which has two inputs, two controls, two outputs, two mechanisms and three activities.

Numbering of the SADT diagrams in the thesis are following. Each diagram box always has a code number placed in the left below corner, begins with letter X, where X indicates the subject of the research (X=M for ***M***odifications, X=E for Maintenance Program Optimisation (***E***scalation) and X=S for Aircraft ***S***election). The letter X is followed by number(s) which indicate(s) the position of the diagram (as an activity box) at one level higher diagram. The sequence of diagram levels is level 0, level 1, level 2, etc. NODE indicates the level of the diagram and has a code begins with letter A followed by the level of the diagram itself. CONTEXT indicates the number of the diagram one level higher where the current diagram

is included. An example of numbering is NUMBER: ***M1-2-3***, which means diagram for the subject of Modifications of the activity box number 3 in the diagram level 2 (M1-2) which is the activity box number 2 in the diagram level 1 (M1) which is the activity box number 1 in diagram level 0 (M0). For this example of NUMBER, the diagram will have CONTEXT: M1-2.

The highest level of SADT diagram is numbered with X0 (X zero) with the NODE of A0 and the CONTEXT is called TOP. One level lower diagrams are numbered with X followed with one number, e.g. M1, M3, E2 and S1. At the highest level, the NODE and CONTEXT are A0 and TOP, respectively. The NODE of further lower diagrams are A1, A2, A3 and so on.



Appendix B

LCC In Systems Engineering

This appendix discusses the role of the LCC concept in Systems Engineering (SE). The approach of SE is applied in the thesis, as it is introduced in Chapter 1. The application of the LCC concept is following the process of target establishment, verification and demonstration (see section 1.1.2 of Chapter 1) and applied in each of the three research subjects.

B.1 Systems Engineering

A complete description of systems engineering (SE) can be found in the MIL-STD-499A [DSMC Guide, 1990]. It is defined as *the application of scientific and engineering efforts to (a) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation; (b) integrate related technical parameters and ensure capability of all physical, functional, and program interfaces in a manner that optimises the total system definition and design; (c) integrate reliability, maintainability, safety, survivability, human engineering, and other such factors into the total engineering effort to meet cost, schedule, supportability, and technical performance objectives*.

The top goals of systems engineering (SE) are **cost**, schedule, supportability and technical performance. It will be explained later that **cost** here addresses to LCC. Two kinds of processes can be identified in this definition, i.e. technical process, i.e. in point (a) and management process i.e. in points (b) and (c), in the definition above.

The systems engineering processes (SE), both technical and management, are generic, iterative, recursive and multi-disciplinary. Generic means that the processes are applicable for almost all kind of systems, iterative means the process will be repeated if the result does not satisfy the requirements and recursive means the same sequence of the process can be applied for all system life cycle phases and system levels. While multi-disciplinary means various engineering disciplines are involved in SE.

DeLaurentis et al [ICAS-96-3.4.4.] divide the engineering disciplines which are involved in SE into two aspects, i.e. product and processes. The product aspect is sometimes referred to as functional or prime engineering, while the process aspect is referred to as quality engineering. The characteristics of each aspect are following:

a. *Product characteristics* are those that pertain directly to the system, such as geometry, materials, propulsion systems, etc.
b. *Process characteristics* refer to those that are related to how the product is designed, produced and sustained over its life cycle.

In aviation, engineering disciplines which influence *product* characteristics are aerodynamics, structure, flight dynamics and control, propulsion, etc. While *process* characteristics are influenced by manufacturing engineering, reliability and maintainability engineering and supportability engineering. *All of those engineering disciplines determine system life cycle cost, and are integrated by systems engineering.*

The (inherent) *objectives* of SE which are mentioned earlier in the definition can be explained in a more explicit way as follows [DSMC, 1990]:

a. Ensure that system definition and design reflects all requirements for **all** system elements, i.e. hardware, software, personnel, facilities, and data. These requirements lead to a specific magnitude of LCC. If a LCC baseline has been established, then it can be verified after the requirements on system elements are satisfied.

b. Integrate technical efforts of the design team disciplines to produce an *optimal balanced design*. This balance includes performance requirements and LCC.

c. Provide a comprehensive framework of system requirements for use as performance, design, interface, production, test and support criteria. LCC will be estimated after specifications of the system have been established, at every life cycle phase.

d. Provide source data for development of technical plans and contract work statements, where LCC is included.

e. Provide a systems framework for logistic analysis, integrated logistic support (ILS) trade studies and logistic documentation, also their impact to LCC.

f. Provide a systems framework for production engineering analysis, producibility trade studies and production/manufacturing documentation, and their impact to LCC.

g. Ensure that *life cycle cost* consideration and requirements (cost-effectiveness) are fully considered in all phases of the design process.

B.2 Objectives of the LCC Concept Application in each Life Cycle Phase

This section discusses more specifically the objectives of the LCC concept application. The relevance of the objectives of LCC concept application depends on the type of systems and the phase in the life cycle of the system being considered. Generally, if the system is complex and/or involves high capital and/or high failure consequences, then it is necessary to consider the following objectives of the LCC concept application. The earlier in the life cycle phases

of the system, the more relevant is the application of the LCC concept. As shown in this thesis, the LCC concept application is still relevant for the operating phase of aircraft due to its high investment and complexity, e.g. for evaluation of modifications.

Regardless the life cycle phase, the purpose of the LCC concept application generally can be categorised into three aspects, i.e. [SAE-RMS, 1992]:

a. LCC baseline or target establishment through sensitivity analysis of cost drivers.
b. LCC trade study of several different alternative designs or supports.
c. LCC tracking for monitoring LCC variations during a specified time period for demonstration of the estimated LCC.

The objectives of the LCC baseline establishment are following:

- establish a LCC baseline for future cost tracking and monitoring
- identify system elements that are major cost drivers
- as an evaluation criterion for contract award
- budgetary estimate of system or project cost.

B.3 The Roles of LCC in the Systems Engineering Process

Systems engineering (SE) process is an iterative process applied throughout the acquisition phase to analyse operational requirements and translate them into design specifications at successively lower levels [DSMC, 1990]. System requirements include the aspect of RAMS and LCC. Systems Engineering process is especially applied in the acquisition phases. However, SE process is also applicable during the operation and support phase, i.e. to find the best solution (modification) for performance degradation of an item or to improve (optimise) maintenance program.

The SE process consists of three main steps, i.e. a) functional analysis, b) configuration synthesis, and c) evaluation and decision. In the beginning of the process, a requirements analysis has to be carried out. Therefore, requirement analysis is discussed as well. At the end of the process, an additional step is given, i.e. description of system specifications [DSMC, 1990]. This appendix concentrates on these three steps of SE process, as shown in Fig. B.1.

As it has been mentioned earlier, the purposes of the LCC concept application are for LCC baseline establishment, trade study and tracking. These three purposes are directly applicable for the steps of SE process, i.e.:

i). LCC target establishment during requirements analysis
ii). LCC trade study during evaluation and decision, and
iii). LCC tracking during description of system specifications.

During the other steps of the SE process, the relationships between each design parameter or specification to LCC has to be defined, especially during configuration synthesis.

a. Requirements Analysis

The objective of requirement analysis is to evaluate whether the requirements derived from the Definition of Need phase or earlier phase are realistic. These requirements must be complete, which means covers the whole system aspects, and in sufficient detail. Initial

requirements usually comes from customer or information on competitor systems, which may include product and process requirements. From customer requirements, project or process requirements can be derived. Requirement analysis has to be able to identify the *critical requirement(s)* which dominates the system LCC (sensitive to system LCC) through requirements allocation (flow-down). Cost drivers identification and sensitivity analysis are the major tools during the requirements analysis. Requirements analysis answers the questions "**what function**" and "**why**". (DSMC guide considers the "what" and "why" questions which have to be answered in the Functional Analysis step).

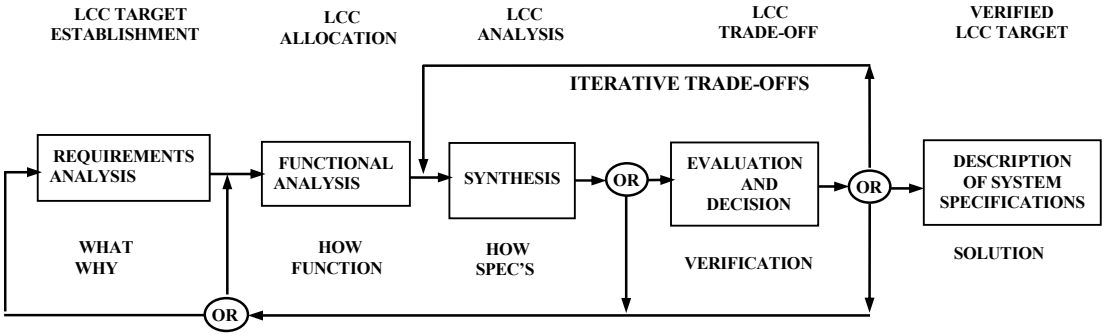


Fig. B.1 The Systems Engineering process [DSMC, 1990; R.G. Burton, et al, 1994]

Requirement analysis consists of two sub-steps [Burton, R.G, 1994], i.e.:
i). *requirement compilation and interpretation*, which results in a detailed listing of customer supplied and derived requirements.
ii). *operation and functional decomposition*, which identifies segments within the total operation and the functions (processes) to accomplish each mission segment.

b. Functional Analysis:
A function is defined as a specific or discrete action that is necessary in order to achieve a given objective, for example, an operation that the system must perform to accomplish its mission, or a maintenance action that is necessary to restore system operational use [Blanchard, 1991]. The objective of the functional analysis is to define the relationships between functions and allocate them into the total system architecture. Every function has a 'cost account', and when aggregated it will form LCC. *In other words, the LCC target is allocated into sub-systems or sub-processes*. Functional analysis answers the "**how**" question, and has three sub-steps, i.e.:
i). control hierarchy analysis which defines the constraints on functions
ii). functional flow analysis which defines the sequences in which functions must occur
iii). functional allocation which maps functions into the total system architecture/hierarchy.

c. Configuration Synthesis:
Configuration synthesis defines the design concept, to be evaluated against the system requirements. LCC analysis is conducted to determine the LCC value, LCC profile and cost risk of the design concept. This step provides the answer of "**how**" questions in sense of system specifications, as implementations of the functions defined in the previous step. This step consists of four sub-steps, i.e.:

i) selection and quantification of design benchmarks which defines *key engineering parameters* to be used in the design process. These key engineering parameters can be the performance killers or (life cycle) cost drivers. Therefore, LCC analysis need to be conducted
ii) sub-systems alternative selection which defines a set of preliminary system specifications to address the system requirements
iii) requirement allocation which maps the system requirements, including LCC, to one or more sub-systems, or one level lower in the system hierarchy
iv) configuration mapping which groups sub-systems candidates into candidate systems and identifies those which meet the system requirements, including LCC.

d. Evaluation and Decision:

Evaluation and decision includes verification that system requirements have been met, trade-offs between system concept alternatives and selection of the preferred concepts. LCC is one of the trade-off criteria. This step is described in an example as shown in Table C.1 below, with Alternative Designs 1 and 2. This step consists of three sub-steps, i.e.:

i) selection of evaluation parameters to define which key design parameters to be used for evaluating alternative designs, and a priority is placed on each of the selection parameter, by using weighing factors. In the example shown in Table C.1, the criteria used are (column a): cost (LCC), weight, risk, maintainability, reliability, delivery schedule, testability and safety. *These parameters are normalised, so that the total of the weighing factors is unity*. The normalised weighing factors of each parameter for the example above are shown in column b of Table B.1.

It needs to be noted that those design parameters might be interrelated to each other, e.g. reliability and maintainability are related to LCC, and vice versa. A combination of LCC and other parameter(s) can be developed also for this evaluation. Because LCC represents the cost side of cost-effectiveness, the effectiveness parameter can be availability (as a function of reliability and maintainability), schedule, risk, etc. If the cost-effectiveness is going to be evaluated, it may use parameters of availability/LCC, schedule/LCC, risk/LCC, etc.

ii) selection of evaluation method, which defines evaluation methods to be used. As shown in Table C.1, the methods which are frequently used, i.e.:
- *analytical*, use an analytical model which represents the system to make a cost estimation, e.g. accounting of all production cost components
- *parametric*, use a parameter to find a correlation between the parameter and to be determined measure, from statistics, e.g. development cost as a function of take off weight
- *simulation*, use of a method (e.g. computer program) to predict the value of a parameter, e.g. prediction on component failure in particular period, which has failure probability following exponential distribution
- *historical data*, use of previous experience (data) to predict future cost.

iii) configuration assessment which is the actual evaluation based on the established criteria. The goals achievement is assigned with a percentage between 0% and 100%, as shown

in column d of Table B.1. If minimum acceptable standards (lower than the goals) are not met for any criterion, the alternative design may be 'dropped out' from evaluation.

Table B.1 shows the results (scores) as assessing Alternative Design 1 (column d), for each criterion. When these scores are multiplied with the normalised weighing value, they result in the end result for each parameter. Total of assessment results is 88.5 (maximum value is 100), as shown in column e. Alternative Design 2 obtains 79.5.

Table B.1 Configurations Evaluation [Burton, 1994]

Selection of weighted evaluation criteria		Selection of evaluation methods	Alternative design Assessment	
(a) Evaluation criteria	(b) Normalised weighing	(c) Methods	(d) Score (%)	(e) End Result (= b x d)
Alternative Design 1:				
1. *Cost (LCC)*	0.30	Analytical	90	27.0
2. Weight	0.15	Parametric	100	15.0
3. Risk	0.10	Simulation	75	7.5
4. Maintainability	0.10	Analytical	82	8.2
5. Reliability	0.15	Historical Data	85	12.8
6. Delivery schedule	0.05	Analytical	90	4.5
7. Testability	0.05	Analytical	80	4.0
8. Safety	0.10	Historical Data	95	9.5
	1.00			+ 88.5
Alternative Design 2:				
1. *Cost (LCC)*	0.30	Analytical	80	24.0
2. Weight	0.15	Parametric	90	13.5
				+ 79.5

e. Description of System Specifications:

The objective of this step is to describe the system configuration selected in the previous steps in a standardised format. A standardised format will ensure that all system elements influencing the system characteristics are sufficiently considered. Due to its strong inter-relationship of systems characteristics, like RAMS to LCC, one or more parameters are mentioned explicitly. The detail of this system elements consideration depends on the life cycle phase.

Appendix C

Maintenance Control By Reliability Methods

Maintenance Control by Reliability Methods (MCRM) provides information required for the application of the LCC-OPS Model in the three areas discussed in this thesis. Proper application of the MCRM will reduce maintenance costs and maintenance dependent costs, while maintaining aircraft reliability and safety at an acceptable level. This appendix presents (only) relevant subjects of MCRM for the application of the LCC-OPS Model, and not to analyse MCRM or its implementation. The description is based on available literature, especially Advisory Circular (AC) 120-17A and the existing implementation of the program at Garuda organisation. The author of this thesis made no contribution on the implementation of MCRM at Garuda organisation.

C.1 Introduction

Maintenance Control by Reliability Methods (MCRM) is required for compliance with the Civil Aviation Safety Regulations (CASR) 18.0.3.1 (2) and (3), and 18.0.6.2 and the equivalent Federal Aviation Regulations (FAR) 121.373 concerning the continuing analysis and surveillance of the performance and effectiveness of its inspection program and the program covering other maintenance, preventive maintenance and alterations. These regulations also require airlines to maintain the continuing analysis and surveillance of performance and effectiveness of their maintenance program. Indonesian Directorate General of Air Communications (DGAC) adopts these CASR and FAR rules and regulations for Indonesian regulations.

The purpose of MCRM is to manage a maintenance program by continuous surveillance, control and audit of the maintenance program effectiveness, to achieve an improved reliability, a better long term planning and to reduce overall cost [Garuda Reliability Control Program Manual]. In other words, the objective of the program is to control and maintain units, systems and aircraft operated by the airlines within acceptable levels of airworthiness, reliability and economics. At Garuda organisation, MCRM is aimed also to fulfil ETOPS requirements for aircraft operated with ETOPS, under approval of the DGAC of Indonesia.

Implementation of the MCRM may lead to improvements by modification of hardware (airframe, engine, systems) and/or software, and improvement of maintenance programs, such as:

a. operation procedures
b. fault finding techniques
c. scope and interval of maintenance processes (tasks)
d. standards of staff training
e. technical documentations
f. storage conditions of spare parts
g. determination of spares holding required, or
h. changes of:
   - material, fuel and lubricant specifications
   - selected third parties repair organisation
   - selected spare parts manufacturers.

Figure C.1 shows the process of MCRM. Explanation of this figure is given in the following sections. Abbreviations list is given in the beginning of this thesis.

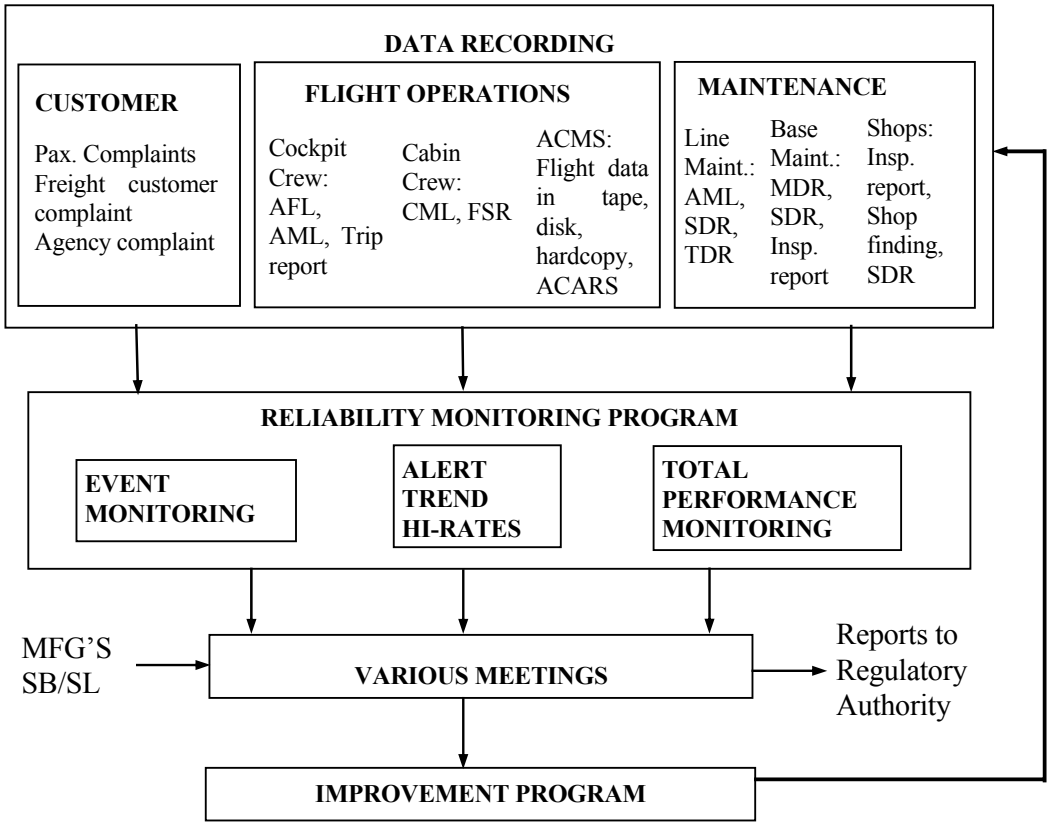


Fig. C.1 The process of Maintenance Control by Reliability Methods
[Garuda RCP Manual, simplified]

C.2 The Method of MCRM

The main activity of MCRM is *monitoring*, which consists of:
a. event monitoring, concerns events related to safety or serviceability of aircraft
b. trend monitoring, concerns trend of troubles including alerts and rate of failures
c. total performance monitoring, concerns overall quality of aircraft and materials based on these two previous monitoring parameters in order to evaluate maintenance standards.

Other activities are data (information) presentation and evaluation (reporting), data analysis and corrective actions. Data presentation and evaluation are statistical analysis, no engineering analysis is required at this stage. Analysis of abnormalities is conducted by the Reliability Program engineer supported by relevant aircraft engineers, to find the root cause of problem (alert exceedance, up-trend or hi-rate). A more detailed analysis to recommend corrective actions is conducted by relevant aircraft engineers. Relevant Manufacturers Bulletins (Service Bulletins/Service Letters) will be used to solve the problem. Several meetings are arranged to manage the program execution. Table C.1 shows the type of meetings, the participants, frequency, subject and source of information.

C.2.1 Data Recording MCRM

Data recording can be divided into data for components, engines and the whole aircraft. Data recording is normally using network-based computer systems (LAN/WAN). Type of data, their sources and data elements for MCRM are shown in Table C.2.

C.2.2 Alert Level Calculation and Trend Analysis

AC 120-17A requires a program to indicate both exceedance from limits and the trends (Alert Type analysis). This program is incorporating statistical analysis. The method for establishing the standard (norm) is usually the normal distribution or Poisson distribution. The normal distribution is more commonly used. For this reason, this sub-section presents the alert level calculation by using normal distribution.

Alert level calculation

The Alert value (control limits) is established from a group of data which normally consists of data from twelve (12) months previous data. The method which is using the standard deviation formula is following [Boeing Evaluation report of Garuda Maintenance Engineering, Appendix F; Garuda RCP Manual].

a. Determine the mean and standard deviation of a normally distributed population:

The mean $= \overline{X} = \dfrac{(\sum X)}{N}$

where: $(\sum X)$ is the sum of the monthly value for each of the N months

N is the number months (usually N=12 or 24)

X is the value of observation.

The standard deviation = $\sigma = \sqrt{\dfrac{\sum X^2 - \dfrac{(\sum X)^2}{N}}{N-1}}$

b. Calculate the Upper Control Limit (UCL)

The Upper Control Limit, **UCL =** $\overline{X} + k\sigma$
where: k = multiplier (typically ranges between 2 and 3).

When k=2.5 is applied for normal distribution, it will assure a 99.4% probability that actual variances from the mean won't be exceeded. In other words, if exceedance of a control limit take place the probability is 0.6% that it is not significant. The smaller the value of *k*, the larger the probability that actual variances from the mean will be exceeded.

An example for Upper Control Limit calculation is following. Assume data recording of a previous twelve months period is as shown in Table C.4 and for the current twelve months period is the same. From Table D.4, the following calculation can be made.

$$\sigma = \sqrt{\frac{152.03 - \dfrac{(42.56)^2}{12}}{12-1}} = 0.314 \qquad \overline{X} = 42.56 / 12 = 3.55$$

For k=2.5, UCL = 3.55 + 2.5 x 0.314 = 4.335

Figure C.2 shows the graphical presentation of this calculation result.

Table C.4 Example of Upper Control Limit calculation

Observation	Month/year	X (MTTF in 000 FH)	X^2
1	Jul - 00	3.08	9.49
2	Aug - 00	3.55	12.60
3	Sep - 00	4.09	16.73
4	Oct - 00	3.28	10.76
5	Nov - 00	3.70	13.69
6	Dec - 00	3.86	14.90
7	Jan - 01	3.28	10.76
8	Feb - 01	3.54	12.53
9	Mar - 01	3.44	11.83
10	Apr - 01	3.89	15.13
11	May - 01	3.70	13.69
12	Jun - 01	3.15	9.92
N = 12		ΣX = 42.56	ΣX^2 = 152.03

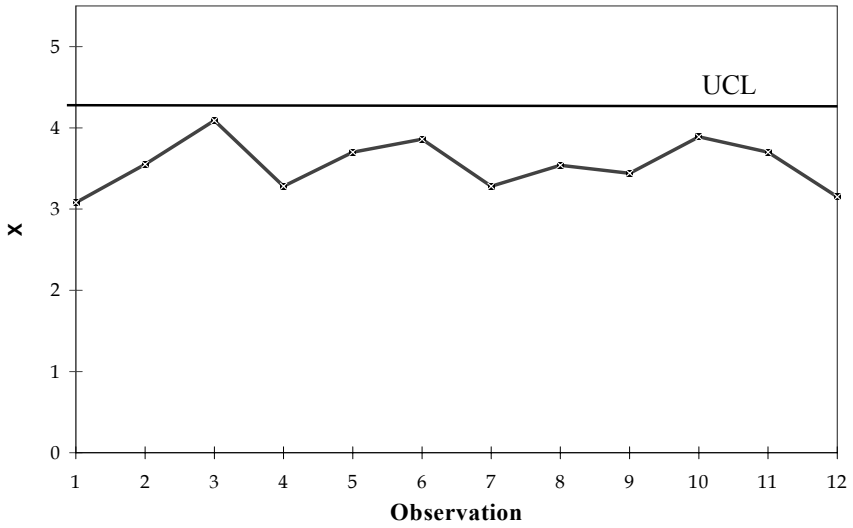


Fig. C.2 Presentation of UCL for the data in Table D.1 with k=2.5

Trend analysis

There are two techniques of trend analysis frequently used, i.e. the moving average and the single or double exponential smoothing. The purpose of smoothing is to identify as early as possible a significant increase of the variable within fluctuating values. The following will discuss these two techniques.

a. Moving Average (MA)

The moving average (MA) technique uses the average of data of previous specified period, e.g. previous 3 months, previous 6 months, etc. With n moving average, the average value of the i^{th} entry, M_i is:

$$M_i = \frac{X_{i-n+1} + X_{i-n+2} + ... + X_i}{n}, i \geq n$$

The following presents an example of the moving average technique application.

Table C.5 Sample data for trend analysis

Month	Nr. of events	Month	Nr. of events	Month	Nr. of events
1	5	13	5	25	12
2	7	14	8	26	10
3	8	15	10	27	6
4	6	16	9	28	10
5	4	17	3	29	12
6	3	18	5	30	16
7	2	19	7	31	13
8	6	20	9	32	8
9	7	21	6	33	10
10	6	22	4	34	12
11	5	23	7	35	18
12	3	24	10	36	16

For the data in Table C.5, the value of moving average entries for n=3 are:

$$M_3 = \frac{5+7+8}{3} = 6.667$$

$$M_4 = \frac{7+8+6}{3} = 7.000$$

etc.

For n=6, the value of the entries are:

$$M_6 = \frac{5+7+8+6+4+3}{6} = 5.500$$

$$M_6 = \frac{7+8+6+4+3+2}{6} = 5.000$$

etc.

Figure C.3 shows the results of moving average calculations, both for n=3 and n=6. The larger the value of *n,* the smoother the plot of moving average, however the later the reaction on an significant increase of the value.

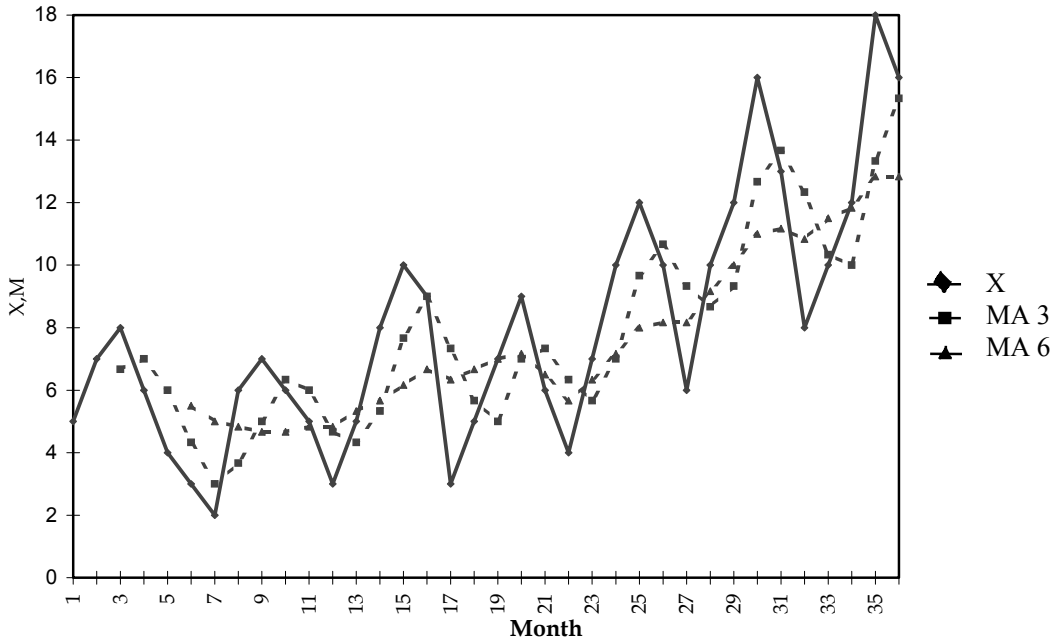


Fig. C.3 Moving Average (MA) technique for 3 months MA and 6 months MA

b. Single Exponential Smoothing (SES)

Trend analysis by using the single exponential smoothing (SES) technique follows the formula bellows.

$$S_1 = X_1$$

$$S_n = \alpha Y_n + (1-\alpha)S_{n-1}, n > 1, 0 \le \alpha \le 1$$

For the data shown in Table C.5, the entries for single exponential smoothing for α=0.7 can be calculated as follow.

$S_1 = 5$

$S_2 = 0.7 * 7 + (1 - 0.7) * 5 = 6.40$

$S_3 = 0.7 * 8 + (1 - 0.7) * 6.40 = 7.52$

etc.

Graphical presentation of the calculation results, for α=0.7 and α=0.2, are shown in Fig. C.4. The smaller the value of α, the smoother the plot of SES.

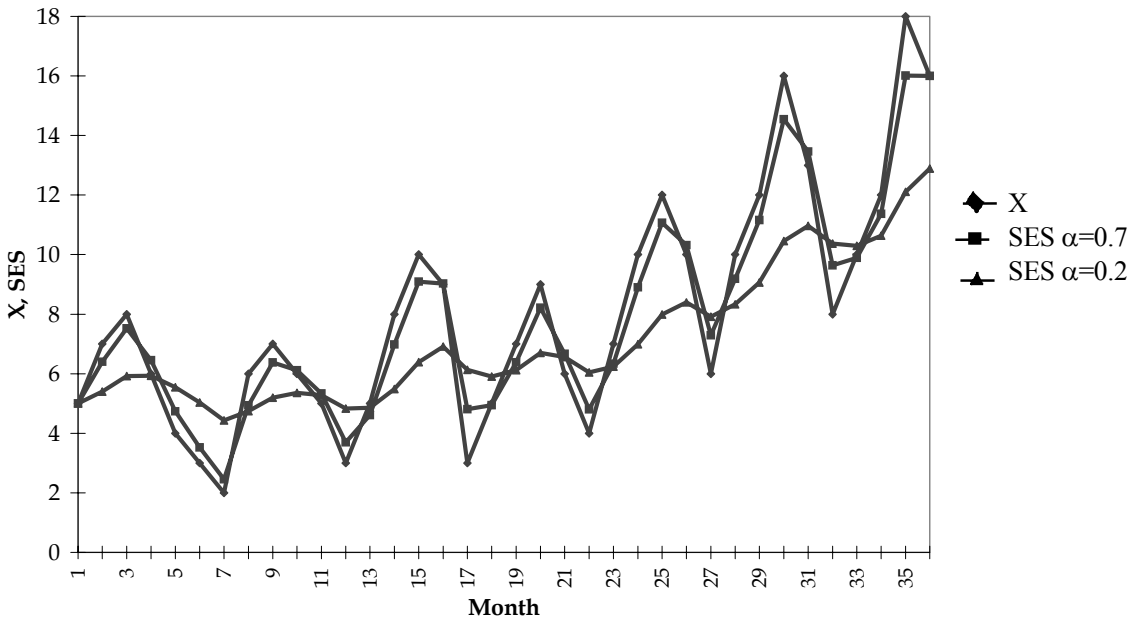


Fig. C.4 Single Exponential Smoothing (SES) with α=0.7 and α=0.2

Table C.1 Meetings for the Garuda MCRM [Garuda RCP Manual]

Name	Technical Delay Meeting	Technical Type Meeting	Engineering Review Committee	Maintenance Review Committee-Working Group	Maintenance Review Committee-Steering Group
Frequency	Daily	Bi-weekly	Monthly	Bi-monthly	Quarterly
Subject	• Identify problem • Take immediate corrective action • Continuous analysis & surveillance program	• Analyse and review to find technical solution • Conduct on-going reliability investigation.	• To review Monthly reliability report and monthly alert report • To report and exchange information on technical problems • To review the activities of reliability monitoring and improvement program	• To draw up procedure and to define maintenance standards for aircraft, engines and components • To review the activities of reliability and improvement program • To propose and draw up new maintenance programs • To implement proposed maintenance program.	• To approve and initiate new maintenance and efficient programs • To decide on matters of principle • To give directives and priorities to the working group.
Source of Information	Event monitoring	RMR (from Event and specific monitoring)	Significant Reliability Item (SRI), from specific, trend and alert monitoring	Total aircraft performance monitoring program	Result of MRC-Working Group

Table C.2 Data areas, sources and elements for GA RCP [Garuda RCP Manual]

Data areas	Data sources	Data elements
A/C Operations	Aircraft Flight Log	A/C flight hours A/C flight cycle Engine shutdown
Delays & Cancellations	Maintenance Control Daily Report (MCDR)	Delays & Cancellations reasons, ATA Chapter of the cause, Rectification and time required, Malfunction, Rectification
PIREPS & MAREPS	Aircraft Maintenance Log (AML)	Complaint and its corrective action (PIREPS). Finding during maintenance and rectification (MAREPS).
	Cabin Maintenance Log (CML)	Complaint which cause delay or cancellation as PIREPS. Complaint which may affect the airworthiness as PIREPS. Finding during base maintenance which may cause delay or cancellation, affect airworthiness as PIREPS. Complaint which may affect passenger comfort.
	Maintenance Discrepancy Report (MDR)	Structural or component failure, generation of excessive heat within component and/or wiring and corrosion as MAREPS.
Components	Tag and Job Card	Component hours/cycle Unscheduled removal justifications Failure confirmation Replaced part and failure mode SB/EO embodiment Task code on component Shop finding and actions
	Vendor/Strip Report	Maintenance task performed Removal justification Failure confirmation Modif. status and incorporated SB. Replaced parts Shop finding and actions
Findings	Service Difficulty Report (SDR)	Finding at Line Maintenance

Appendix D

MSG-3

This appendix presents a short description of MSG-3, specifically for aircraft systems and powerplants. The logic of MSG-3 for aircraft systems and powerplants is mentioned several times in Chapter 5.

The Maintenance Steering Group (MSG)-3 is developed by the Air Transportation Association of America, Inc. (ATA). The original issue of MSG-3, in September 1980, is a revision of MSG-2. The current MSG-3, revision 2002.1, is the fifth revision from the original document. The changes of each revision can be seen in the ATA MSG-3 document [ATA, MSG-3, 2002].

There are two decision logics being used in the MSG-3, i.e.:

a. Maintenance task determination for systems and powerplants
b. Maintenance task and interval determination for structures.

The logic for structures is very extensive and is not going to be discussed in this appendix.

Figure D.1 shows the logic of MSG-3 for systems and powerplants. This logic is applied after system decomposition to identify Maintenance Significant Items (MSI's). MSI is an item which its functional failure has safety, operational or major economic consequences.

LEVEL 1 of the logic is to determine the failure consequences, whether it is a safety evident, operational evident, economic evident, safety hidden or non-safety hidden failure. In the LEVEL 2 applicable and effective maintenance tasks will be selected. The candidate tasks are lubrication/servicing, operational check, functional check/inspection, restoration or discard. The applicability and effectiveness of tasks combination will be evaluated for safety consequences of the functional failure.

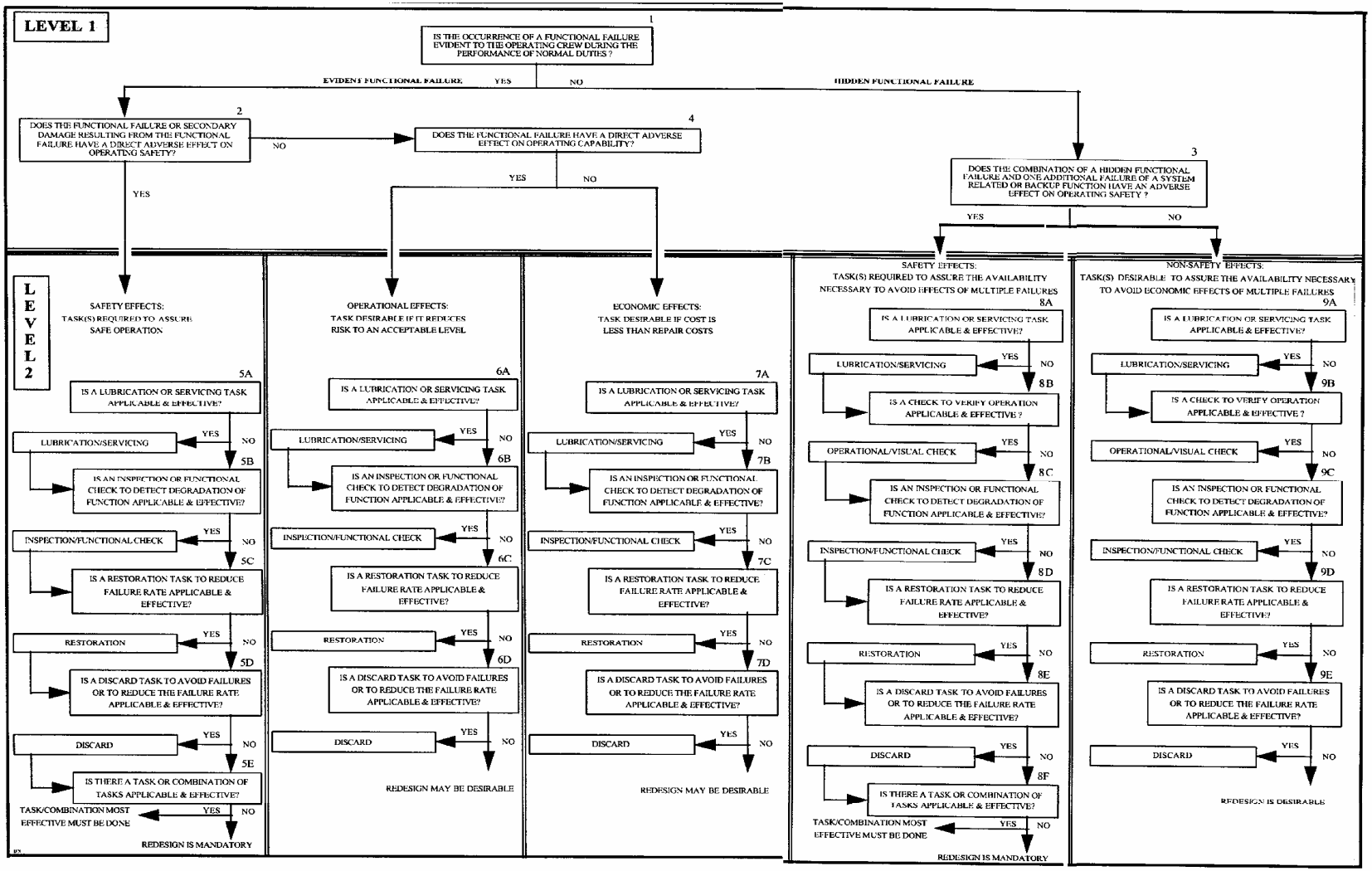


Fig. D.1 The logic diagram of MSG-3 [ATA MSG-3, 2002]

Appendix E

Economic Analysis

This appendix describes some important economical aspects to be considered during evaluating alternatives. The description is based on the references listed in section E.6, combined together. These subjects can be found in most economic textbooks, therefore to indicate the reference for each formula or example is considered not necessary. The aspects being considered are the time value of money, depreciation models and criteria for profitability evaluation. Inclusion of time value of money in the evaluation requires a selection of the most appropriate method for a specific situation. This applies also for selection of the most relevant depreciation model. Profitability analysis is discussed in this appendix because it includes the time value of money. There are some criteria commonly used for evaluating the profitability of available alternatives. Each criteria has its own advantage to the other. All of these criteria require information on revenue, as opposite of the costs for the alternatives. The introduction of this appendix discusses the relevance of these economical aspects to the LCC concept.

E.1 INTRODUCTION

The effect of the timing of expenses on the present value is considered with a discounting factor. Two alternatives may have the same total expenses, but if the timing of expenses is different, then the present value (PV) is also different. In general, the closer the significant portion of expenses to the end of the life cycle, the lower the present value. The criteria which are relevant for evaluating alternatives with respect to the timing of expenses are present value (PV) and uniform annualised cost (unacost). These will be explained later.

In evaluating alternatives, the resale value of the item needs to be considered. The resale value is not necessarily the value of the item at the end of technical life. This mostly depends on the policy of the operator. For some airlines, aircraft are “retired” at a very early life, say 5-7 years. For that situation, resale value will be based on this 5-7 years. Principally, resale value is determined by the market. However, resale value can be estimated by using the depreciation models. Implementation of any modification or refurbishment need to be included and depreciated as well in the resale value.

Economic evaluation of alternative system designs **should** always include the revenue as a result of operating the system. When revenue is included in the evaluation, the term normally

used is **profitability analysis.** Meanwhile, Life Cycle Cost (LCC) includes **only** the expenses. Therefore, LCC is **not** part of the profitability analysis criteria. A modified LCC, which is called LCC-OPS, is applied in this thesis to evaluate alternatives in the operating phase. LCC-OPS includes the opportunity revenue (due to an increase of up-time) and the Maintenance Dependent Costs (MDC). Application of the LCC concept which includes also revenue consideration are called *life cycle profits (LCP).* LCP concentrates more on forecasting of revenues, instead of expenses (see also section E.5). Therefore, LCP is beyond the scope of this thesis.

The criteria which frequently is applied for *profitability* analysis are for instance the Internal Rate of Return (IRR) also called the Discounted Cash-Flow Rate of Return (DCFRR), the Payback Period, or Return On Investment (ROI). Section E.4 explains further details of these criteria.

E.2 TIME VALUE OF MONEY

Time has a money value. Equal quantities of money received or spent at different times do not have equal values. This aspect is important for LCC comparison of alternatives, because these alternatives usually have different timing of cash out-flows. This section presents the foundation of the effect of timing of cash flow to the present value (PV). There are three subjects to be explained, i.e. the time value effect in discounting, the calculation of the discount rate and the present value of uniform annual cost.

E.2.1 Discounting (Discounted Cash Flows, DCF)

If a quantity of money, **P**, earns *interest* **r** (expressed in decimal form) for a specified time period, its value at the end of that time period becomes:

$$F_1 = P(1+r) \tag{E.1}$$

where: F_1 = the value money after one time period
P = present value of the money
r = the interest rate.
When the time is extended until n time periods, then Eq.(E.1) becomes

$$F_n = P(1+r)^n \tag{E.2}$$

where: n = number of periods
F_n = future value after **n** time periods
r = interest rate
The most common time period used is the annum (year), although any time period can be used for compounding interest.

The expressions of Eq. (E.1) or (E.2) can be used also to calculate the present value of money if the future value after n time periods is known. The process of converting future value into its equivalent in present value is called discounting. This name comes from the fact that future value is being reduced (discounted) to its current or present value equivalent. The expression is following:

$$P = \frac{F_n}{(1+d)^n} \tag{E.3}$$

where: **d** = discount rate.

The difference between interest rate and discount rate is describes in sub-section E.2.2.

E.2.2 Interest rate and discount rate

Interest of a quantity of money is the additional amount given by a bank at the end of time period when some money is deposited in that bank. The percentage of interest with respect to the original amount is called interest rate, **r**. The value of **r** is determined by the bank.

Discount rate is determined by two factors, i.e.:
a) the inflation and escalation rates, **i**, and
b) the long-term market cost of capital (borrowing or finance capital for a project), **c**.

Inflation is the time-oriented increase in costs brought about by rising the prices and rising cost of materials, subcontracts, parts, supplies, good and services. Escalation is the time-oriented increase in costs brought about by increases of labour-hours, wage rates, and non-productive labour encountered in providing a given work output [Stewart, 1991]. The distinction between inflation and escalation is sometimes considered necessary for estimation of cost elements of a cost breakdown structure (CBS). The cost elements are estimated from work packages which requires labour-hours and materials.

If the estimated inflation/escalation rate is **i** and the long-term market cost of capital is **c**, the discount rate, **d**, is calculated by:

$$d = \frac{1+c}{1+i} - 1 \tag{E.4}$$

In sub-section E.2.1 the interest rate is treated as a **discrete** quantity to be compounded periodically, usually on an annual basis. But, it is more realistic to calculate interest continuously for a relatively continuous cash flow. For continuous interest rate, Eq. (E.2) becomes

$$F_n = P e^{rn} \tag{E.5}$$

where: e = Naperian constant = 2.7182
r = interest rate
n = number of periods

The continuous interest rate gives a higher interest than the discrete one. The shorter the period for interest calculation, the closer the discrete interest method is to the continuous one. This phenomena is shown in Table E.1. The future value (FV) factor times the amount invested is equal to the future value.

Table E.1 The future value factor for r=0.06, one year period

Period	Relation	FV factor
Annually	$(1 + r)^1$	1.06000
Monthly	$(1 + r/12)^{12}$	1.061678
Daily	$(1 + r/365)^{365}$	1.061831
Continuous	e^r	1.061837

E.2.3 Uniform annual amount cash-flow (Unacost)

The net cash flow per unit of time sometimes has a constant amount, and is called uniform annual amount cash-flow or unacost. Figure E.1 shows an annual net cash out-flow of \$100 for **investment recovery** of \$1000 in the beginning of a system life. For this situation, the Present Value of an Annuity (PVA) factor can be used. PVA factor expresses the present value of \$1 annually for n years with discount rate of **d**:

$$PVA = \frac{(1+d)^n - 1}{(1+d)^n . d} \tag{E.6}$$

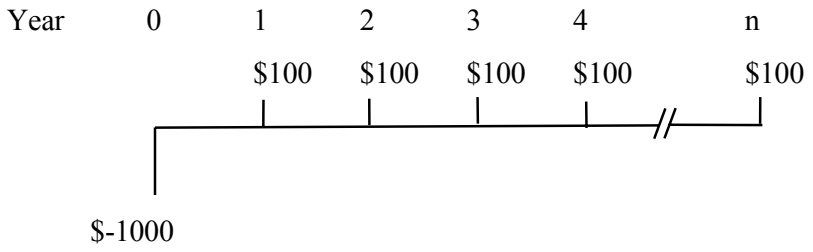


Fig.E.1 The cash-flows in time scale

For the example shown in Fig. E.1, by assuming **d=0.035**, the problem becomes finding **n** which satisfies the equation of:

$$1000 = \frac{(1+0.035)^n - 1}{(1+0.035)^n x 0.035} 100 \tag{E.7}$$

By using a trial and error process, the result is **n = 12.522** years or about 12 years 6 months. The term which is frequently used and more relevant for this example is the **payback period** (This will be reviewed in sub-section E.4.1). If the **system life** is less than 12.522 years, then the investment is not recovered.

E.3 DEPRECIATION

Even though depreciation is not a time value of money phenomena, the calculation of depreciation is a function of time. Depreciation can be defined as the value reduction of an investment, like production machinery, with respect to time. There is no actual cash-flow caused by depreciation. However, income is reserved for future system replacement.

There are at least seven types of depreciation model [Humphreys, 1993; Jelen, 1983], i.e.
a) straight-line (SL)
b) declining-balance (DB)
c) sum-of-the-years-digits (SD)
d) double-declining-balance (DDB)
e). unit of production (UP)
f) accelerated cost recovery system (ACRS), and
g) modified accelerated cost recovery system (MACRS).

The last two ones will not be discussed in this appendix, because the application of these models is limited in the USA, and also ACRS is not used any more.

Straight-line depreciation (SL):
The depreciation is constant for all the years and for each year is:

$$\frac{C_d}{n} \tag{E.8}$$

where: C_d = depreciable first cost = initial cost - salvage value
n = depreciable life (years).

Declining-balance depreciation (DB):
A factor F_{DB} is determined first,

$$F_{DB} = 1 - \sqrt[n]{\frac{C_{sal}}{C_i}} \tag{E.9}$$

where: C_{sal} = salvage value
C_i = initial cost.
The depreciation for the years is obtained from the following sequence:
$D_1 = C_i F_{DB}$
$D_2 = C_i(1 - F_{DB}) F_{DB}$
$D_3 = C_i (1 - F_{DB})^2 F_{DB}$
etc.

Sum-of-the-year-digits depreciation (SD):
The general formula for this model is

$$D_m = C_i \left(\frac{n - m + 1}{0.5n(n+1)} \right) \tag{E.10}$$

where: D_m = depreciation in year m
$C_d = C_i - C_{sal}$ = depreciable amount
n = depreciable life time

Example: An investment has 4 years life, then
$D_1 = C_d\ 4/10$ $D_2 = C_d\ 3/10$
$D_3 = C_d\ 2/10$ and $D_4 = C_d\ 1/10$

Double-declining-balance depreciation (DDB):
A factor F_{DDB} is determined first,

$$F_{DDB} = \frac{2}{n} \tag{E.11}$$

The depreciation for the years is obtained from the following sequence:
$D_1 = C_i\ F_{DDB}$
$D_2 = C_i(1 - F_{DDB})\ F_{DDB}$
$D_3 = C_i\ (1 - F_{DDB})^2\ F_{DDB}$
etc.

Unit of production (UP):
This depreciation model is used for a capital acquisition which has definite production capacity (M) over its life. In this model,

$$D_m = C_d\left(\frac{M_m}{M}\right) \tag{E.12}$$

where: D_m = depreciation in year m
M_m = production in year m

E.4 PROFITABILITY ANALYSIS

Profitability is defined a measure of the total income for a project compared to the total outlay (expenses). Profitability can be applied to a single cost centre, an entire project, or an organisation as a whole [Jelen, 1983]. In this discussion the application of profitability is limited to a single cost centre where the cost pattern of an investment is evaluated. The profitability criteria discussed here are the basic ones which can be used for initial evaluation of alternatives. These profitability criteria can also be combined with the cash-flow study for life cycle profit evaluation.

The profitability criteria can be classified into four categories, as shown in Table E.2. Category I concerns the period to earn back the investment. Category II concerns the rate of returning the investment, but neglecting the timing of cash-flow. Category III recognises the timing of cash-flow and the profitability is evaluated at a rate of return reference. Category IV uses the rate of return and recognises also the timing of cash-flow. The cash-flow of the project for the example of application is shown in Table E.3, where a Straight Line deprecation is assumed. Each of the profitability criteria of these categories above will be discussed in following sub-sections. Comparison of these criteria is given in sub-sections E.4.5 and E.4.6.

The problems to be evaluated mainly can be classified into two, i.e.:
a) equal life cycle and
b) unequal life cycle.

For an equal life cycle problem, the criteria in Table E.2 can be directly applied. For an unequal life cycle, some modification of these criteria is required. *The assumption used for evaluation of an unequal life cycle is that at the end of the life cycle the returned investment can be re-invested with the same rate of return*. The criteria used for an unequal life cycle is the uniform annualised cost (unacost). This is discussed in sub-section E.4.3.

Table E.2 The profitability criteria [Jelen, 1983; Humphreys, 1993]

Category	The profitability criteria
I. The payback period	a. Payback period without interest b. Payback period with interest
II. Return on investment	a. Return on original investment b. Return on average investment
III. Present value	a. Net present value b. Excess present-value index c. Uniform annualised cost (unacost)
IV. Rate of return	Discounted-cash-flow rate of return (DCFRR), or Internal rate of return (IRR)

Table E.3 Cash-flow for project A [Jelen, 1983]

Time end year (a)	After-tax profit (k$) (b)	Depreciation (k$) (c)	Cash-flow (k$) (d)
0	-1,000	0	-1,000
1	275	200	475
2	200	200	400
3	130	200	330
4	70	200	270
5	0	200	200

E.4.1 The Payback Period

The payback period is the amount of time that will elapse before the net revenues return the cost incurred, or number of years until investment is recouped. The net cash inflow is not necessarily constant. If it is constant, payback period = investment/net cash inflow. Otherwise, the payback period is determined by adding the expected cash inflow until the total equals the initial investment. This method ignores the cash flow beyond payback period and the timing of the cash flows (time value of money).

Payback period without interest

The payback period of project A is calculated as shown in Table E.4. From Table E.4, it can be seen the investment will be reduced to zero between 2 and 3 years, or approximately 2.4 years by interpolation.

Table E.4 The payback period of project A without interest

Time, end year	Cumulative cash flow (k$) ($\sum$ d)
0	-1,000
1	-525
2	-125
3	+205
4	+475
5	+675

Payback period with interest

The payback period with interest is seldom used, and the term payback period should mean "without interest" unless interest is specifically mentioned. It is used when a charge is applied on the invested money. The payback period with an interest of 10% for project A is calculated as shown in Table E.5. Investment for each year, in column (2), is the investment of the previous year less the cash-flow after the investment change of the previous year, in column (5). The result is a payback period between 2 and 3 years, or approximately 2.95 years by interpolation.

Table E.5 Payback with interest period for project A (k$) with interest

End year (1)	Investment for year (2)	10% interest on investment (2) (3)	Cash-flow (4)	Cash-flow after investment charge (5)	Cumulative net cash-flow (6)
0			-1,000		-1,000
1	1,000	100	475	375	-625
2	625	62.5	400	337.5	-287.5
3	287.5	28.75	330	301.25	+13.75

E.4.2 Return on Investment

The return on investment indicates the margin of the profit to the balance (when no profit). This will be explained later. The timing of cash-flow is not considered in the return on investment category.

Return on Original Investment (ROI)

The Return on Original Investment, also called the *DuPont* or *Engineer's* method, is the percentage relationship of the average annual profit (sometimes the average annual cash-flow) to the original investment, including non-depreciable items such as working capital [Jelen, 1983]. It can be formulated as

$$\frac{Average\ yearly\ profit\ during\ earning\ life}{Original\ fixed\ invesment + working\ capital}(100) \qquad \text{(E.13)}$$

The working capital is additional investment (funds) to get a project started and to meet subsequent obligation [Jelen, 1983]. For project A depicted in Table E.3, the Return of Original Investment is calculated as follows. The average profit is:

$$\frac{275+200+130+70+0}{5} = 135\ k\$/year \tag{E.14}$$

By using Eq. (E.13), the return on original investment is:

$$\frac{135}{1000+0}(100) = 13.5\%/year \tag{E.15}$$

The time value of money is **not** considered in this criterion, since only the average profit is used. The Return on Original Investment would be the same even though the profits from years 1 through 5 is reversed.

Return on Average Investment (RAI)

The Return on Average Investment is similar to the Return on Original Investment, except that the denumerator in Eq. (E.13) is the average outstanding investment. The outstanding investment is the investment of previous year less the depreciation of the investment in that year.

For the example shown in Table E.3, the average outstanding investment is calculated and shown in Table E.6, i.e. 600 k$/year. The return on average investment is then,

$$\frac{135}{600}(100) = 22.5\%/year \tag{E.16}$$

The return on average investment at 22.5% is higher than the return on original investment at 13.5%, even though the project evaluated is the same. This is because the average investment is lower than the original investment. The return on original investment and return on average investment are independent criteria, and must be used separately. Comparing the return on original investment of one system with the return on average investment of another system will be unfair.

Table E.6 Average outstanding investment

Year	Outstanding investment (k$)
1	1,000
2	1,000 - 200 = 800
3	800 - 200 = 600
4	600 - 200 = 400
5	400 - 200 = 200
	Average = 600

E.4.3 Present Value (PV)

The present value criteria evaluates the total cost in present time. All of the cost components are transferred to the present time by discounting them. The discounting method is discussed in section E.2, with considering whether the cost is uniform annualised cost (unacost) or discrete cost.

This section discusses three types of criteria, i.e.:
a) the net present value (NPV)
b) the excess present-value index, and
c) the uniform annualised cost (unacost).
The superiority of the unacost, compared to other criteria, is that it can be applied easier for evaluation of systems with different length of life cycles.

Net present value (NPV)
The net cash flow each year is discounted at a fixed interest rate, usually **the minimum acceptable rate of return on capital**. The value of minimum acceptable rate of return on capital is determined by the company policy and it can be **estimated** with the **discount rate**, explained in section E.1. The net present value can be formulated as

$$NPV = \sum_{t=0}^{n} \frac{R_t - C_t}{(1+d)^t} \tag{E.17}$$

where: R_t = revenue (in-flow) in year t
C_t = cost (out-flow) in year t
t = year
d = discount rate or minimum acceptable rate of return
n = system life cycle (year).

For the example of project A shown in Table E.3, the net present value with 10% minimum acceptable rate of return on capital is following:

$$\frac{-1000}{1.10^0} + \frac{475}{1.10^1} + \frac{400}{1.10^2} + \frac{330}{1.10^3} + \frac{270}{1.10^4} + \frac{200}{1.10^5} = 318.92 \text{ k\$} \tag{E.18}$$

But, if the minimum acceptable rate of return on capital is 25%, the NPV is:

$$\frac{-1000}{1.25^0} + \frac{475}{1.25^1} + \frac{400}{1.25^2} + \frac{330}{1.25^3} + \frac{270}{1.25^4} + \frac{200}{1.25^5} = -18.91 \text{ k\$} \tag{E.19}$$

The negative NPV at the minimum acceptable rate of return on capital of 25% does not mean that the project is a loss, but it is only unacceptable with respect to company policy.

Evaluation of alternative system designs with respect to NPV should be done on the equal minimum acceptable rate of return on capital. The rank is made based on the value of NPV in decreasing order. The higher the NPV, the more profitable the project is:

Excess present-value index
The NPV criterion actually is not a real profitability criterion, because the definition of profitability itself is a measure of the total income for a project compared to the total outlay (expenses). By using the NPV, two projects A (see Table E.3) would have a NPV of 2 x 318.92 k$ = 638.8 k$, at 10% minimum acceptable rate of return on capital. The profitability of project A and two projects A, by definition of profitability, must be the same, i.e. 1.31892 (the Present Value of revenues divided by the Present Value of costs). This criterion is called **excess present-value index**, and is formulated as

$$\frac{\textit{Present value receipts}}{\textit{Present value outlays}} \tag{E.20}$$

The excess present-value index is used for correction of the investment size (amount). The profitability evaluation is then carried out on equal amount of investment.

Uniform annualised cost (unacost)

The uniform annualised cost (unacost) criterion converts the net present value into an equal annual amount cost. In this criterion the length of life cycle is included, while in all of the previous criteria it does not. *The assumption used in this criterion is that at the end of system life cycle the investment can be re-invested with the same rate of return*. Therefore, the annual cash-flow can be assumed constant (uniform). The unacost can be formulated as:

$$Unacost = NPV \frac{(1+d)^n \times r}{(1+d)^n - 1} \tag{E.21}$$

where: n = system life cycle (usually in years)

d = discount rate or acceptable minimum rate of return

$\frac{(1+d)^n \times r}{(1+d)^n - 1}$ = unacost factor.

The formulation in Eq.(E.21) can also be corrected for the size of the investment [Jelen, 1983], and call it Excess Unacost Index (EUI). The equation is then,

$$EUI = \frac{NPV}{C_i} \frac{(1+d)^n \times r}{(1+d)^n - 1} \tag{E.22}$$

where C_i = initial investment

The higher the unacost, or the EUI, the more profitable the project is.

Project A has a 5 years life, as shown in Table E.3, with the NPV of 318.92 k$, as calculated in sub-section E.3.1, will be compared with project W having an initial investment of 1500 k$, a 7-years life, and a NPV of 585 k$. The **discount rate is 10%,** corrections for project size and life cycle length are taken into account. The result is:

$$EUI_A = \frac{318.92}{1000} \frac{(1+0.10)^5 \times 0.10}{(1+0.10)^5 - 1} = 0.3189 \times 0.26380 = 0.08413 \text{ /(k\$ year)} \tag{E.23}$$

and $$EUI_W = \frac{585}{1500} \frac{(1+0.10)^7 \times 0.10}{(1+0.10)^7 - 1} = 0.3900 \times 0.20541 = 0.08011 \text{ /(k\$ year)} \tag{E.24}$$

Project A is more profitable than project W at a 10% discount rate, although the NPV of project A is lower.

For the same excess present-value index and the same length of life cycle, the unacost index will be higher for a higher discount rate. For the same excess present-value index and the same discount rate, the unacost index will be higher for a shorter project life cycle.

E.4.4 Rate of Return (DCFRR or IRR)

In the category of Rate of Return, the criterion is the **Discounted Cash-Flow Rate of Return (DCFRR)** or also called **Internal Rate of Return (IRR)**. The DCFRR criterion recognises the life cycle of the project, the timing of cash-flow and the size of the investment. The DCFRR is a rate of return which makes the NPV equal to zero. This can be formulated as:

$$NPV = \sum_{t=0}^{n} \frac{R_t - C_t}{(1 + DCFRR)^t} = 0 \qquad \text{(E.25)}$$

where: R_t = revenue (in-flow) at year t
C_t = cost (out-flow) at year t
t = year
n = the length of life cycle (year).

The process of finding DCFRR is by trial and error. But, by using a small computer program, Eq. (E.27) can easily be solved to find DCFRR. In Eq. (E.27), the life cycle length is considered in **n**, the size of investments is considered in R_t and C_t, and the timing of cash-flow is considered in **t**. It means that two projects can be compared directly by comparing the DCFRR's.

For project A described in Table E.3, the DCFRR can be calculated as:

$$\frac{-1000}{(1+r)^0} + \frac{475}{(1+r)^1} + \frac{400}{(1+r)^2} + \frac{330}{(1+r)^3} + \frac{270}{(1+r)^4} + \frac{200}{(1+r)^5} = 0 \qquad \text{(E.26)}$$

where **r is the rate of return in decimal form**. The value of **r** which satisfies the equation above is r=0.239, or the DCFRR is 23.9%.

If the value of DCFRR is grater than the discount rate or minimum acceptable rate of return, the project is profitable. The higher the value of DCFRR, the project is more profitable.

E.4.5 Comparing Three Projects

Three projects A, B and C are compared, with the cash-flows shown in Table E.7. The depreciation model is straight-line (SL) or constant 200 k$/year. All of the profitability criteria mentioned in Table E.2 are used for evaluation. The final result is shown in Table E.8. The calculation procedures are presented below.

Payback period without interest:
Project A: 1000 - 475 - 400 - 330*(X-2) = 0 $\Rightarrow$ X = 2.379 years
Project B: 1000 - 355 - 355 - 355*(X-2) = 0 $\Rightarrow$ X = 2.817 years
Project C: 1000 - 200 - 300 - 400 - 450*(X-3) = 0 $\Rightarrow$ X = 3.2224 years

Payback period with interest (interest rate=10%/year):
Project A: 1000 - 475/1.1 - 400/1.1^2 - 330*(X-2)/1.1^X = 0 $\Rightarrow$ X = 2.954 years
Project B: 1000 - 355/1.1 - 355/1.1^2 - 355/1.1^3 - 355*(X-3)/1.1^X = 0 $\Rightarrow$ X = 3.459 years
Project C: 1000 - 200/1.1 - 300/1.1^2 - 400/1.1^3 - 450*(X-3)/1.1^X = 0 $\Rightarrow$ X = 3.867 years

Table E.7 Cash-flows of projects A, B and C for profitability evaluation [Jelen, 1983]

End	Project A		Project B		Project C	
year	Cash-flow	Net profit	Cash-flow	Net profit	Cash-flow	Net profit
0	-1,000		-1,000		-1,000	
1	475	275	355	155	200	0
2	400	200	355	155	300	100
3	330	130	355	155	400	200
4	270	70	355	155	450	250
5	200	0	355	155	490	290
	Average net profit = 135		Average net profit = 155		Average net profit = 168	

Return on Original Investment (ROI):
Project A: X = 135/1000 = 13.5%
Project B: X = 155/1000 = 15.5%
Project C: X = 168/1000 = 16.8%

Return on Average Investment (RAI):
Because of the initial investment and the depreciation are the same for those three projects, the average investment per year is also the same, i.e. 600 k$/year
Project A: X = 135/600 = 67.5%
Project B: X = 155/600 = 77.5%
Project C: X = 168/600 = 84.0%

Net Present Value (NPV) at 10% interest rate:
Project A:
X = -1000 + 475/1.1 + 400/1.1^2 + 330/1.1^3 + 270/1.1^4 + 200/1.1^5 = 318.93 k$
Project B:
X = -1000 + 355/1.1 + 355/1.1^2 + 355/1.1^3 + 355/1.1^4 + 355/1.1^5 = 345.73 k$
Project C:
X = -1000 + 200/1.1 + 300/1.1^2 + 400/1.1^3 + 450/1.1^4 + 490/1.1^5 = 341.89 k$

Excess Present-Value Index:
Project A: X = 1318.93/1000 = 1.319
Project B: X = 1345.73/1000 = 1.346
Project C: X = 1342.89/1000 = 1.342

Uniform annualised cost (unacost):
Because the size of the projects are equal, correction for project size (excess unacost index) is not required. The unacost factor at 10% interest rate and 5 years life cycle is

$$\frac{(1+r)^n xr}{(1+r)^n - 1} = \frac{1.1^5 x0.10}{1.1^5 - 1} = 0.26380$$

Project A: X = 318.93 * 0.26380 = 84.13 k$/year
Project B: X = 345.73 * 0.26380 = 91.20 k$/year
Project C: X = 342.89 * 0.26380 = 90.45 k$/year

Discounted Cash-Flow Rate of Return (DCFRR):
Project A:
-1000 + 475/(1+X) + 400/(1+X)^2 + 330/(1+X)^3 + 270/(1+X)^4 + 200/(1+X)^5 = 0
$\Rightarrow$ X = 23.9%
Project B:
-1000 + 355/(1+X) + 355/(1+X)^2 + 355/(1+X)^3 + 355/(1+X)^4 + 355/(1+X)^5 = 0
$\Rightarrow$ X = 22.8%
Project C:
-1000 + 200/(1+X) + 300/(1+X)^2 + 400/(1+X)^3 + 450/(1+X)^4 + 490/(1+X)^5 = 0
$\Rightarrow$ X = 20.8%

Table E.8 Summary of projects evaluation (ranking)

Criteria	Project A	Project B	Project C
Payback period without interest	1	2	3
Payback period with interest	1	2	3
Return on original investment	3	2	1
Return on average investment	3	2	1
Net present value	3	1	2
Excess present-value index	3	1	2
Uniform annualised cost	3	1	2
Discounted-cash-flow rate of return	1	2	3

Table E.8 shows that various criteria give also various ranking sequences. It means that a single criterion is not sufficient for profitability evaluation. The payback period and the DCFRR give the same sequence of ranking. It does not mean that one of these criteria can be omitted. *The NPV and ROI give different sequences, it shows the effect of timing of cash-flow on evaluation*. The following sub-section shows that a single criterion is not sufficient for evaluation.

E.4.6. Insufficiency of a Single Criterion

Consider three projects X, Y, and Z with the cash-flows shown in Table E.9. These projects will be evaluated, first with the Discounted Cash-Flow Rate of Return (DCFRR). And later these are evaluated with other criteria.

The DCFRR's of those three project are the same, i.e. 20%.
Project X: -1000 + 750/1.20 + 390/1.20^2 + 180/1.20^3 = 0
Project Y: -1000 + 350/1.20 + 470/1.20^2 + 660/1.20^3 = 0
Project Z: -1000 + 533/1.20 + 467/1.20^2 + 400/1.20^3 = 0

Table E.9 Project X, Y and Z cash-flows

End year	Project X	Project Y	Project Z
0	-1,000	-1,000	-1,000
1	750	350	533
2	390	470	467
3	180	660	400

Evaluation of these projects with respect to DCFRR gives the same profitability. It means the DCFRR cannot be used for this situation. Other criteria have to be applied, and here **one criterion of each category** shown in Table E.2 is used. The result of evaluation of these projects with respect to other criteria is shown in Table E.10.

When the uncertainty of revenues and/or the discount rate is high, then project X is preferable, because it has a shorter life cycle. However, when the uncertainty is low, then project Y is more preferable, because it provides highest NPV. The uncertainty becomes an additional criterion as weighing factor for the results of the evaluation. Without weighing factor, project Y is preferred.

Table E.10 Evaluation project X, Y and Z.

Criteria	Project X	Project Y	Project Z
Payback period	1.7 (years)	2.2 years	2.0 years
ROI	32%	48%	40%
NPV (10%)	1139.4 k$	$1202.5 k$	1171.0 k$

E.5. LIFE CYCLE PROFIT (LCP)

The effectiveness of commercial systems can be quantified in money. For this reason, it will be appropriate to concentrate on profit, as a result of operating the system. From this point of view, evaluation of alternatives will require a consideration of the total profit in the course of the life cycle. This total profit, total revenue minus total cost, is referred to Life Cycle Profit (LCP). Figure E.1 shows a graphical presentation of the LCP concept. By referring to Fig. E.1, it can be seen that the total cost, the acquisition cost + exploitation cost + disposal cost, is equal to LCC.

The term Life Cycle Profit is firstly introduced by Bazovsky [Bazovsky, 1974]. He applied this concept for optimising system support policies and for evaluation of make, buy, or lease alternatives. According to this concept, minimisation of support cost is not necessarily optimum, but an optimum policy is assured when the expected net profit is maximised. Bazovsky developed a probabilistic model for evaluating the impact of replacement policies on life cycle profitability of a system.

Figure E.1 shows the Life Cycle Profit of a system from its initial operation (T_1) until disposal (T_2). From Fig. E.1, Life Cycle Profit can be calculated as follows:

$$LCP = \int_{LC} [Revenue(t) - Exploitation\,cost\,(t)]dt - Acquisition\,cost + Disposal\,\cos t \qquad (E.27)$$

where: LCP = Life Cycle Profit
LC = life cycle.

Ahlmann revived the LCP concept about ten years later [Ahlmann, 1984]. He emphasises the superiority of the LCP concept over the LCC concept with respect to the fluctuation of the market demand. Application of the LCP concept is relevant during the acquisition phase, due to the consideration of total profits (magnitude) which can be obtained during the life cycle, to convince the operators. While during operation and support phase the Return On Investment (ROI) is more important, due to the concern of operator for returning of the invested money as soon as possible. Discussion on these are given in Chapter 1, section 1.1, of this thesis.

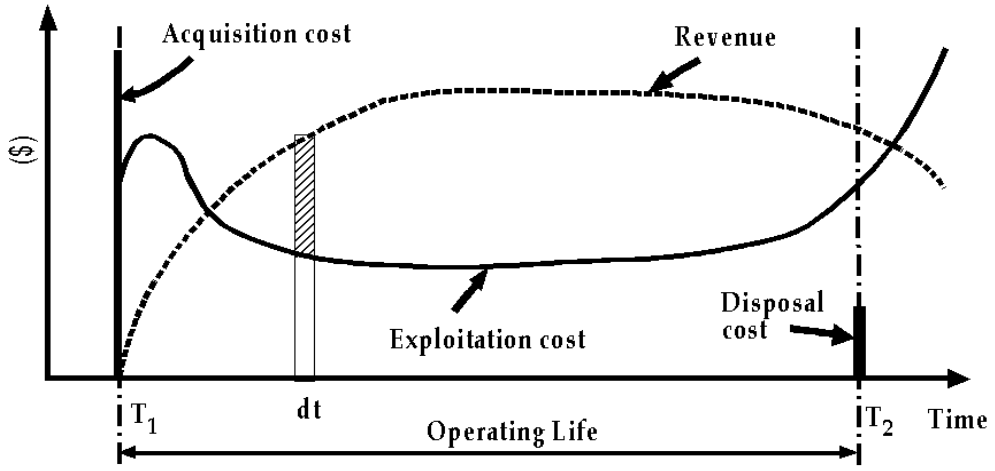


Fig.E.1 Presentation of life cycle profits [Bazovsky, 1974; Ahlmann, 1984: modified]

Appendix F

Life Cycle Cost Analysis Procedure

This appendix presents a short description of the procedure how to implement the LCC concept containing eight steps which are applicable for any type of system, any life cycle phase and any objective of analysis. This procedure is the basis for application of the LCC-OPS for Aircraft Modifications, Maintenance Program Optimisation and Aircraft Selection. This procedure is a result of a literature study of the author. If the reference is not indicated, then it is the author's own view.

The activities to evaluate alternative designs with respect to LCC is referred to as *Life Cycle Cost Analysis* (LCCA). LCCA consists of LCC model development and LCC model application for design alternatives, including Aircraft Modifications, Maintenance Program Optimisation and Aircraft Selection.

LCC model development consists of (see also the description of each step below):

a. definition of the objectives of the analysis
b. definition of the scope of the analysis
c. development of Cost Breakdown Structure (CBS)
d. historical data inventory (collection), and
e. selection of cost component estimation method.

The primary activities of the LCC model development are the Cost Breakdown Structure (CBS) development and cost component estimation method selection. The inputs for the LCC model development are the system specifications and historical data of similar systems, if available. System specifications are for instance operational specifications (mission profile, speed, capacity, etc.), reliability, availability, maintainability and supportability (RAMS) characteristics, environmental influence, etc.

The activities of LCC model application are:

f. LCC profile development
g. cost drivers identification
h. sensitivity analysis and (cost) risk evaluation.

The output of LCCA is a LCC estimate, by means of the developed LCC model, including its distribution on a time scale (LCC profile), cost drivers, sensitivity of the LCC estimate to particular (design) parameters and the risk due to uncertainty of design parameters. The following will clarify the procedure to implement LCCA above.

a. Define the objective of the analysis

The objective of analysis determines the form of the CBS, where only relevant cost components for the analysis are taken into account. More detailed objective analysis are for example the impact of reliability and maintainability specifications of a system to LCC, evaluation on the effect of a maintenance policy to LCC and availability, the impact of hardware modification on LCC, etc.

b. Define the scope of the analysis

The purpose of this step is to define which aspects of the system have to be included or not in the analysis. This leads to the identification of relevant alternatives. The level of system breakdown is frequently used to define the scope of the analysis. An example of scope definition is following. When the objective of analysis is defined as 'selection of material', the aspects need to be considered are for instance: the fuel savings due to weight saving, the changes of inspection method and interval, the required testing to prove the design, the required training and tools, certification costs, production process selection, etc. The parameters/variables used indicate the scope of the analysis.

c. Development of the Cost Breakdown Structure (CBS)

CBS is a breakdown of LCC into its cost components. The form of CBS is based on the objective and scope of the analysis. Selection or detailing of relevant cost components depends on the objective and scope of analysis. Figure F.1 shows a general CBS of a system, where LCC is divided into the acquisition cost and exploitation cost in the first division. The acquisition is divided into research and development (R&D) (or engineering) cost and production cost. While the exploitation cost is divided into operation and maintenance costs, and disposal cost. For modification of hardware or maintenance program improvement, the R&D cost is equivalent to the engineering man-hours required for evaluation and analysis, the production cost is equivalent with implementation cost of the modification. The operation and maintenance cost is equivalent with the savings as a result of modification, while disposal cost is equivalent to the increase of the resale value.

A CBS should satisfy three major requirements [Ahmed, 1995]:

- identify *major items* or *significant activities* and be well defined having the same meaning throughout the entire organisation
- be designed in a such manner that it is possible to identify the impact of cost change in a particular area without effecting the other areas
- be compatible with the data requirements for management cost reporting and control.

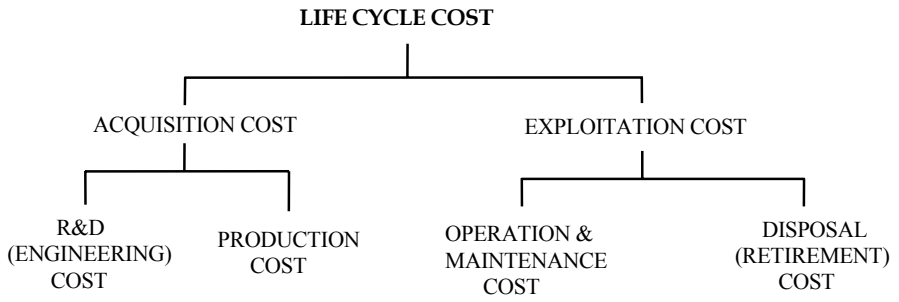


Fig. F.1 General Cost Breakdown Structure (CBS) of a system

d. Historical data inventory

Historical data is required for estimation of cost components identified in the CBS. Historical data is data of similar systems or components with respect to the development, production, operation and disposal. The similarities may include parameters of weight, volume, capacity, the required power, reliability, complexity, or the required production process. Some data sources are:
Historical Data : manufacturer/vendor data and field experience from operators.
Reliability Data Banks : MIL-STD-756 and MIL-HDBK-217

e. Selection of Cost Estimation Method (CEM)

The purpose of this step is to select the most appropriate Cost Estimating Methods for selected cost components. CEM is selected based on the availability of information/ specifications for the system to be estimated and the data from similar systems. CEM's range from the simplest expert opinion until complex regression techniques. Figure F.2 shows the flow-chart (logic) for cost estimating method selection. In aviation, parametric (cost estimation relationships, CER's) method for LCC estimation of transport and fighter aircraft is available, like given by Roskam [Roskam, 1991]. When the prime variable of the cost estimation is a stochast, a simulation method is recommended. Appendix G discusses the cost component estimation methods.

As shown in Fig. F.2, the logic begins with asking the availability of system specifications. In the exploitation phase, normally system specifications are detailed. The next question is whether the prime variable is a stochast. If it is a stochast, then simulation method is recommended. Further question is addressed to the availability of data from similar system, to select the most appropriate CEM's, both for the stochastic method or the deterministic one.

f. LCC Profile Development

When the CBS has been developed and the cost estimating methods have been selected, a further step is presenting the cash-(out)-flows on time scale, which is called the LCC profile. The purpose of LCC profile development is to evaluate the effect of time value of money. Expenditures in the future contain uncertainty, therefore knowing the distribution of expenditure is highly desirable. Figure F.3 shows an example of LCC profile of three alternatives, A, B and C.

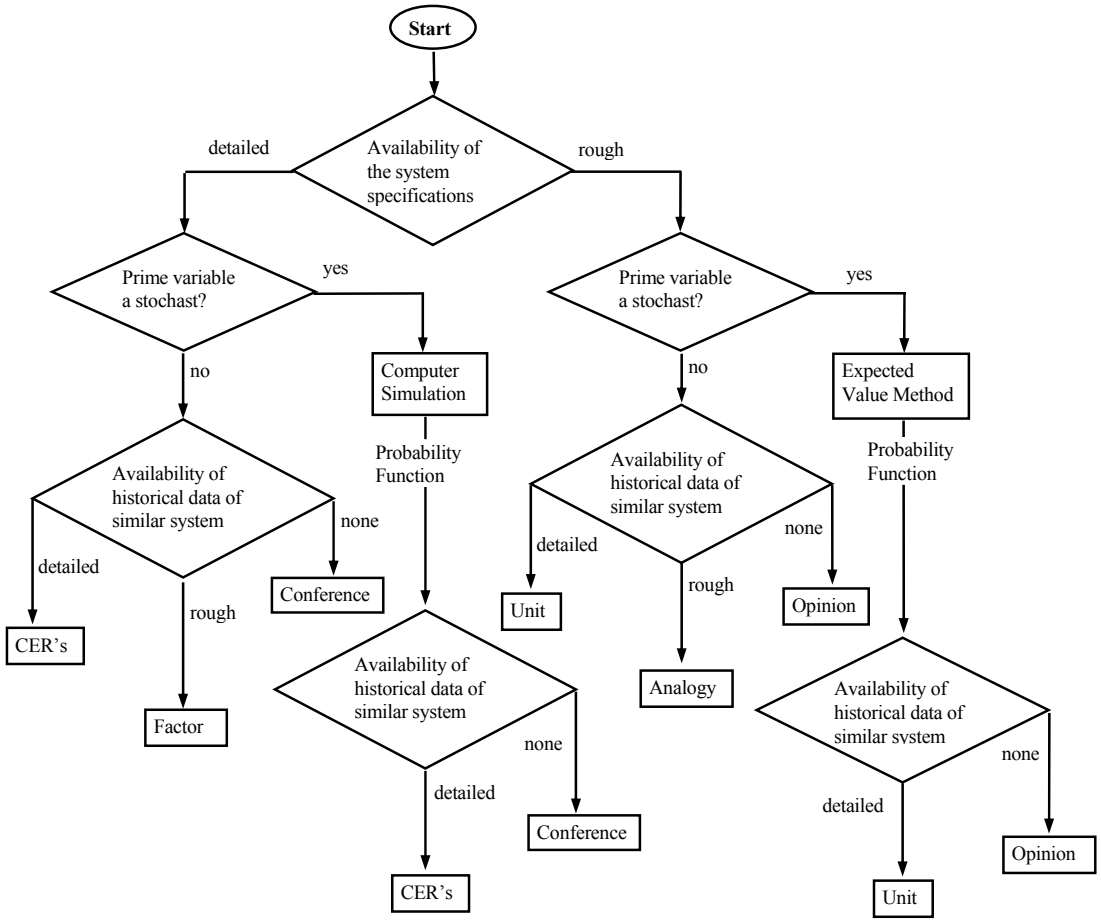


Fig. F.2 The logic of cost estimating method selection

g. Cost drivers identification

This step will identify the system components which dominate LCC percentages. Identification can be carried out by ranking all cost components. The famous method for this purpose is the Pareto analysis, which shows that 80% of total cost is usually caused by 20% of system components or activities. An analysis has to be carried out to reassure that cost drivers are consequences of the customer requirements.

h. Sensitivity and Risk Analysis

The purpose of sensitivity analysis is to evaluate the impact of system parameter variations on the total LCC. If parameter *x* changes 1%, what is the influence to the LCC. This can be carried out easily when the LCC model is computerized. Variation of system parameters should be in a reasonable range. The impact of system reliability variations on LCC is the famous example for this step.

The main objective of risk analysis is to take into account the uncertainty of the system and

operation characteristics due to the uncertainty of material characteristics, production process, usage, environment, etc. These uncertainties should imply probabilistic LCC estimating methods. Figure F.4 shows an example of uncertainty of project schedule accomplishment and its relation to the total project cost. There is 39% probability that the project can be completed within targeted cost, but 61% probability of cost will be overrun. This kind of project can be system development, production or a heavy maintenance project.

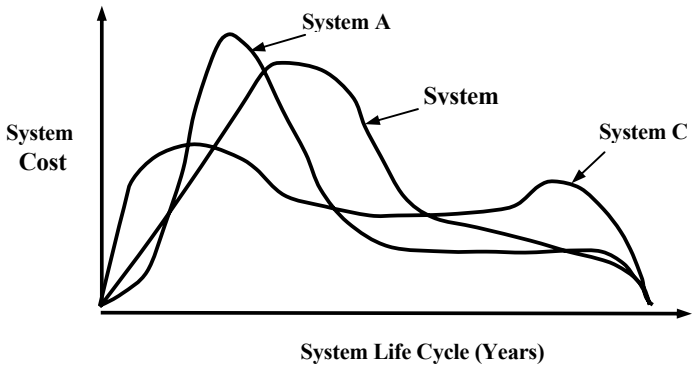


Fig. F.3 Life cycle cost profile of three design alternatives [Blanchard, 1991].

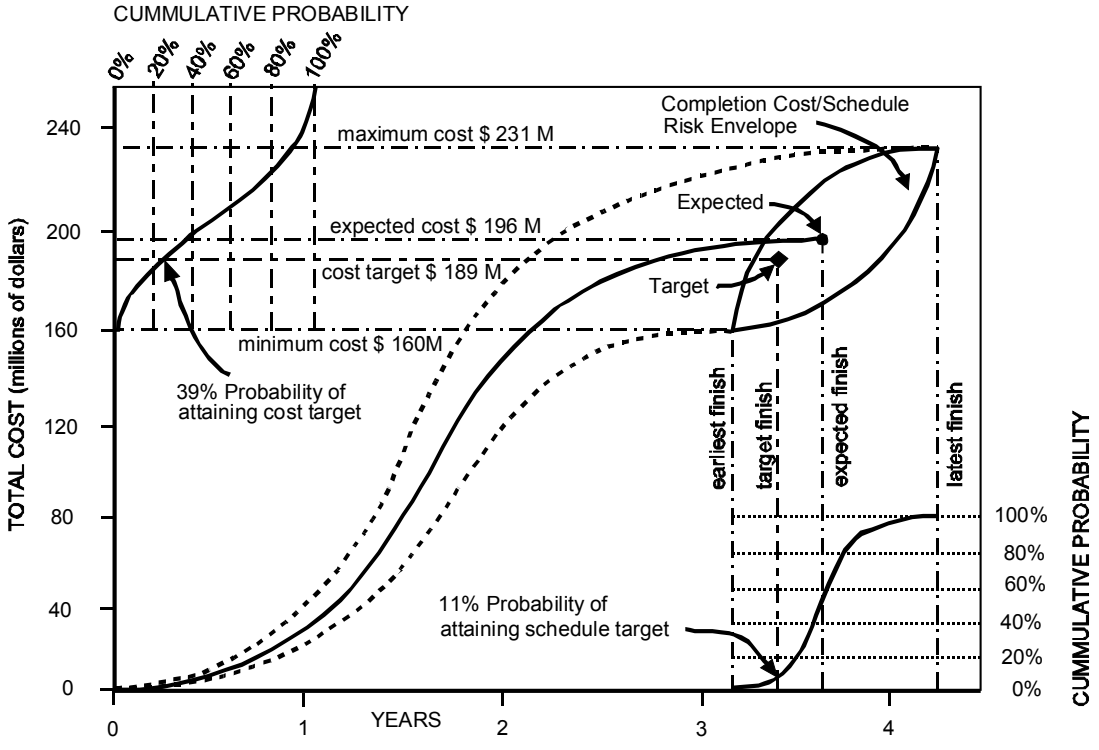


Fig. F.4 The probability of project schedule accomplishment versus total project cost [Feiler, 1986]

Appendix G

Cost Component Estimation Methods

This appendix presents a short description of various methods to estimate the cost components of LCC. In other words, it is to support the Life Cycle Cost Analysis Procedure. This description is a combination of the references listed at the end of this appendix, therefore only for specific citation the references will be indicated. The breakdown of LCC into its components, which is called Cost Breakdown Structure (CBS), is discussed shortly in Appendix F.

Cost estimation methods (CEM) can be divided broadly into two categories, i.e. applied for preliminary and detailed CEM. The preliminary CEM is used in the early stages of analysis where limited information is available. Most of the preliminary CEM are quantitative where no rigid formulation is used, the comparison method for example. Attention turns to detailed CEM as information more available. Detailed CEM are more quantitative. Arbitrary and excessive judgmental factors are suppressed, although they are never eliminated. The judgement to apply certain CEM depends purely on the availability of data, both data of the system to evaluated (specifications) and historical data (information) of similar systems.

The CEM discussed in this appendix are the major ones, where other name(s) of the respective CEM is (are) mentioned in brackets in the title of the relevant section. These CEM's are opinion, conference, comparison, unit, cost and time estimating relationships, probability approach and factor methods.

G.1 OPINION (EXPERT JUDGMENT, EXPERT OPINION)

This method is applied when there is no/limited data available and/or shortage of time. The estimator is selected for the job because of his or her observational experience, common sense, and knowledge about the systems. The famous term for this method is called "expert judgement" or "expert opinion". The latter has a more developed systematic methodology.

Opinion estimating is also done collectively, one example is the DELPHI Technique which is a polling technique. The experts in a given technical area are polled by letter. They are asked to estimate the cost for a system displaying certain characteristics. Their responses are summed-up and a mean, standard deviation or range are established. This data is fed back to the experts in other letter and they are allowed to change their estimates, if they desire. After several interactions, an order of magnitude estimate (the mean) results [SAE SP-721, p.23].

G.2 CONFERENCE

The conference method provides a single value or estimate made through experience. The procedure involves representatives from various departments conferring with estimating in a round-table fashion and jointly estimating cost as a lump sum. Sometimes labour and material are isolated and estimated with overhead, and a profit is added later through various methods by estimator.

The way in which the method is managed depends on the available information. Various gimmicks can be used to sharpen judgement. A *hidden-card* technique can be used to reveal the experts personal value. This could provide a consensus. If an agreement is not initially reached, discussion and persuasion are permitted as influencing factors. Sometimes, it is called estimate-talk-estimate. The hidden-card technique prevents from brain-storming, which generally tends to provide optimistic estimates. In a conference on estimating, the estimator will serve as a moderator and provide questions such as "What is the labour and material cost for this part?".

G.3 COMPARISON (SIMILARITY, ANALOGY)

The comparison method is also called similarity or analogy. It is difficult to make a cost estimate for a new design where historical data of similar systems is not available. The comparison method can solve this problem by employing other (virtual) designs for which the cost estimate can be made, and then compare them. Let's designate the system design to be estimated as problem "a", and construct a simpler design for which a cost estimate can be found, and call it "b". This simpler design might arise from a manipulation or a relaxation of the technical constraints of the original design. The alternative design "b" must be selected to bound the original problem "a" in the following way:

$$C_b\,(D_b) \le C_a\,(D_a) \qquad \text{(G.1)}$$

where: $C_{a,\,b}$ = value of estimate for designs "a" and "b"
$D_{a,\,b}$ = design "a" or design "b"

Also, D_b must approach D_a as nearly as possible. An additional upper bound is possible. Assume a similar circumstance for a known or nearly known design "c", and the logic can be expanded to have

$$C_b\,(D_b) \le C_a\,(D_a) \le C_c\,(D_c) \qquad \text{(G.2)}$$

G.4 UNIT (AVERAGE, ORDER OF MAGNITUDE, LUMP SUM, MODULE)

The unit estimating method is the most popular in the preliminary estimating methods. Many other names exist that describe the same thing: average, order of magnitude, lump sum, module estimating, and involve various refinements. Extensions of this method lead to the factor estimating method, discussed section G.7.

Unit method is defined as the mean, where the denominator is the principal (major) cost driver, or

$$C_a = \frac{\sum C_i}{n_i} \tag{G.3}$$

where: C_a = average cost per unit of design
C_i = value of design i, dollars
n_i = design i unit (lb, kg, inch, mm, count, etc.), which is called the cost driver

Consider the design of cast iron sphere where there are three observations as shown in Table G.1. By using Table G.1, the cost per kilogram is \$2.444 (=11/4.5). A new casting design would be estimated by finding the sphere weight and multiplying this value by \$2.444/kg. If there are more data to be used to develop an estimate, application of linear regression usually gives a better estimate. Comparison of unit method and linear regression is discussed bellow.

Table G.1 The Weight and Cost of Sphere [Ostwald, 1984]

Design Weight (kg	lb)	Cost (Dollars)
1.0	2.205	\$ 2.0
1.5	3.308	3.0
2.0	4.410	6.0
----- +	------- +	------ +
4.5	9.923	\$11.0

If linear regression technique is applied for the data above, it gives [Ostwald, 1984]:

$$a = \frac{\sum x^2 \sum y - \sum x \sum xy}{n\sum x^2 - (\sum x)^2} = \frac{7.25*11 - 4.5*18.5}{3*7.25 - 20.25} = -2.333 \tag{G.4a}$$

$$b = \frac{\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2} = \frac{3*18.5 - 4.5*11}{3*7.25 - 20.25} = 4.0 \tag{G.4b}$$

And the linear regression equation is:

$$y = a + bx = -2.333 + 4.0\,x \tag{G.5}$$

If the unit method above is expressed in linear regression, the equation is $y = 0 + 2.444x$, where y and x are the cost and the weight of the sphere, respectively.

When using $C_a = 2.444$, or $y = 0 + 2.444x$, the unit method can be either an over or an underestimate when compared with the linear regression technique. For a sphere with 1.0kg weight, its cost is \$2.444, and for 4.0kg weight, \$9.776. But, by using linear regression technique, for a sphere with 1.0kg weight, its cost is \$1.667, and for 4.0kg weight, \$13.667. However, the linear regression technique is suspected, in this case, since it gives a minus result (cost) for a zero weight of a sphere, which in practice is impossible.

G.5 COST- AND TIME-ESTIMATING RELATIONSHIPS

Cost-estimating relationships (CER's) and time-estimating relationships (TER's) are mathematical models or graphs that estimate cost or time. Simply, CER's and TER's are statistical regression models that mathematically describe the cost of an item or activity as a function of one or more independent variables. These independent variables can be physical or performance characteristics (e.g. weight, speed, power, thrust, etc.) of the system. Sometimes these characteristics or parameters are called *cost drivers* for CER's and *time drivers* for TER's. An example of CER's is the linear regression technique which is shown in section G.4. The following sub-sections discuss some models of CER's.

G.5.1 Power Law and Sizing Model

The power law and sizing model is frequently used for estimating equipment cost. This model is concerned with *designs varying in size but similar in type*. The unknown costs of a 200-gallon kettle can be estimated from data for a 100-gallon kettle provided for both are similar in design. No one would expect that the 200-gallon kettle would be twice as costly as the smaller one, this is called the law of economy of scale. The power law and sizing model is given as:

$$C = C_r \left(\frac{Q_c}{Q_r} \right)^m \tag{G.6}$$

where: C = cost value sought for design size Q_c
C_r = known cost for a reference size Q_r
Q_c = design size expressed in engineering units
Q_r = reference design size expressed in engineering units
m = correlating exponent, in general.

The value of m can also be more than 1 for a centrifugal fan or compressor, for instance. The value of m depends also on the range of the parameter considered (size). Table G.2 shows some values of m for some equipment. m can be derived by using curvilinear regression technique.

The model can be altered to consider changes in price due to inflation or deflation and effects independent of size, or

$$C = C_r \left(\frac{Q_c}{Q_r} \right)^m \frac{I_c}{I_r} + C_1 \tag{G.7}$$

where C_1 is the constant un-associated cost, e.g. cost of additional equipment other than C, and I_c and I_r are the price indexes. The price index is an index for equipment in certain year,

which indicates the value of the equipment in the associated year. The price index is changing by the change of year (time value of money).

If the statistical analysis assumes constant dollars, then the index ratio I_c/I_r is used for increasing or decreasing of inflation or deflation effects. The model usually does not cover those situations where the estimated design Q_c is greater or less than Q_r by a factor of 10. The value of m is important in several ways. If m>1, it means that the economic law of scale is denied, or the cost is more than doubled if the size is doubled. If m=0, the size of the equipment can be doubled without affecting cost.

Table G.2 Some Value of m (exponent) for Power Law Model [Ostwald, 1984]

Equipment	Size Range	m
Blower, centrifugal (with motor)	1 - 3 hp	0.16
Blower, centrifugal (with motor)	7.5 - 350 hp	0.96
Compressor, centrifugal (motor drive, air service)	20 - 70 hp drive	1.22
Compressor, centrifugal (motor drive, air service)	5 - 300 hp drive	0.90
Dryer, drum (including auxiliaries, atmospheric)	20 - 60 ft^2	0.36

G.5.2 Other Form of Power Law and Sizing Model

The power law and sizing model shown in Eq. (G.6) can also be expressed in different form, e.g.:

$$\frac{C}{Q_c^m} = \frac{C_r}{Q_r^m} = K \tag{G.8}$$

where K is a constant for a plant, equipment, or part. Other symbols are the same as Eq. (G.6). The ratio of equipment cost and design size is a constant, or:

$$C = KQ^m \tag{G.9}$$

This method looks like the unit method, except that the capacity is powered with m.

The effect of learning in series production or installation can also be included by modifying Eq. (G.9) becomes

$$C = KQ^m N^s \tag{G.10}$$

where N = number of units

s = slope of improvement rate in the learning curve.

The exponents of Eqs. (G.9) and (G.10) are derived also by using a curvilinear regression technique.

G.6 PROBABILITY APPROACHES

The parameters or variables in these approaches are not deterministic, but stochastic. The expected value of these variables depend on the probability of their occurrence. The following sub-sections discuss some models which are frequently used in cost estimation.

G.6.1 Expected Value Model

The expected value model uses a probability distribution of the variables to determine its possible value. The techniques for deriving probabilities are the following:
a. analysis of historical data to give relative frequency interpretation
b. convenient approximations like the normal distribution, and
c. introspection, or what is called *opinion probability*.

The expected value method incorporates the effect of risk on potential outcomes by a weighted average. Each outcome of an alternative is multiplied by the probability that the outcome will occur. This sum of products for each alternative is entered in an expected value column, or mathematically for the discrete case,

$$C(i) = \sum_{j}^{n} p_j x_{ij} \tag{G.11}$$

where C = expected value of the estimate for alternative i
p_j = probability that x take on value x_j
x_{ij} = design event (a stochast).
The p_j's represent the independent probabilities that their associative x_{ij}'s will occur with.

The following example discuss a simple example of the expected value method.

There is a market for a system with a price of $650. Unit cost to produce this system is estimated $450, but this is subject to change of material price. If the probability of unit cost to be a certain value is as follow:

Unit Cost	Probability
$450	0.7
$500	0.2
$550	0.1

C = 0.7 x 450 + 0.2 x 500 + 0.1 x 550 = $470

The expected profit is calculated as:

profit = (price - unit cost)*volume of production = ($650-$470)*volume = $170*volume

If without risk, profit = ($650 - $450)*volume = $200*volume

G.6.2 Simulation

Simulation is defined as the manipulation and observation of a mathematical model representative for a real design which for technical or economical reasons is not susceptible to direct experimentation. This synthetic model ideally represents the essential characteristics of the real design with the frills excluded. Simulation models are classified into several groupings:

1. Real versus abstract. A real design would be a prototype of aircraft, for example, versus mathematical or logical statements

2. Deterministic versus probabilistic. In the deterministic model the value used for the parameters is an ideal approximation for a particular design, and in the probabilistic model the value of the various parameters of operations are affected by random events. Sometimes probabilistic simulation models are termed MONTE CARLO, which is a simulation tool and convenient performed with digital computers

3. Machine versus man-machine. The "machine" is a pure computer simulation in which all eventualities are programmed into the computer. The man-machine simulation allows the program interrupted by human beings and permits intervention at strategic points (interactive program).

The intention of a simulation is the collection of pertinent data from the experiment as one runs and watches the outcome of many simulation trials. This "running" and "watching" by simulation is described in Fig. G.1.

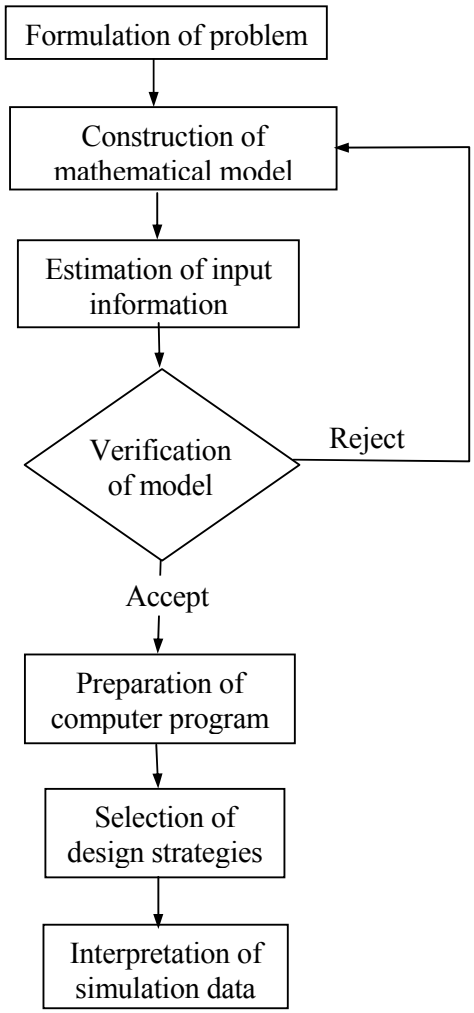


Fig. G.1 Typical flowchart for simulation method [Ostwald, 1984]

First approach is collecting field data and determining Monte Carlo numbers using random number generators and the distributions of field data. The example of this approach is as follow. The distribution of probability density function (pdf), f(x), is found from the field data is shown in Table G.3. Thus \$1.1 x 10^6 has an interval of 0.00 to 0.05. In simulation it is assumed that random numbers are the probability of cost item. If a random number of 0.18 is drawn, it is said that this corresponds to \$1.3 x 10^6 after entry in the Monte Carlo table, because it falls in that range.

The second approach uses the theoretical distributions fitted with empirical coefficients. The probability cumulative distribution F(x) of a random variable is given by

$$F(x) = P(X \le x) = \int_{-\infty}^{x} f(x)dx \tag{G.12}$$

Table G.3 Assumed relative frequency from field data [Ostwald, 1984]

Cost of x x 10^6	Relative Frequency	Monte Carlo Numbers
\$1.1	0.05	0.00 - 0.05
1.2	0.10	0.06 - 0.15
1.3	0.15	0.16 - 0.30
1.4	0.20	0.31 - 0.50
1.5	0.20	0.51 - 0.70
1.6	0.15	0.71 - 0.85
1.7	0.10	0.86 - 0.95
1.8	0.05	0.96 - 1.00

In simulation, various random number, 0 to 1, substitute for F(x) and solve for the upper value of integration, x. This value is the simulated value. The following is an example of this approach.

Assume that a negative exponential function represents a cost element, where f(y) is given by a density with a functional form of

$$f(y) = \frac{1}{8}e^{-y/8}, \qquad y \ge 0 \tag{G.13}$$

To find the cumulative probability distribution, use

$$F(y) = \int_0^{C_y} f(y)dy = \int_0^{C_y} \frac{1}{8}e^{-y/8}dy$$

$$F(y) = 1 - e^{-C_y/8}$$

$$C_y = -8\ln[1 - F(y)]$$

A random number 0.18 is supplied to the functional model:

C_y = - 8 ln (1 - 0.18) = 1.587 or \$1,587,000.

This procedure, draw a random number and supply it to the model, is repeated many times, and finally a distribution of cost can be found. Then the statistical properties, i.e. the mean, range, standard deviation, can be derived.

G.6.3 Range

The range estimating method makes a single-valued estimate by bracketing this estimate for each cost element. The following procedure is based on a method developed for PERT-Cost (program evaluation and review technique, which actually a scheduling technique). It involves making a most likely cost estimate, an optimistic estimate (lowest cost), and pessimistic estimate (highest cost). These estimates are assumed to correspond to the *beta distribution* shown in Fig. G.3. This particular figure is skewed left. Symmetric and skewed-right distributions are also possible. The total area under the curve is 1.

By using those three estimates, a mean and variance for the cost element can be calculated as follows:

$$E(C_i) = \frac{L + 4M + H}{6} \tag{G.14}$$

and $$Var(C_i) = \left(\frac{H - L}{6}\right)^2 \tag{G.15}$$

where: $E(C_i)$ = expected cost (mean) for element i, dollars
L = lowest cost, or best case, dollars
M = modal value of cost distribution, dollars
H = highest cost, or worst case, dollars
$Var(C_i)$ = variance of element i

Table G.4 shows an example of an estimate using range estimating method.

Table G.4 Calculation of Expected Cost and Variance using Range Estimating Method

Item	Lowest cost, L	Most likely, M	Highest cost, H	Expected cost, $E(C_i)$	Variance $Var(C_i)$
Flashlamp	$370	$390	$430	$393.33	100.00
Data grid	910	940	1,030	950.00	400.00
Computer	200	210	270	218.33	136.11
Power supply	260	290	350	295.00	225.00
				--------+	--------+
				$1856.66	861.11

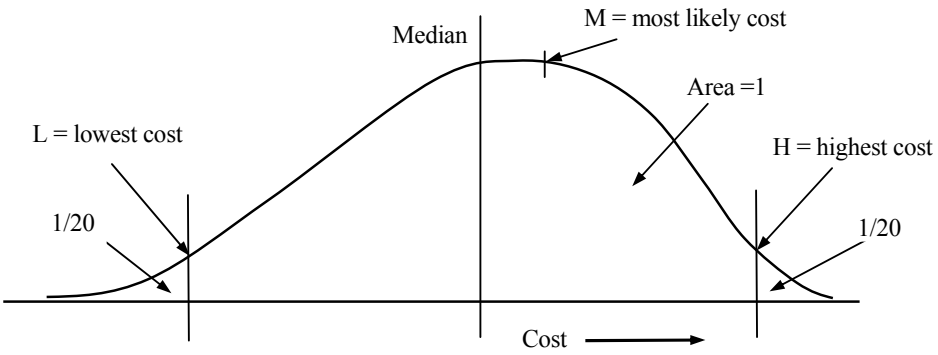


Fig. G.3 Location of estimates for PERT-based beta distribution

G.7 FACTOR (RATIO, PERCENTAGE)

The factor method is a basic and important method for project estimates. However, this method can be adopted for estimation system cost, especially when improvement of the unit method is desired. The factor method determines the estimate by summing the product of several quantities, or:

$$C = (C_e + \sum_i f_i C_e)(f_1 + 1) \tag{G.16}$$

where C = value (cost, price of design)
C_e = cost of the selected major equipment
f_i = factor for the estimating of other than major equipment
f_I = factor for estimating indirect expenses such as engineering, contractor's profit, and contingency
i = 1, ... , n factor index.

The unit-cost estimating method (see section G.4) was limited to a single factor for calculating overall costs. The factor method achieves improved accuracy by adopting separate factors for different cost items. For example, the approximate cost of an office building can be estimated by multiplying the area by an appropriate unit estimate such as the dollars-per-square-foot factor. As an improvement, individual cost-per-unit-area figures can be used for heating, lighting, painting, and the like, and their value C can be summed for separate factors and designs.

Appendix H

Inspection Intervals and Delay Time Models

This appendix shows the delay time models to be used to determine the optimum inspection interval. It begins with a discussion of system's condition degradation, the definition of failures and inspection intervals. It is continued by a description of delay time concept, derivation of the basic delay time model and finally the variations of the delay time model due to imperfect inspection and non-uniform defect initiation. This appendix is closed with an evaluation of the utilisation of the approved interval. The evaluation is conducted by the author of this thesis.

H.1 Inspection Intervals

Figure H.1 shows the degradation of a system (element) condition (simplified). The maximum condition of the system, the initial condition, is at t=0. t=0 can be the Time Since New (TSN), Time Since Overhaul (TSO) or Time Since Install (TSI). The condition of the system is degrading due to the operation, where after certain period of time the system cannot fulfil the specified function. Generally, a failure is defined as an unforeseen unsatisfactory condition [Christer, A.H., et al, J. Oper. Research Soc. Vol.35, No.11, pp.967-984, 1984]. Two type of failure conditions can be defined, as shown in Fig. H.1, i.e.:

a. functional failure, defined as the inability of an item, or the equipment containing it, to meet a specified performance standard.
b. potential failure, defined as an identifiable physical condition which indicates an imminent functional failure. At this point the system begins to be considered defective.

The defect of an item is initiated at potential failure, but this is not always noticed immediately. Normally an indication that the system condition has been defective can be noticed as an increase of power required or fuel consumption, vibration level, mechanical defect, etc. *The time distance between the potential failure condition (called defect) to functional failure is called the delay time*. When an inspection is considered applicable (see reference [Smit, K., 1993]) and necessary, it has to be carried out in the delay time. The optimum inspection interval depends on the distribution type of the delay time.

As shown in Fig. H.1, inspections are conducted at a regular interval until a potential failure is discovered. The determination of inspection intervals is based on the estimate of the time distance between potential failure and functional failure. This time distance must be consistent (has small spread), as an applicability requirement of inspections.

Inspections are applied because the progress of condition degradation is unknown (large spread distribution). The number of inspections carried out until a potential failure is discovered has a large range. ***Therefore the determination of inspection interval cannot be based in the ratio of number of findings and number of inspections***, because inspection intervals are originally determined based on the time distance between potential failure and functional failure. If the time span from the initial condition until a potential failure can be detected is somewhat fixed, then a hard time maintenance policy better be applied. An age-exploration program is conducted to investigate the form of the failure distribution and to adjust the maintenance tasks [Nowlan, S. F., 1978]. Sometimes the manufacturer indicates the initial inspection interval and the repeat interval, but these interval are rarely found in the Maintenance Program.

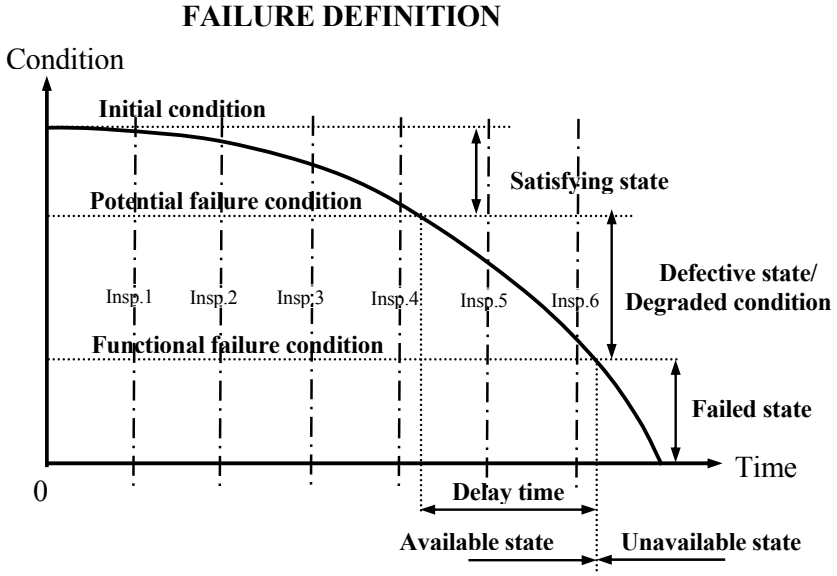


Fig. H.1 Failure definition [Smit, K., 1993]

Figure H.2 shows the time division from t=0 until functional failure. The delay time models to be discussed in this thesis are using this type of time breakdown, which is typical for the Christer and Waller model [Christer, A.H., 1984] (see also Fig. H.1). The time period from t=0 to the defect initiation is designated by a variable *y*. It is assumed that if the defect is initiated than it will be detected, and this defect indicates a potential failure condition. This assumption is not used in the Baker and Wang model [Baker, R.D., 1993]. The delay time, the period from defect initiation until functional failure, is designated by a variable *h* (see Fig. H.2). Both *y* and *h* are a stochast, i.e. its value depends on the probability.

The Baker and Wang model divides the time from t=0 until functional failure into three periods [Baker, R.D., 1993], (but it is beyond the discussion in this chapter due to its complexity) i.e.:

a). the defect initiation period
b). the time to make the defect visible or noticeable by inspection
c). the delay time from the defect is detected until it is causing a functional failure, *h*.

The Baker and Wang model for condition degradation is ideal, as it is used also by Nowlan and Heap [Nowlan, S. F., 1978]. However, the development of the model requires rare data. The Baker and Wang model is more appropriate for laboratory test or investigation, therefore it is not discussed further in this thesis. For application in aviation operation and maintenance, the Christer and Waller model is sufficient.

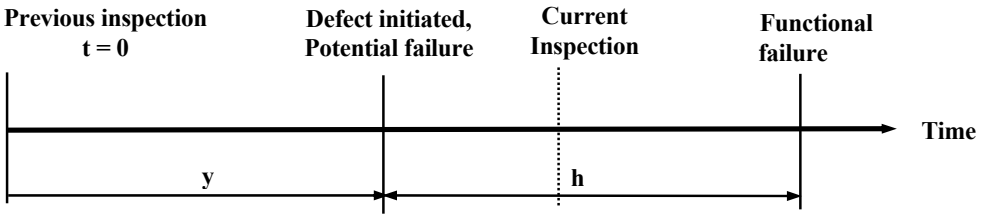


Fig. H.2 The time division for the Christer and Waller model.

H.2 The Concept of Delay Time

The delay time, *h*, of a defect (see Fig. H.2) , is defined as the time lapse from when a defect could first be detected, until the time when its repair no longer can be delayed because of unacceptable consequences [Christer, A.H., J. Oper. Research Soc. Vol.35, No.5, pp.401-406, 1984]. A repair can be carried out anytime within the delay time.

At inspection and/or repair, the following questions can be asked.
c. How long ago could the defect have first been noticed by an inspection or operator (=HLA)?
d. If the repair was not carried out, how much longer could it be delayed (=HML)?

The delay time for each defect is estimated by *h*=HML+HLA (see Fig. H.2). By observing the degradation of the system condition and its cause(s), or component defects, a prior distribution for *f(h)* may be obtained. It is assumed that the defects are independent of each other. If a dependence of the defects is found in the analysis of defects, the delay time model should be modified according to the nature of the dependence.

A defect is detected when the system fails (functional failure) or during an inspection (potential failure). If the sum of the defect initiation period and the delay time, (*y*+*h*), is less then the inspection interval, the system will fail before a scheduled inspection. This failure is rectified by *corrective maintenance, b(T)*. But, if (y+h) is larger than the inspection interval, the defect will be detected during inspection at *T*. It will be rectified by *inspection repairs*, where the repair is carried out together with inspection. If the inspection period (interval) *T* increases, the probability of corrective maintenance, *b(T)*, increases. In general, it may be assumed that the total costs due to corrective maintenance is higher than inspection cost. For this reason, it is important to estimate *b(T)*.

Based on Fig. H.1, the data required to judge an interval is the estimate of the delay time. Estimate of delay time can be established based on the investigation of the discovered findings (potential failure) and functional failure, by estimating HLA and HML. Occurrence of functional failure with similar failure modes indicates that the delay time is shorter than the inspection interval. The number of inspections which has been conducted cannot be used to estimate the delay time, because for inspections without findings the condition degradation has not been initiated yet.

Question for "How many inspections (checks) is required to judge the escalation?" is not relevant, because it does not give any information concerning the delay time. A more appropriate question is how many findings is required to estimate the delay time? It depends on the required confident level of the estimate. For a large number of data it is determine using the normal distribution and for small number of data it is determined using the student t distribution.

The problem is to determine the estimate of the delay time of the population, μ_X. The basic equation being used in solving this problem is following:

$$P(\overline{X} - Z_{\alpha/2}\sigma_{\overline{X}} < \mu_X < \overline{X} + Z_{\alpha/2}\sigma_{\overline{X}}) = 1 - \alpha$$

Where $\sigma_{\overline{X}}$ = the standard deviation of the mean

$Z_{\alpha/2}$ = the value of Z which provides an area (1-α/2) under the standard normal distribution for Z=0 until Z= $Z_{\alpha/2}$.

$\overline{X}$ = the mean of the sample (the delay time of the findings and functional failures)

μ_X = the mean of the population

1-α = the required confidence level

The situation is the mean of the sample can be calculated while the standard deviation of the population is not available. The data of the sample is mostly not sufficient to calculate the *standard deviation of the mean* directly. The standard deviation of the population is then estimated by the standard deviation of the sample. For one sided estimate of the mean of population the equation above becomes:

$$P(\overline{X} - Z_{\alpha/2}\frac{s}{\sqrt{n}} < \mu_X) = 1 - \alpha/2$$

Where s = the mean of the sample

n = number of sample

The equation above indicates that the value of n determine the estimate of μ_X for the required confidence level $(1-\alpha/2)$.

If the number of sample is small (less than 30) then the equation above becomes:

$$P(\overline{X} - t_{\alpha/2,d.f.}\frac{s}{\sqrt{n}} < \mu_X) = 1 - \alpha/2$$

where: $t_{\alpha/2,d.f.}$ = the value of t which provides an area (1-α/2) under the t student distribution with (n-1) degree of freedom for t=0 until t = $t_{\alpha/2,d.f.}$

H.3 Basic Model

The simplest inspection policy is characterised by the following assumptions.

a. An inspection takes place every T time units, with cost I, and requires d time units, $d<<T$.
b. The inspections are *perfect*, any defect presents within the system will be detected.
c. Defects detected at an inspection will be repaired within the inspection period.
d. The time of origin of the defects, i.e. the first instant when the defect may be assumed to first arise within the system, is *uniformly distributed* over time since the last inspection and independent of h. Defects arise at the rate of k per unit time.
e. The *probability density function* of delay time $f(h)$ is known (*subjective*).

Assumption **c** requires that all repairs have to be completed within fixed period d, independent of the number of repairs. Assumption **d** provides an estimate of the expected number of defects arising in the period of T, i.e. kT. This assumption is valid as far as assumption **a** is satisfied.

Suppose that a defect arising within the period $(0, T)$, has a delay time (functional failure) in the interval of $(h, h + dh)$, the probability of this event is $f(h)dh$. If the defect arises in the period of $(0, T - h)$ (see Fig. H.3), the defect is repaired as corrective maintenance, otherwise as an inspection repair. The probability of the defect arising before $(T - h)$, given that a defect will arise, is $((T-h)/T)$. Therefore, the probability that a defect is repaired as a corrective maintenance and has delay time in $(h, h+dh)$ is

$$\frac{(T - h)}{T} f(h)\ dh \qquad \text{(H.1)}$$

where: T = inspection interval
h = delay time
f(h) = probability density function of delay time.

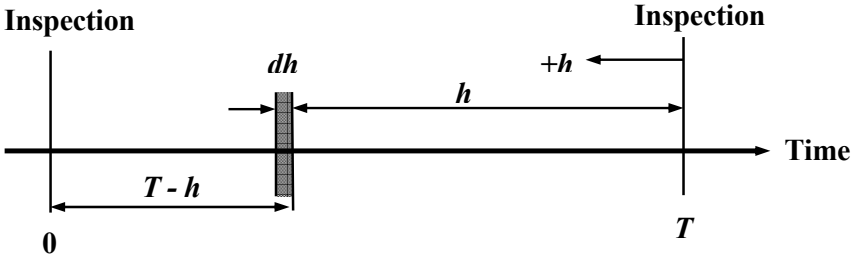


Fig. H.3 The delay time h in inspection period T

Summing for all possible h, the probability of a defect arising as a breakdown $b(T)$,

$$b(T) = \int_{h=0}^{T} \frac{(T - h)}{T} f(h)\ dh \qquad \text{(H.2)}$$

Equation (2) shows the defects which have to be repaired before inspection action at T.

If the average downtime for corrective maintenance is d_b, the expected downtime per unit time where inspection time d is also included is

$$D(T) = \frac{1}{(T + d)} [k T d_b b(T) + d] \quad \text{(H.3)}$$

where k is, again, the rate (number) of defects per unit of time. Equation (3) excludes the downtime caused by corrective maintenance, otherwise it will be:

$$D(T) = \frac{1}{(T + k T d_b b(T) + d)} [k T d_b b(T) + d] \quad \text{(H.4)}$$

The expected cost for maintaining the system per unit of time with inspection period of T is following.

$$C(T) = \frac{1}{(T + d)} [k T \{c_b b(T) + c_i [1 - b(T)]\} + I] \quad \text{(H.5)}$$

where: C(T) = maintenance cost per inspection period T
c_b = corrective maintenance cost per defect
c_i = inspection repair cost per defect
I = inspection cost (excluding inspection repair cost)

Christer and Waller call equations (2), (3) and (5) as *the basic model of delay time* [Christer, A.H., J. Oper. Research Soc. Vol.35, No.5, pp.401-406, 1984]. Equation (5) for the maintenance cost does not include downtime cost (the cost when the system is down, or opportunity revenue loses). For a system with high capital, an aircraft for instance, the downtime cost should be taken into account. The author proposes the following expression for the total maintenance cost:

$$C(T) = \frac{1}{(T + k T d_b b(T) + d)} [k T \{c_b b(T) + c_i [1 - b(T)]\} + I] + R D(T) \quad \text{(H.6)}$$

where: R = revenue per unit of time
D(T) = downtime, as expressed in Eq. (H.4).

Example:

This example presents a simple calculation of k and h, as follows. From aircraft inspection, the following data is obtained:

a. interval utilisation = 100%
b. inspection interval, T = 200 FH
c. number of findings to number of inspections ratio = 0.1
d. number of corrective maintenance to number of inspections ratio = 0.1

Assume the defect initiation has a uniform distribution. The length of delay time is determined from the number of corrective maintenance to number of inspection ratio, as follows.

$\frac{(T - h)}{T} = 1 - \frac{h}{T} = 0.1$ or h = 0.9 T = 180 FH

The number of findings to number of inspections ratio, kh = 0.1. Therefore,
k = 0.1/0.9T or k = 0.111/T = 0.000555/FH.

H.4 Non-perfect inspection case

Non-perfect inspection means that there is a probability that some defects arise but are not detected during inspection at *T*. When the probability of defects to be detected at inspection *T* is β, then $(1-\beta)$ is the probability of defects which are not detected.

Consider a defect which arises at time *y* after an inspection at point 0 (see Fig. H.4). If this defect is subsequently detected at an inspection, it could be the inspection at *T* if $h>(T-y)$, or at *2T* if $h>(2T-y)$, or the inspection at *3T* if $h>(3T-y)$, and so on (otherwise it leads to a corrective maintenance). In general, for defect arising at point *y*,

P(defect detected at T) = P(being detected) . P(not resulting a breakdown before T)

$$= \beta R(T-y) \tag{H.7}$$

where: $$R(T - y) = \int_{T-y}^{\infty} f(h)\, dh \tag{H.8}$$

$f(h)$ is the probability density function of delay time, and $R(T-y)$ is actually an expression for the probability of *h* more than $(T-y)$ (see the direction where *h* is positive in Fig. H.4).

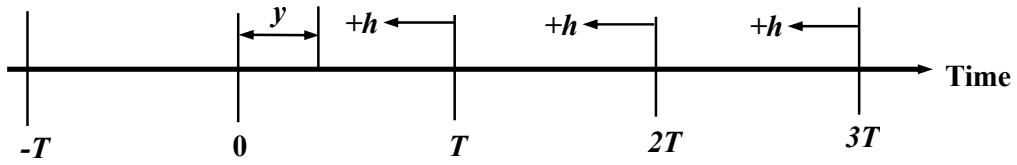


Fig. H.4 A defect arises at *y* after an inspection at point 0

Similarly, for inspection at *2T*

P(defect detected at 2T) = P(being detected) . P(not resulting a breakdown before 2T)

$$= \beta (1-\beta) R(2T-y) \tag{H.9}$$

The expression $\beta (1-\beta)$ mentions the probability of a defect to be not detected at *T*, but it is detected at *2T*.

In general, the probability that a defect initiated at point *y* will be detected at an inspection at *nT* is

$$\beta\ (1 - \beta)^{n-1}\ R(nT - y), \quad n = 1,\ 2,\ 3,\ \ldots \tag{H.10}$$

Therefore, the probability that a defect arising at y will be detected at an inspection is

$$\sum_{n=1}^{\infty} \beta\ (1 - \beta)^{n-1}\ R(nT - y) \tag{H.11}$$

For all possible *y* which is uniformly distributed between 0 and *T*, the probability of corrective maintenance, i.e. (1 - the probability that a defect arises at y will be detected at an inspection), is given by

$$b(T) = 1 - \left\{ \int_{y=0}^{T} \sum_{n=1}^{\infty} \frac{\beta}{T}\ (1 - \beta)^{n-1}\ R(nT - y)\ dy \right\} \tag{H.12}$$

To determine the total maintenance cost for non-perfect inspection case, b(T) in Eq. (H.6) must be substituted by Eq. (H.12). This maintenance cost includes also the loses of revenue.

H.5 Non-uniform Distribution of Defect Initiation

In practice, the distribution of defect initiation between 0 and T is generally not uniform. If y is the time since the last perfect inspection and $g(y)$ is the rate (density) of defect initiation at time y, then the expected number of defects in a small interval $(y, y+dy)$ is $g(y)dy$. Therefore, the expected number of defects arising on the interval of $(0, T)$ is

$$K(T) = \int_0^T g(y)\ dy \tag{H.13}$$

For a defect arising in the interval $(y, y+dy)$, it must have a delay time of less than $(T-y)$ to be corrective maintenance, otherwise it will be an inspection repair. Therefore expected number of defects which causes corrective maintenance in interval $(y, y+dy)$ is (see also Eq. (7))

$$g(y)\ dy\ .\ \int_0^{T-y} f(h)\ dh = F(T-y)\ g(y)\ dy \tag{H.14}$$

where $$F(T-y) = \int_0^{T-y} f(h)\ dh \tag{H.15}$$

is the probability of delay time h less than $(T-y)$ for defect arises in the interval $(y, y+dy)$.

The expected number of corrective maintenance in $(0, T)$ is

$$B(T) = \int_0^T F(T-y)\ g(y)\ dy \tag{H.16}$$

And the probability of defect which causes corrective maintenance in $(0, T)$ is

$$b(T) = \int_0^T F(T-y)\ \frac{g(y)}{K(T)}\ dy \tag{H.17}$$

or $$b(T) = \frac{1}{K(T)} \int_0^T \left\{ \int_0^{T-y} f(h)\ dh \right\} g(y)\ dy \tag{H.18}$$

The downtime per unit time is given by

$$D(T) = \frac{1}{(T + d)} \left[d_b B(T) + d \right] \tag{H.19}$$

where d_b is the average downtime for corrective maintenance.

The cost of maintaining the system with T inspection period is

$$C(T) = \frac{1}{(T + d)} \left\{ c_b B(T) + c_i [K(T) - B(T)] + I \right\} \tag{H.20}$$

where: c_b = cost of corrective maintenance
c_i = cost of inspection repair
K(T) = probability of defects in interval $(0, T)$
B(T) = expected number of corrective maintenance
I = inspection cost

If the downtime cost is taken into account, then the total maintenance is expressed as:

$$M(T) = \frac{1}{(T + d_b B(T) + d)} \{ c_b B(T) + c_i [K(T) - B(T)] + I \} + R\ D(T) \qquad \text{(H.21)}$$

where: R = revenue per unit of time
D(T) = downtime, includes the time rectify functional failure, expressed as:

$$D(T) = \frac{1}{(T + d_b B(T) + d)} [\, d_b B(T) + d \,] \qquad \text{(H.22)}$$

H.6 Utilisation of the Approved Intervals

This section will evaluate the impact of the utilisation of the existing approved interval [42]to the probability of the corrective maintenance. In the same manner, it will evaluate the impact of the postponement of an inspection (increase of the interval, which means an escalation) to the probability of corrective maintenance. The description in this section makes use the method of reference [Christer, A.H., Int. J. of Production Economics, Vol.24, pp.227-234, 1992], which is called relaxation of inspection interval. This evaluation is conducted by the author of this thesis to support the analysis described in section 6.3.

The basic assumptions in this discussion are:
a. the defect initiation is uniformly distributed.
b. the length of delay time function is constant, *h*.
c. any inspection is nearly perfect, therefore the probability of a defect to be undetected is p<<1. (p = 1-β, β is the probability of detection if defect arises).

In practice, inspections are not always carried out at exactly the same intervals. It depends on the operational situation, where inspections are frequently done earlier than the established interval. But, inspections cannot be done later than the established interval, because it will require an approval from the regulatory authority. This section discusses two situations where h<T and h>T. For h>2T, h>3T, etc., are considered not important due to assumption c (explained later).

H.6.1 Reduced Inspection Interval for h<T

Consider an inspection conducted at interval (T-x), where T is the established (approved) interval, with delay time h where h<T, as shown in Fig. H.5. Situation when the delay time is larger than the reduced interval, h>(T-x), is not discussed, because it is less critical.

The probability of breakdown (unscheduled) repair when the inspection conducted at T is

$$P(U) = \frac{AC}{T} + \frac{CE}{T} p = \frac{1}{T}\left[(T - h) + ph\right] \qquad \text{(H.23)}$$

where: A = time when T=0
B = defect initiation time point

[42] The utilisation of an approved interval is the ratio between the implemented interval and the stated interval in the approved maintenance program document of a scheduled maintenance for an item.

D = the time point of the implemented inspection interval
T = approved inspection interval, where E is the time point of it.
x = (T-AD), i.e. approved interval minus implemented interval.
h = the delay time of the defect.

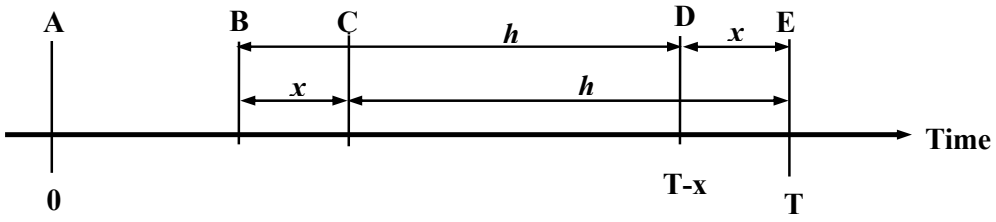


Fig. H.5 Reduced interval for h<T.

The first term of the equation above indicates the probability of corrective maintenance due to defect arises before the delay time. The second term indicates the probability of corrective maintenance which is caused by an undetected defect during inspection at T.

The probability of corrective maintenance when the inspection is conducted at (T-x) is

$$P'(U) = \frac{AB}{T-x} + \frac{BD}{T-x}p = \frac{1}{T-x}\left[(T-h-x)+ph\right] \qquad \text{(H.24)}$$

In order to know the changes of the probability for corrective maintenance, Eq. 23 and 24 are compared and results in the following.

$$\frac{P'(U)}{P(U)} = \frac{T}{(T-x)} \bullet \frac{(T+ph-h-x)}{(T+ph-h)} \qquad \text{(H.25)}$$

For the established (fixed) T, this ratio depends on the value of p, h and x. Assume the following values of p are reasonable, p=0.0, 0.1, 0.2 and 0.3. The value of h and x can be made non-dimensional by dividing with T, as applied in the figures below. By varying the values of h and x, the ratio of these two probabilities is shown in Fig. H.6. and Fig. H.7.

As shown in Fig. H.6, the increase of x values, which means a reduction of the utilisation of the existing approved interval, leads to a reduction of the probability of corrective maintenance. It is logical, because the inspection interval is smaller, or more frequent inspections are conducted. The variation of the probability of defect detection has influence on the probability of corrective maintenance. If the probability of defect detection is high (p is low), then the reduction of corrective maintenance probability is faster. It means that the reduction of inspection interval is effective to reduce the probability of corrective maintenance. In other words, *if the probability of defect detection is low (inspection imperfection, p, is high), then reduction of inspection interval has limited impact to the probability of corrective maintenance.* However, it still depends of the value of delay time, h, as explained below.

The impact of delay time h variations to the probability of corrective maintenance for x=0.2 (*equal to 80% utilisation of the existing approved (scheduled maintenance) interval*) is show in Fig. H.7. *If the delay time h is very low as compared to the inspection interval T (h<0.3T), then the probability of corrective maintenance is high (see Fig. H.7), because a lot of defects*

initiated are not able to reach the inspection time. Reduction of 20% of T does not have any significant meaning to the probability of corrective maintenance. This can be seen in the value of the ratio of the probability of corrective maintenance between the reduced and the original inspection interval, P'(U)/P(U), which is closed to one.

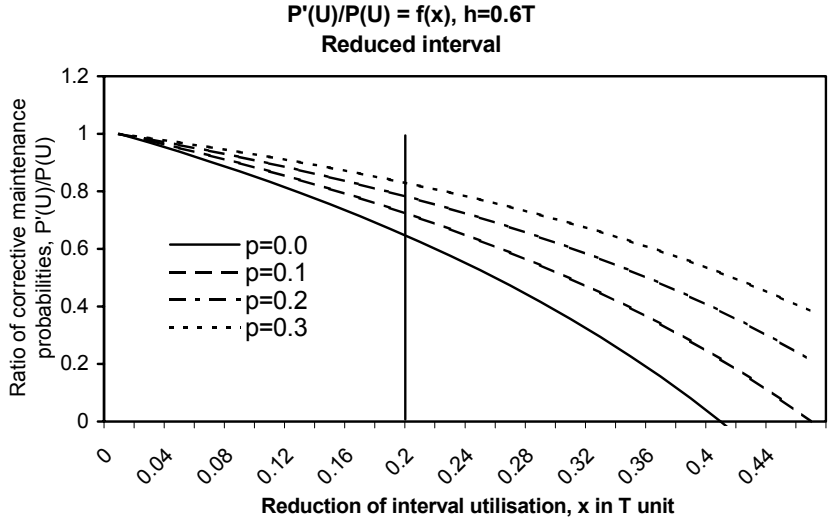


Fig. H.6 The influence of interval utilisation reduction, x, on the ratio of corrective maintenance probabilities of reduced interval for h<T.

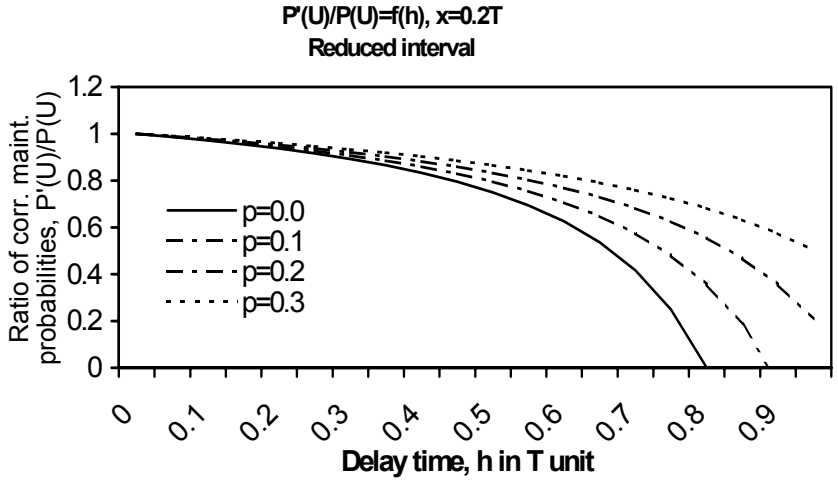


Fig. H.7 The influence of delay time, h, on the ratio of corrective maintenance probabilities of reduced interval for h<T.

If h is relatively high, the reduction of 20% of T has significant impact. For example, if h=0.8, reduction of 20% of T leads to a more than 50% reduction of corrective maintenance probabilities, for inspection imperfection p=0.1. For a higher p, this value of P'(U)/P(U) will be lower.

H.6.2 Reduced Inspection Interval for T<h<2T

When the implemented interval is lower than T and the length of the delay time is in the interval of T<h<2T, the role of inspection imperfection, p, is important. This is because only when the defect **is not detected** during inspection at T or 2T corrective maintenance is necessary. Figure H.8 shows this situation. Because the inspection interval is reduced to become (T-x), then the first inspection occurs at (T-x) while the second one at (2T-2x). If p=0, any defect will be detected during inspection at T and no corrective maintenance will happen, because h>T. Therefore, p=0 is excluded in the discussion. Interval reduction of more than 50% of T is excluded as well, because it is complicated and not practical.

The probability of corrective maintenance, P(U), when the inspection is conducted at T and 2T is

$$P(U) = \frac{AC}{T} p + \frac{CE}{T} p^2 = \frac{p}{T}\left[(2T - h) + (h - T)p\right] \qquad \text{(H.26)}$$

where: A = time when T=0
B = defect initiation time point
AE = EG = T, the approved inspection interval
AD = DF = implemented inspection interval
x = (T-AD), i.e. the approved inspection interval minus implemented interval.
AC = 2T-2x
h = the delay time of the defect.
P = inspection imperfection, p=0 is not discussed.

The first term in the equation above indicates the probability of corrective maintenance due to a defect arising before the delay time and not detected during inspection at T. The second term indicates the probability of corrective maintenance which is caused by a defect arising in the interval CE and not detected during inspection at T *and* 2T.

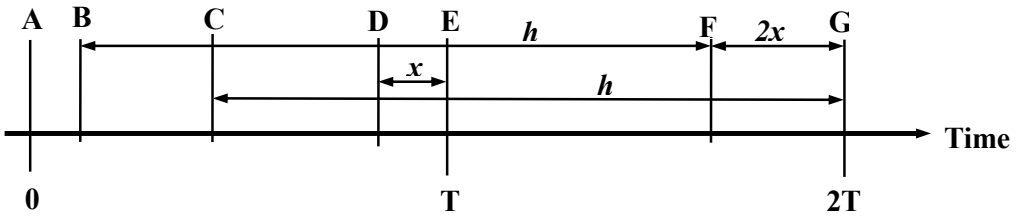


Fig. H.8 Reduced interval for T<h<2T.

The probability of corrective maintenance when inspections are conducted every (T-x) is

$$P'(U) = \frac{AB}{T - x} p + \frac{BD}{T - x} p^2 = \frac{p}{T - x}\left[(2T - h - 2x) + (h - T + x)p\right] \qquad \text{(H.27)}$$

Comparison of Eq. H.26 and Eq. H.27 indicates the changes of the probability of corrective maintenance when the inspection interval becomes (T-x).

$$\frac{P'(U)}{P(U)} = \frac{T}{(T - x)} \bullet \frac{(2T + ph + px - pT - h - 2x)}{(2T + ph - pT - h)} \qquad \text{(H.28)}$$

By varying the values of h and x, with the same conditions as mentioned in the beginning of this section, the ratio of those two probabilities is shown in Fig's. H.9 and H.10.

By comparing Fig. H.9 and Fig. H.6, it can be seen that *the ratio of corrective maintenance probabilities between the reduced and approved interval, P'(U)/P(U), for h=1.6 is reducing faster than for h=0.6. This is because a reduction of the inspection interval of x% of T will reduce the length of AC two times of x% of T.* For x=0.2, this is shown in Fig. H.6 and Fig. H.9. AC is the time period where any defect initiated in this period will not reach inspection time at T, for the case of h<T. For the case of T<h<2T, any defect initiated in AC time period will not reach 2T, if it is not detected at inspection time at T.

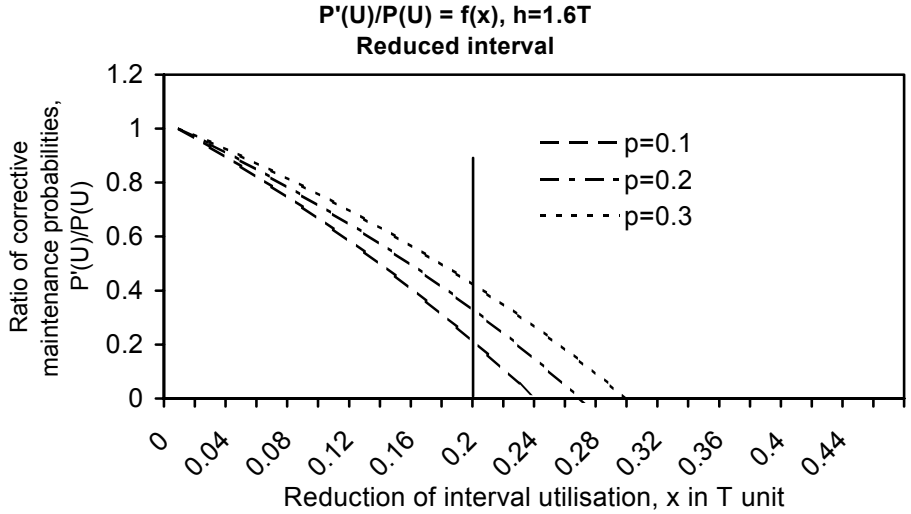


Fig. H.9 The influence of interval utilisation reduction x variations on the ratio of corrective maintenance probabilities of reduced interval for T<h<2T.

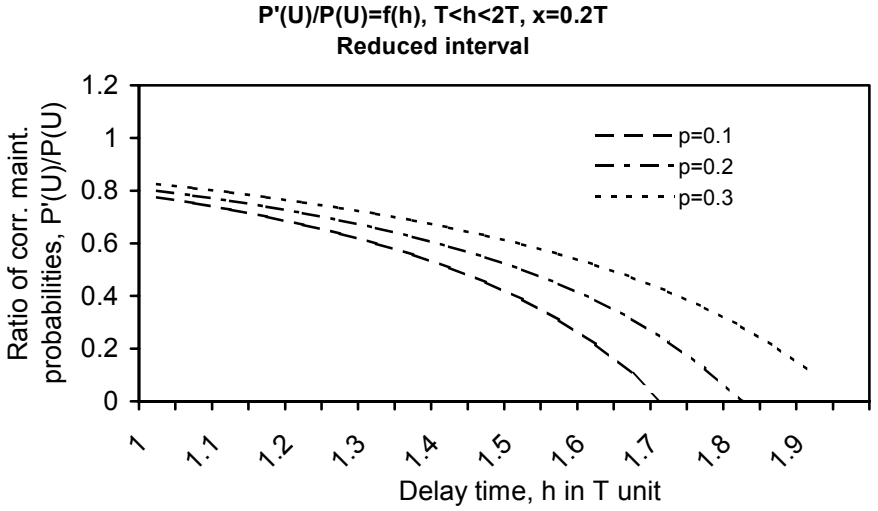


Fig. H.10 The influence of delay time h variations on the ratio of corrective maintenance probabilities of reduced interval for T<h<2T

By increase of reduction of inspection interval x, the value of p (inspection imperfection) has

a more significant role. *The higher p then the higher the ratio of corrective maintenance probabilities between the reduced and approved interval, P'(U)/P(U). It means that when p is high, changes of inspection interval has minor impact to the probability of corrective maintenance.* Because when p is high, inspection won't be able to detect defects appropriately.

H.6.3 Increased Inspection Interval for h<T

Consider an inspection interval (T+x) which is larger than the approved interval T, with delay time h where h<T. Figure H.11 shows this situation.

The probability of corrective maintenance when the inspection is conducted at T is

$$P(U) = \frac{AB}{T} + \frac{BD}{T} p = \frac{1}{T}\left[(T-h) + ph\right] \tag{H.29}$$

The probability of corrective maintenance when the inspection is conducted at (T+x) is

$$P'(U) = \frac{AC}{T+x} + \frac{CE}{T+x} p = \frac{1}{T+x}\left[(T-h+x) + ph\right] \tag{H.30}$$

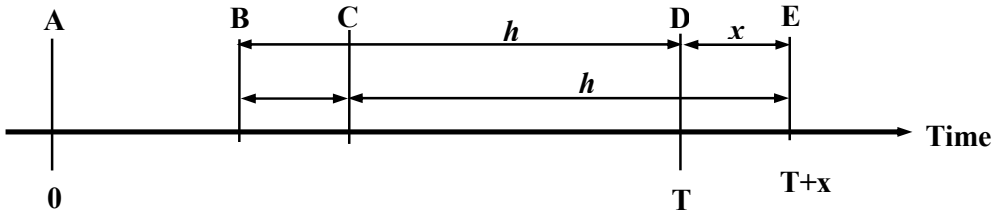


Fig. H.11 Increased interval for h<T.

The ratio of these two probabilities is following.

$$\frac{P'(U)}{P(U)} = \frac{T}{(T+x)} \bullet \frac{(T + ph - h + x)}{(T + ph - h)} \tag{H.31}$$

For the assumptions as described in the beginning of this section, by varying the values of h and x, the ratio of these two probabilities is shown in Fig's. H.12 and H.13.

Figure H.12 shows *for h=0.6T, the corrective maintenance probability is almost not sensitive to the increase of the inspection interval, even for perfect inspection (p=0). However, the probability of corrective maintenance is sensitive to the value of h, especially for perfect inspection. For h=0.8T, increase of 20% interval leads to a 60% increase of corrective maintenance probability, for perfect inspection. The estimate for h is very essential for judging interval escalation proposal.*

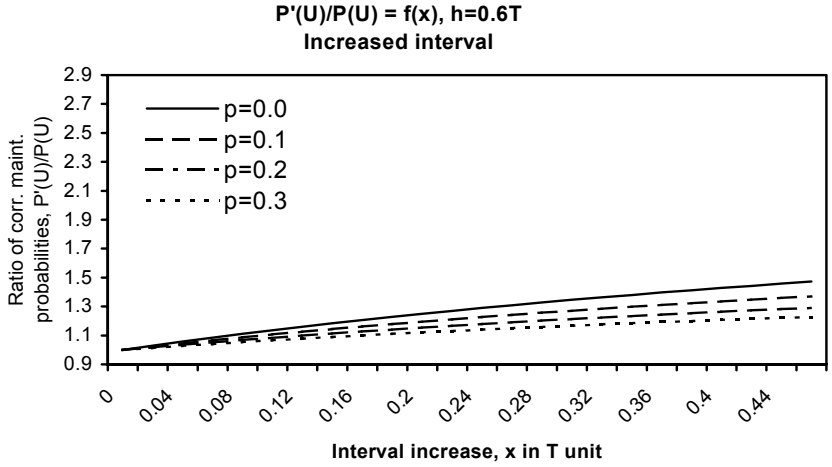


Fig. H.12 The influence of x variations on the ratio of corrective maintenance probabilities of increased interval for h<T.

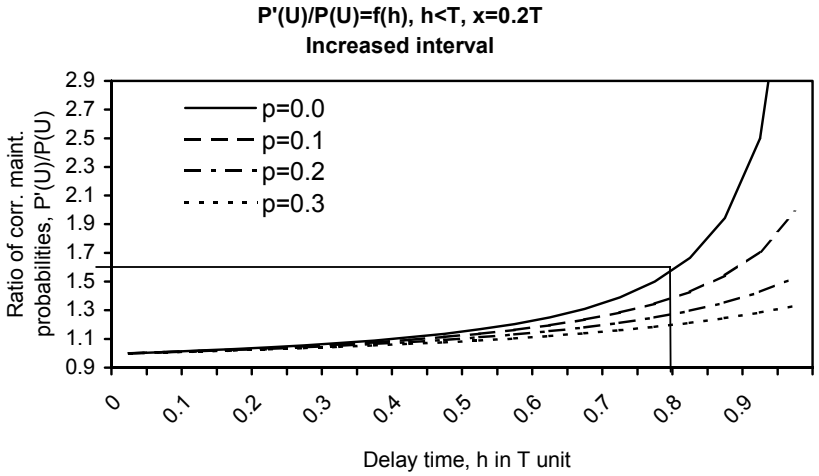


Fig. H.13 The influence of h variations on the ratio of corrective maintenance probabilities of increased interval for h<T.

H.6.4 Increased Inspection Interval for T<h<2T

Figure H.14 shows this situation. Because the inspection interval is increased to become (T+x), the first inspection occurs at (T+x), while the second one is at (2T+2x). If h<(T+x), the equation to estimate the probability of corrective maintenance is different with h>(T+x) situation. Therefore these two cases are separated. For situation h>(T+x), if p=0, any defect will be detected during inspection at (T+x) and no corrective maintenance will happen. Therefore, p=0 is excluded in the discussion of h>(T+x) situation.

The probability of corrective maintenance when the inspection conducted at T and 2T is

$$P(U) = \frac{AB}{T} p + \frac{BD}{T} p^2 = \frac{p}{T}\left[(2T - h) + (h - T)p\right] \tag{H.32}$$

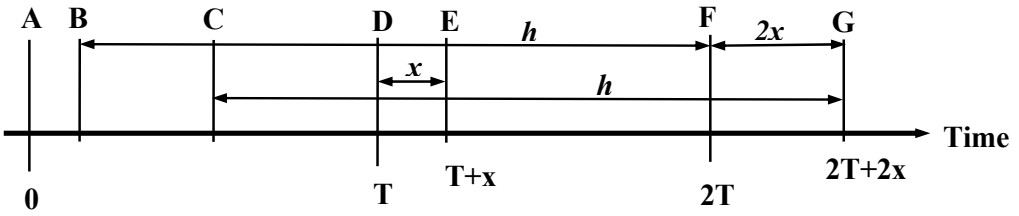


Fig. H.14 Increased interval for T<h<2T.

Situation of h>(T+x):

If the delay time is larger than the increased inspection interval, h>(T+x), the probability of corrective maintenance when inspections are conducted every (T+x) is

$$P'(U) = \frac{AC}{T+x} p + \frac{CE}{T+x} p^2 = \frac{p}{T+x}\left[(2T - h + 2x) + (h - T - x)p\right] \tag{H.33}$$

Comparison of Eq. H.32 and H.33 indicates the changes of the probability of corrective maintenance when the inspection interval becomes (T+x).

$$\frac{P'(U)}{P(U)} = \frac{T}{(T+x)} \bullet \frac{(2T + ph + 2x - pT - px - h)}{(2T + ph - pT - h)} \tag{H.34}$$

By varying values of h and x, with the same conditions as mentioned in the beginning of this section, the ratio of these two probabilities is shown in Fig. H.15 and H.16.

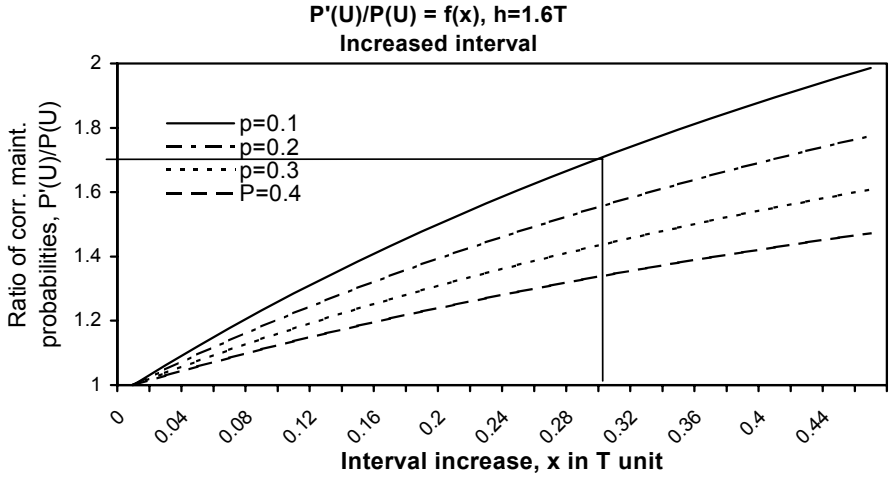


Fig. H.15 The influence of inspection interval reduction x variations on the ratio of corrective maintenance probabilities of increased interval for T<h<2T, if h>(T+x).

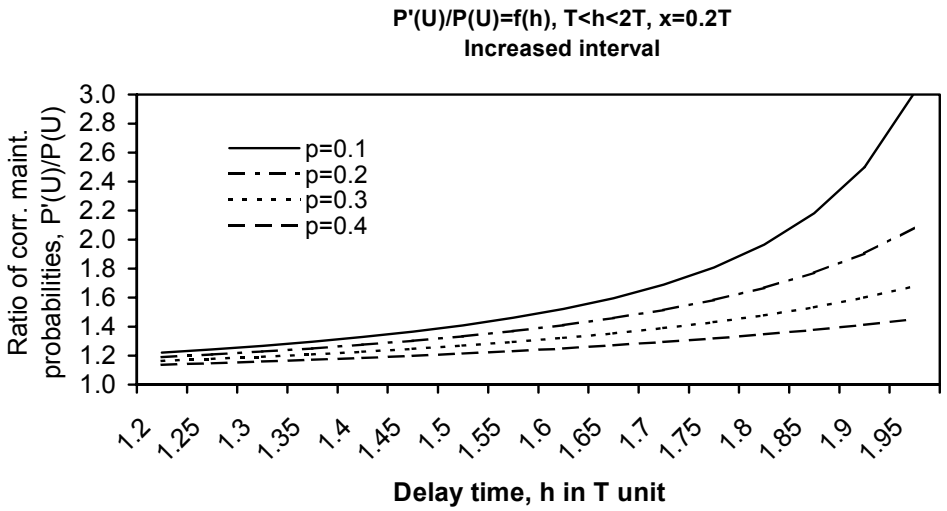


Fig. H.16 The influence of delay time h variations on the ratio of corrective maintenance probabilities of increased interval for T<h<2T, if h>(T+x).

As shown in Fig. H.15, for h=1.6, increase of interval by 30% leads to a 70% increase of probability of corrective maintenance, for a nearly perfect inspection (p=0.1). This increase of corrective maintenance probability will be lower for a higher value of p.

Figure H.16 shows that the probability of corrective maintenance is sensitive to the value of delay time h. For this reason, estimate of delay time h determines the feasibility of inspection interval escalation.

Situation of h<(T+x):

If the delay time is smaller than the increased inspection interval, h<(T+x) (see Fig. H.17), the probability of corrective maintenance when inspections are conducted every (T+x) is

$$P''(U) = \frac{AB}{T+x} + \frac{BC}{T+x}p = \frac{T+x+ph-h}{T+x} \qquad \text{(H.35)}$$

Comparison of Eq. 32 and 35 indicates the changes of the probability of corrective maintenance when the inspection interval becomes (T+x) and if h<(T+x):

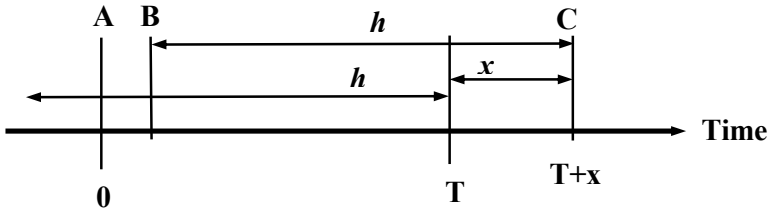


Fig. H.17 Increased interval for T<h<2T and h<(T+x)

$$\frac{P''(U)}{P(U)} = \frac{T}{p(T+x)} \bullet \frac{(T+x+px-h)}{(2T+ph-pT-h)} \tag{H.36}$$

By varying values of h and x, with the same conditions as mentioned in the beginning of this section, the ratio of these two probabilities is shown in Fig. H.18 and H.19.

As shown in Fig. H.18, for h=1.2T, the ratio of corrective maintenance probabilities, P"(U)/P(U), is very sensitive to the increase of inspection interval, for a nearly perfect inspection (p=0.1). This increase of corrective maintenance probability will be lower for a higher value of p, but it is still increasing. *For this situation, h<(T+x), increase of inspection interval has a bad effect on P"(U)/P(U). Therefore, it is not recommended to increase interval when the h<(T+x).*

Figure H.19 shows that the ratio of corrective maintenance probabilities, P"(U)/P(U), is decreasing if the value of delay time h gets closer to (T+x), as long as h<(T+x). *In other words, the closer the length of delay time to (T+x), the lower the ratio of corrective maintenance probabilities, P"(U)/P(U), as long as h<(T+x).*

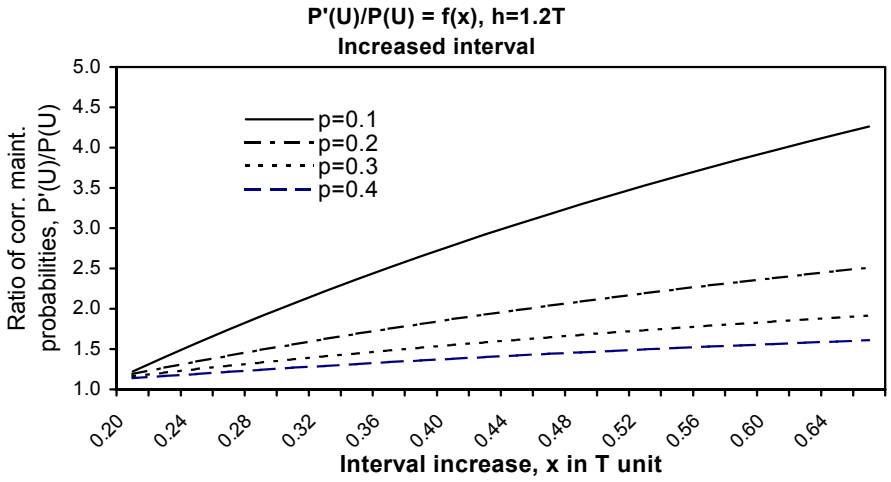


Fig. H.18 The influence of inspection interval reduction x variations on the ratio of corrective maintenance probabilities of increased interval for T<h<2T, if h<(T+x).

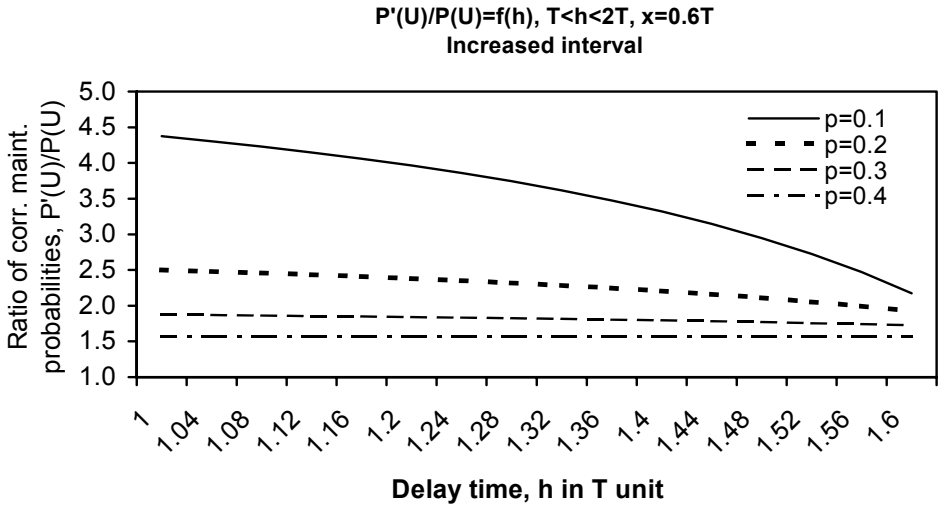


Fig. H.19 The influence of delay time h variations on the ratio of corrective maintenance probabilities of increased interval for T<h<2T, if h<(T+x).

Appendix I

LCC-OPS Case: Aircraft Modifications

This appendix describes a case study of LCC-OPS model application for aircraft modifications. The case study is selected because it includes the most of the cost components of LCC-OPS (see Fig. 3.1). The objective of the application is to compare the LCC-OPS the existing Fuel Quantity Indication System (FQIS) of B747-200 which is subject to modification by two AD Notes and a new designed FQIS by BFGoodrich, Ltd. Retrofit with this new FQIS and an addition with a small inspection results in complying with those AD Notes. The new designed FQIS is more reliable and accurate, but it requires some acquisition cost and a significant ground time for installation. Comparison will be on the required costs of implementation and savings during operation. A specific aircraft operation route is chosen and will be used to investigate the fuel cost savings[43].

I.1 Introduction

Since the TW-800 accident in 1996, two Airworthiness Directives (AD Notes) were issued for inspection and modification of the Fuel Quantity Indication System (FQIS) of Boeing 747-200, namely the AD 98-20-40 and AD 99-08-02. The accident itself was caused by an explosion in the centre wing fuel tank [NTSB report, July 28, 1999]. No final conclusion has been drawn concerning the root-cause of this accident [John Goglia, NTSB Report, Jan. 24, 2000].

AD 98-20-40 concerns on prevention from electrical transients induced by electromagnetic interference (EMI) or electrical short circuit conditions from causing arcing of the FQIS electrical wiring or probes inside the fuel tank(s), which could result in ignition of the fuel vapour in the tank. This requires a replacement of all of the FQIS wiring outside of the fuel tanks and surge tank with shielded wiring, and install that wiring so as to provide separation of the FQIS wiring from other airplane system wiring [AD 98-20-40]. This AD Note has a due date of November 4, 2001. Service Bulletin No. 747-28-2231 was issued specifically for

[43] This activity is conducted by the author of this thesis during his visit to Garuda Maintenance Facility at Cengkareng Airport, with supports of Mr. P. E. Latumeten from the Aircraft Engineering Unit of Garuda Indonesia Airlines.

installation of the BFGoodrich Digital FQIS to comply with this AD Note. No other SB's is available.

AD 99-08-02 is to prevent ignition sources and consequent fire/explosion in the centre fuel tank, by accomplishing:

a. One-time visual inspection of the centre fuel tank wiring and components to detect discrepancies, and rectification when a discrepancy is detected. One-time electrical bounding test of the centre fuel tank components, and if any measured resistance exceeds the limits specified by the service bulletin (Boeing SB 747-28-2205, rev.1), rework the discrepant component.
b. One-time insulation resistance test of the FQIS, a one-time visual inspection of the FQIS wiring and components to detect discrepancies, replacement of FQIS probes, system adjustment and operational test according to Boeing Alert SB 747-28A2208, and if any discrepancy is detected, perform corrective actions.
c. Installation of flame arrestor in the inlet line of the electrical motor-operated scavenge pump of the centre fuel tank, according to Boeing Alert SB 747-28A2210.

AD 99-08-02 has a due date of May 11, 2001 [AD 99-08-02].

BFGoodrich has designed a new FQIS where retrofit of this FQIS will comply to the mentioned AD Notes, after the one-time visual inspection of the centre fuel tank wiring and components, mentioned in AD 99-08-02 point a, is conducted. The new designed FQIS has an improved reliability as well as an increased reading accuracy of the actual fuel quantity. The new FQIS consists of transmitter (sensor, probe), densitometer, compensator, fuelling control panel, FQIS processor and aft equipment centre. This is similar to FQIS of B747-400, B757 and B767, as shown in Figure I.2 in the last page. The transmitters detect the fuel levels in the tank where their signal is transmitted to the FQIC processor which reads the total fuel quantity. Densitometer measures the specific gravity of the fuel, while the compensator provides secondary signal to the FQIS processor in case the main sensing sub-system is defective. The existing FQIS does not have densitometers as well as fuelling control panel at the lower wing skin.

Reliability improvement is represented by a significant increase of Mean Time Between Failure (MTBF) of the FQIS from 600 Flight Hours (FH) to 6,000 FH (both are based on laboratory test, but not mentioned for which component). Experiences of other airlines which have implemented BFGoodrich FQIS mentioned that the FQIS only requires calibration of the Volumetric Top Off (VTO) where the cost of calibration can be neglected. In other words, this FQIS can be considered as almost *preventive maintenance free* up to now.

The use of densitometer in the new FQIS has improved the accuracy of the system in reading the actual quantity of the fuel in all tanks, from 3% to 1% [design specification]. Field data shows that average (in)accuracy of the existing FQIS is –3% for the total fuel uplift of about 80 tons. It means that 3% more fuel will be added, generally, on top of the 80 tons. This is because the amount of fuel indicated by the FQIS is used as reference. Therefore, accuracy improvement of the FQIS leads to a great saving of fuel uplift.

Comparison of these two alternatives, i.e. accomplish the AD Notes or to retrofit with the new designed FQIS, requires an economic evaluation within a specified period of consideration. The period of consideration is the rest operating life of the B747-200. Both of alternatives require ground time to drain the fuel, install wiring and finally to conduct test

flight. Application of the Life Cycle Cost (LCC) concept is the *most* appropriate for this case *because the period of evaluation is specified*.

I.2 Objectives

The objective of the analysis is to compare the Life Cycle Cost (LCC-OPS) of the existing FQIS to the new designed FQIS from BFGoodrich. This new designed FQIS is recommended by Boeing, as an Alternate Means Of Compliance (AMOC) for the earlier mentioned AD Notes. Another objective is to apply the LCC-OPS model for Aircraft Modifications, discussed in Chapter 3.

I.3 Scope

Period of evaluation is for the year 2000-2005 due to operating life projection of the owned B747-200. For each of the alternatives, a more detailed scope of the evaluation is following:

Existing FQIS:
It includes the required costs of modification to comply with the AD Notes (ground time, material and man-hour), material and labour for inspections due to Engineering Order and inspections due to scheduled maintenance program (Maintenance Specifications). The cost resulted by schedule interruption (delay) is estimated by using the material consumption records. This is due to the lack of information on delay at ATA six digits or component level.

BFGoodrich FQIS:
It includes the price of modification kits for nine tanks (each aircraft), the ground time of the aircraft, man-hours and the fuel cost savings due to accuracy improvement. The impact of weight increase will be included as well, if it is significant. Reliability improvement results in no need for preventive maintenance, thus there is no maintenance cost required. Engineering hours required to develop Engineering Order (EO) for the modification is neglected, because EO development occurs in both alternatives.

I.4 Cost Breakdown Structure

Based on aforementioned scope of the investigation, Cost Breakdown Structure (CBS) for each alternative is developed and they are shown in Figure I.1. The CBS is made as generic as possible and the value of not relevant cost components will be zero. The contents of the CBS of alternative are as follows.

Existing FQIS:
Modification cost: material and labour for implementing AD Notes, the required ground time and test flight. Operation and maintenance: maintenance costs are resulted from inspections due to Engineering Order (EO) and inspections due to scheduled maintenance program. No fuel savings and no increase of residual value.

BFGoodrich FQIS:
Modification cost: retrofit kit and labour for installing the new FQIS, ground time and test flight. Operation and maintenance: fuel cost savings due to accuracy improvement, and fuel cost penalty due to weight increase. Increase of residual value.

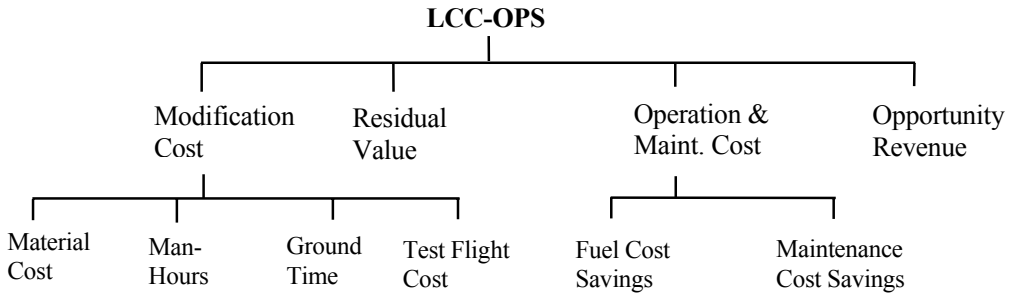


Fig. I.1. Breakdown of LCC-OPS into cost components (CBS) for the FQIS Retrofit.

I.5 Cost Components Estimation

After the included cost components are identified, estimation (calculation) of those cost components is conducted below. The labour rate used is USD 30/hour. Estimation is done for 5 years basis, namely for the period of 2000-2005. However, the aircraft life is estimated up to 30 years, therefore period of 2006-2010 is investigated as well. The results of calculation are presented in Table I.4. The process of calculation is following.

a. Existing FQIS

Some of the cost components for the existing system are considered as a baseline. Therefore, they are not listed in Table I.4.

Modification costs:
The modification cost to maintain the existing FQIS are the costs to implement AD Notes. Per aircraft, the material cost is estimated USD 90,000 for AD 98-20-40 and USD 30,000 for AD 99-08-02. The labour cost to implement those two AD Notes is estimated USD 46,500. The required ground time is about 15 days [BFGoodrich brochure]. Test flight cost occurs in both alternatives, therefore it can be neglected in the comparison.

Fuel cost:
The existing one is as a baseline. Weight changes due to modification to comply with the AD Notes is estimated to be very small and can be neglected.

Scheduled Maintenance cost:
The required maintenance cost consists of the cost of annual inspections based on Engineering Order's which could be omitted in the future (based on evaluation on findings), and inspections based on the scheduled maintenance program which have to conducted during overhaul (year 2001 and 2006). The detailed of the maintenance costs are shown in

Table I.1 and I.2. For five years, inspections based on EO's leads to cost of USD 5,200,-. Inspection at D-check leads to cost of USD1,845.-

Table I.1 Annual inspections due to Engineering Order

EO number	Labour hours	Cost (USD)	Material (USD)
B4/S28-41-0302	8	240	20
B4/S28-41-0303	8	240	15
B4/S28-41-0304	8	240	10
B4/S28-41-0305	8	240	35
Total	32	960	80
Total cost		1,040 USD/year	

Table I.2 Inspections due to scheduled maintenance program (D-check)

Maintenance Spec. Number	Labour hours	Cost (USD)	Material (USD)
2841020301	13	390	20
2841020302	45.5	1,365	70
Total	58.5	1,755	90
Total cost		1,845 USD/D-check	

Schedule interruption (delay) costs:
Estimated material cost and delay cost (due to delay duration) for the period of 2000-2005 (aircraft age 20-25 years) and 2006-2010 (aircraft age 26-30 years) due to the failure of the components is shown in Table I.4. The method of estimation is following.

First of all, the MTBF of the components must be determined. There are two methods of estimation, namely with censoring and without censoring. Censoring is applied to take into account the information of survivors, as far as possible. It means that censoring is only applicable when the number of failures is less than the number of items installed on aircraft (except with replacement), and the MTBF will be higher than the average age. Otherwise, only failure data is used, and the MTBF will be less than the average age.

Available data are the total number of components consumed since aircraft delivery and the period of ordering components. If the date of component consumption is available, then the prediction of the components MTBF will be easier. For censoring, it is assumed that the failing components failed at the average age, i.e. the mid of the ordering period. Therefore, for censoring [Nowlan and Heap, 1978],
MTBF = (# survivors * evaluation period + # failures * average age) / # failures
For without censoring,
MTBF = (Qty/ac * # aircraft * average age) / # failures
Evaluation period of historical data is the time since aircraft delivery (1980) up to evaluation time (end of 1999), therefore it is equal to 20 years. The expected number of failures at aircraft age of 20 years, Ef(20), can be calculated as follows.
Ef(20) = Integer (20/MTBF) * Qty/ac * # aircrafts

Further, the number of failures at the period of aircraft age of 20-25 years and 26-30 years are calculated, designated as F(20-25) and F(26-30). It is assumed that the survivors at aircraft age of 20 years will fail before the next multiplication of MTBF and all of the installed components will fail at a multiplication of MTBF. Therefore,
F(20-25) = (Ef(20) – Use) / # aircrafts + (Integer(25/MTBF) – Integer (20/MTBF))* Qty/ac
F(26-30) = (Integer (30/MTBF) –Integer (25/MTBF))* Qty/ac
As shown in Table I.5, for component number 03 part-number 69B41818-3, 0.333 component as survivors at aircraft age 20 years (will fail before 4*5.3 year), one component will fail at 4*5.3 year in interval of F(20-25), and one component will fail at 5*5.3 year in F(26-30). While for component number 04 part-number 69B41818-4, 0.5 (=3/6) components has failed before aircraft age 20 years and 1.5 will fail in F(20-25).

It is assumed that the failure of the components leads to delay with average delay duration and standard (Garuda) delay cost per unit of time. The material cost and the delay cost for aircraft age of 20-25 years and 26-30 years are shown in Table I.5. For the period 20-25 years of aircraft age,

- the total material cost is USD 29,822.-
- the total delay cost is USD 301,727.-

Residual value and *Opportunity revenue:*
The existing one is as a baseline.

b. BFGoodrich FQIS

Modification costs:
Material costs: Retrofit kit, USD 294,450 for nine tanks/aircraft.
Man-hours cost: USD 42,000 (1400 man-hours)/aircraft.
Ground time: estimated additional 15 days when conducted together with C or D-check [BFGoodrich folder, 1997]. For this reason, no difference between the required ground time with maintaining the existing FQIS and to install the new one. If there is, then opportunity cost (revenue) must be included by using a standard revenue per passenger kilometre (RPK) times the flight distance.

Total of modification cost is:
295,450 + 42,000 = USD 337,450.-

Fuel cost:
It is assumed that the aircraft is operated from Bali to Japan with the route of Denpasar-Narita-Denpasar, two departures per day, where the average of fuel burn per departure is 78,600 kg, and average block hour of 7.00 hours [Garuda Operation data].

Fuel cost changes due to 2% reading accuracy improvement and weight increase:

There are two fuel cost reductions due to FQIS accuracy improvement, namely the reduction of fuel uplift due to reading accuracy improvement and reduction of fuel burn due to reduction of aircraft weight (due to fuel uplift reduction and the difference in FQIS weight).

For the amount of fuel uplift of about 80 tons, the reading accuracy of the existing FQIS is –3% [BFGoodrich data]. The BFGoodrich FQIS has reading accuracy of 1% at that fuel

weight. Therefore, reading accuracy improvement of the BFGoodrich FQIS is 2%. Reduction of fuel uplift due to 2% accuracy improvement is
= 0.02 * 78,600 kg = 1,572 kg/departure

Fuel cost reduction due to reduction of fuel uplift for five years:
= 2*285*(end date –begin date)/365*1,572*0.1619/0.8 = **USD 907,177.-**
Where:
2 = number of departures per day
285 = number of operating days per year
end date = end date of evaluation (31st December 2004)
begin date = begin date of evaluation (1st January 2000)
365 = number of days in a year
0.1619 = fuel price per litre
0.8 = fuel specific gravity

Fuel cost reduction due to weight reduction is estimated as follow. Extra fuel uplift due to inaccuracy can be considered as an extra weight of aircraft empty weight, because this fuel remains in the tank. Other factor is the weight difference between the existing FQIS and the new one, where the new one is 20 kg heavier [BFGoodrich brochure].
Total weight reduction is 1,552 kg (=1,572 – 20).

Study of Suwondo [E. Suwondo, "Fuel burn reduction due to MTOW reduction", TU Delft, 1996] shows that 1.0% reduction of Maximum Zero Fuel Weight (MZFW) results in 0.445% fuel burn reduction for 12 hours block hour of B747-100 at MTOW (MZFW ≈ (2/3)*MTOW). It means that for each kilogram reduction of MZFW will result in reduction of 0.01857 kg fuel burn per flight hour. This result is lower than the Boeing estimate, i.e. 4.6% of the total fuel is required to bring the fuel per flight hour (or 55.2% for 12 hours) [BFGoodrich brochure, originally from Boeing]. Boeing estimate is not realistic, because the estimate implies if the aircraft flies for 12 hours 55.2% of the total aircraft weight is fuel. Therefore, estimate of Suwondo is selected.

It is assumed that the aerodynamic characteristics (CL-CD relations) of B747-200 are not much different from B747-100. For the total weight reduction above, fuel cost savings:
1552 * 0.01857 * 7.0* 0.1619 / 0.8 = USD 40.83/trip, or:
40.83 * 2 * 285* (end date –begin date)/365 = USD 116,424.- for **5 years**

Where:
0.01857 = Fuel burn reduction per flight hour due to one kilogram MZFW reduction.

The total of fuel cost reduction
= 907,177 + 116,424 = USD 1,023,601.-

Maintenance cost:
As mentioned earlier, the scheduled maintenance cost, unscheduled maintenance cost and delay cost can be neglected for the BFGoodrich's FQIS.

Increase of residual value:
Increase of residual value can be equalised to the depreciated value of the implementation cost of the retrofit. It is assumed that the aircraft can be operated up to 2010, as a freighter for instance.

The increase of residual value at the end of 2005 is equal to a half of the direct implementation cost (material and man-hours), with linear depreciation, i.e.:
0.5 * USD 337,450.- = USD 168,725.-

Opportunity revenue:
Opportunity revenue is the gained revenue due to increase of aircraft availability. While the increase of aircraft availability is resulted by reliability improvement of components or systems which causing delay or cancellation, or elimination of scheduled maintenance. Opportunity revenue is a relative of the new design to the existing one. Estimation of opportunity revenue is based on the aircraft revenue per hour.

For the retrofit of FQIS analysed in this appendix there is no records on the required time to conduct the scheduled maintenance and the non-routine maintenance. It is considered as very small as compared to the total time of the relevant maintenance package. The opportunity revenue in this case is only resulted by the unscheduled maintenance. The contributing components to opportunity revenue are shown in Table I.3. Table I.3 is derived from Table I.5. It is assumed that each removal leads to delay of 3.21 hour, as the average delay duration [Garuda data].

Table I.3. Total ground time due to unscheduled maintenance (based on Table I.5)

Unscheduled maintenance Name:	Ground time (hr)/Removal	Number of removal in LC	Total Time (hr)
Connector plug-3	3.21	1.333	4.27893
Connector plug-4	3.21	1.5	4.8150
MT Jumper plug 37-14	3.21	3.0	9.6300
MT Jumper plug 47-14	3.21	1.167	3.74607
R1 Receptacle-1105	3.21	0.5	1.6050
R4 Receptacle-1205	3.21	0.333	1.0689
Total			25.14393

For the new design FQIS there is no unscheduled maintenance. Therefore, the opportunity revenue of the retrofit is:
= 431 * 0.65 * 6000 / 7.0 * 0.13 * 25.14393 = USD 784,911.- for 5 years.
Where:

431 = number of passenger
0.65 = load factor
6000 = flight distance in km
7.0 = block hour
0.13 = RPK in USD/(pax. km) [Airline Business, 1999]
25.14393 = total delay time caused by the existing FQIS in hours (see Table I.3).

From Table I.4, the LCC-OPS for 5 years by implementing the BFGoodrich FQIS is USD 2,144,881 without considering the Present Value. The Present Value of LCC-OPS is taken into account by spreading the savings in the course of the evaluation period (5 years).

The Present Value of the savings each year is
= (Savings – Expenses) /(1+interest rate)^year
Table I.6 shows the calculation results. The total of LCC-OPS in PV is USD **1,666,957** for each aircraft.

Table I.4 The results of cost components calculation for period 2000 – 2005 per aircraft with operating route of Denpasar-Narita-Denpasar, 2 departures/day

Existing FQIS		BFGoodrich FQIS	
Cost component	USD	Cost component	USD
Modification:	*166,500*	*Modification:*	*337,450*
AD 98-20-40 (material)	90,000	Retrofit kit	295,450
AD 99-08-02 (material)	30,000	Man-hours	42,000
Estimated man-hours (2 AD Notes)	46,500		
		Other costs:	*-166,500*
Operation &Maintenance:	*338,594*	2 AD Notes Avoidance	-166,500
Inspections due to EO (for 5 years)	5,200		
Insp. from Sched. Maint. (D-check)	1,845	***Operation & Maintenance***	*-1,362*,195
Material	29,822	Elimination of O&M Cost	-338,594
Delay cost due to FQIS problems	301,727		-1,023,601
		Fuel cost savings (5 years)	*-168,725*
			-784,911
		Increase of residual value	
		Opportunity revenue	
TOTAL (5 years LCC-OPS)	505,094	TOTAL (5 years LCC-OPS)	- 2,144,881

Table I.6 shows the LCC-OPS savings in Present Value. The modification cost is spent in the present (zero) year, while the savings are distributed evenly in the course of evaluation period. The Present Value of the LCC-OPS is the total of the savings in Present Value.

Table I.6 LCC-OPS savings in Present Value

Year	Expenses	Savings (USD)	Total PV (USD)
0	337,450	496,466	159,016
1		496,466	443,273
2		496,466	395,780
3		496,466	353,375
4		496,466	315,513
Total LCC-OPS in PV			1,666,957

I.6 SENSITIVITY ANALYSIS

Sensitivity analysis for the BFGoodrich FQIS is concentrated on the changes of the number of delays, because delay cost is a high cost contributor and its value depends on the number of failures. In the period of 2000-2005, it is predicted that 7.833 failures will occur (see Table I.5, column F(20-25)), which lead to delays. The following calculates the changes of LCC-OPS in percentage by the changes of the number of failures.

Changes of one failure will reduce the LCC savings of the retrofit by delay cost of:

1 * 3.21 * 60 * USD 200 = USD 38,520

and opportunity revenue reduction of:

431 * 0.65 * 6000 / 7.0 * 0.13 * 3.21 = USD 100,205.-

The total is **USD 138,725.-,** and relative to the total of LCC-OPS is:

138,725 / 1,666,957= 8.322%

The direct maintenance cost (material and man-hours) is excluded, because it is normally much lower than the delay cost and opportunity revenue. With the BFGoodrich FQIS, one failure for the evaluation period is considered high, because the design is new and the experience of using this FQIS shows that no problem exists.

As shown in Table I.4, nearly a half of the total cost savings comes from fuel cost reduction due to improvement of the FQIS accuracy. But, the improvement of reading accuracy is the objective of the BFGoodrich FQIS, therefore sensitivity analysis on this is not appropriate.

I.7 CONCLUSIONS

Based on those calculation results, implementation of the BFGoodrich FQIS is beneficial., with **LCC-OPS** of **USD 1,666,957.-,** in **Present Value**, under assumption that the FQIS improve 2% of reading accuracy and it has a zero failure.

I.8 RECOMENDATIONS

Based on the discussion above, recommendations are followings.

- The estimate of the required ground time and material cost to implement the AD Notes are rough, therefore further investigation on this is recommended.
- Because a great deal of the LCC savings comes from the improvement of reading accuracy of the FQIS, therefore it is necessary to verify the achieved reading accuracy of the FQIS (demonstration).

TABLE I.5 THE COMPONENTS OF THE EXISTING FUEL QUANTITY INDICATING SYSTEM (FQIS) B747-200

No.	Part Number	Description	Price	Use	Qty/ac	Order Y	Av. Age	MTBF (Y)	Ef(20)	F(20-25)	F(25-30)	M(20-25)	M(26-30)	D(20-25)
01.	69B41818-1	Plug, Connect..	306	6	1	96-97	16	16.0	6	0	0	0	0	0
02.	69B41818-2	Plug, Connector	306	2	1	95-97	15.5	55.5	0	0	0	0	0	0
03.	69B41818-3	Plug, Connector	306	16	1	92-97	14	5.3	18	1.333	1	408	306	51347
04.	69B41818-4	Plug, Connector	306	15	2	90-97	13	10.4	12	1.5	0	459	0	57780
05.	69B41818-6	Plug, Connector	306	2	1	96-98	16.5	56.5	0	0	0	0	0	0
06.	60B40037-14	Plug, MT 1234 Jumper	4675	30	4	94-98	15.5	12.4	24	3	0	14025	0	115560
07.	60B40147-14	Plug, MT 1234 Jumper	3969	17	4	91-96	13	21.2	0	1.167	0	4632	0	44953
08.	60B40037-4	Plug, CT Jumper	5270	2	1	91-96	13	53.0	0	0	0	0	0	0
09.	60B40147-14	Plug, CT Jumper	3820	-	1	No order	0	INF	0	0	0	0	0	0
10.	60B40037-1105	Receptacle Assy R1	12900	9	1	90-99	14	9.3	12	0.5	1	6450	12900	19260
11.	60B40037-1205	Receptacle Assy R4	11555	4	1	90-97	13	23.0	0	0.333	0	3848	0	12827
12.	60B40037-906	Receptacle Assy M1 & M4	10927	6	2	95-96	15	35.0	0	0	0	0	0	0
13.	60B40147-106	Receptacle Assy M1 & M4	10581	3	2	91-98	14	74.0	0	0	0	0	0	0
14.	60B40037-707	Receptacle Assy M2	9647	4	1	95-98	16	26.0	0	0	0.333	0	3212	0
15.	60B40147-107	Receptacle Assy M2	7204	2	1	92-96	13.5	53.5	0	0	0	0	0	0
16.	60B40037-807	Receptacle Assy M3	9160	4	1	96-97	16	26.0	0	0	0.333	0	3050	0
17.	60B40147-207	Receptacle Assy M3	8022	-	1	No order	0	INF	0	0	0	0	0	0
18.	60B40147-108	Receptacle Assy CT	5821	0	1	96	16	INF	0	0	0	0	0	0
19.	60B40037-308	Receptacle Assy CT	7731	1	1	96	16	116.0	0	0	0	0	0	0
	TOTAL									7.833	2.666	29822	19469	301727

LEGEND:

Use = total consumption since delivery; Qty/ac = quantity per aircraft;
Order Y = Order year
Av. Age = Aircraft age during average order year (in year); Zero age is at 1980
MTBF(Y) = Estimated Mean Time Between Failure (=MTBR in this case) in year = Qty/ac * Av. Age * #ac / Use <=== without censoring ; #ac = Number of ai
= ((#ac * Qty/ac - Use) * 20 + Use * Av. Age)/Use <=== with censoring, when (#ac * Qty/ac - Use)>0
INF = infinite (due to divided by zero)
Ef(20) = Expected number of component failures at aircraft age of 20 years = Integer(20/MTBF) * Qty/ac * #ac
ND = not defined, because the MTBF is more than 20 years.
F(20-25), F(26-30) = number of failures per aircraft at aircraft age 20-25 years and 26-30 years = number of survivors and new installation which fail at a multipl
F(20-25) = (Ef(20) - Use)/#ac + (Integer (25/MTBF) - Integer (20/MTBF))* Qty/ac; F(26-30) = (Integer (25/MTBF) - Integer (20/MTBF))* Qty/ac;
M(20-25), M(26-30) = Material cost per aircraft at aircraft age 20-25 years and 26-30 years = number of failures * component price
D(20-25), D(26-30) = Delay cost per aircraft at aircraft age 20-25 years and 26-30 years = Number of failures * average delay duration * delay cost /hour;
average delay duration = 3.21 hours/delay for the last 12 months period; delay cost/hour = USD 200 * 60

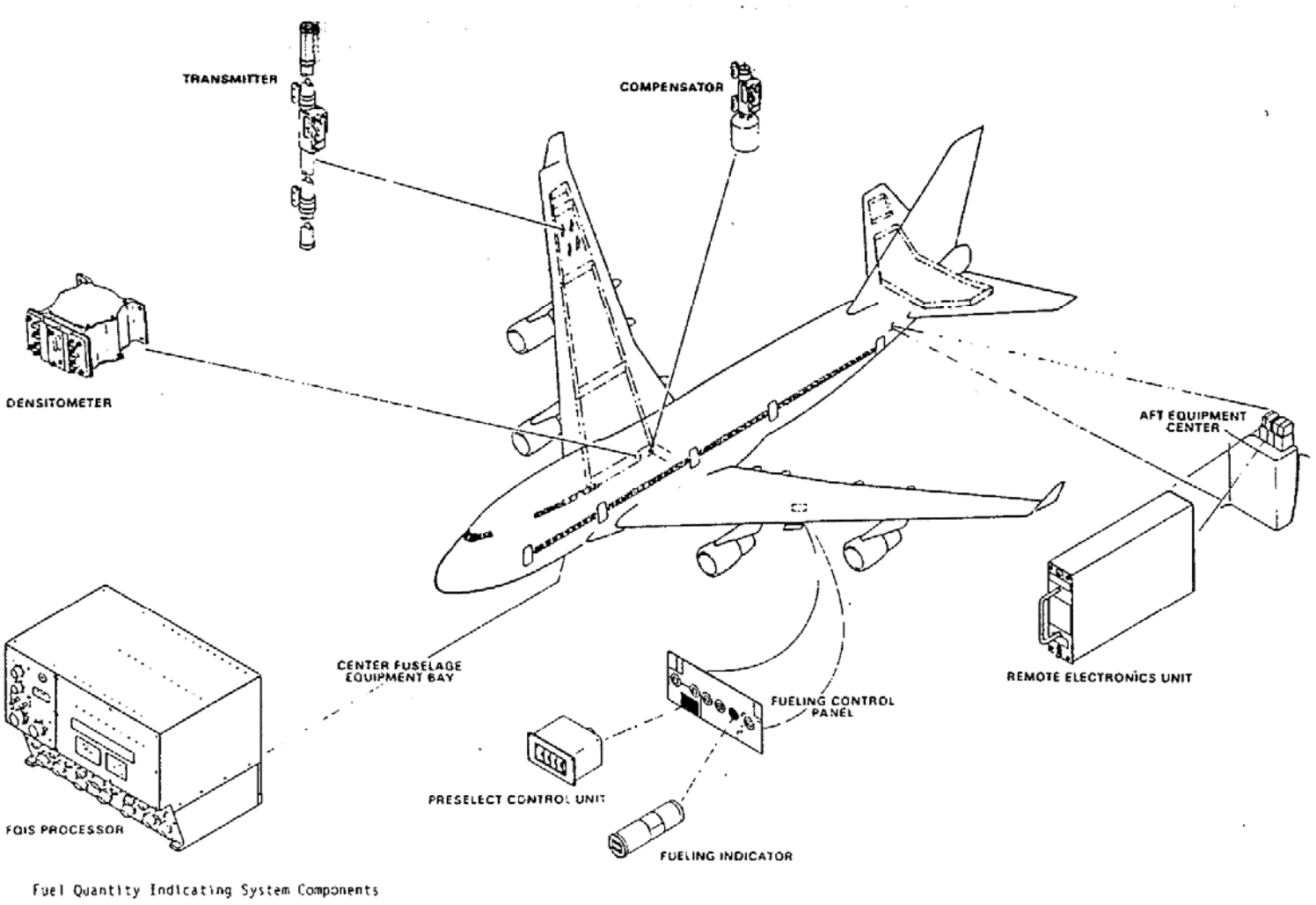


Fig. I.2 BFGoodrich Fuel Quantity Indicating System

Appendix J

LCC-OPS Case: Maintenance Program Optimisation

This appendix describes a case study of the LCC-OPS model application for Maintenance Program Optimisation, specifically on A-check interval escalation of B737-300/400/500 from 200 flight hours (FH) to 250 flight hours (FH). This interval escalation is for the first time for Garuda Indonesia, therefore the author chooses it for a case study. However, some past data is not available, therefore it is replaced by a hypothetical data. The purpose of the description is to verify the LCC-OPS for maintenance program optimisation.

J.1 Introduction

Current A-Check interval of B737-300/400/500 is 200 FH, it is still the same as the MRB document. At this interval, the ratio of number of findings and number of inspections within the A-check package is very small (average less than 1%). Some airlines in Europe have their A-Check interval of B737-300/400/500 is more than 250 FH. Without having experience with A-Check interval of 250 FH, is it impossible to escalate the A-Check interval for higher than 250 FH.

J.2 Objectives

The objective of the analysis is to evaluate the technical feasibility and LCC-OPS savings of the interval escalation of A-Check B737-300/400/500 from 200 FH to 250 FH.

J.3 Scope

For simplicity, the period of evaluation is 5 years, from 1st January 2003 until 1st January 2008. This is to assess the short term impact of the escalation. Actually, the period of

evaluation is up to the technical or economical life of the aircraft, which is normally equal to the design objective life.

The scope of the evaluation is to compare the LCC-OPS of the existing A-Check interval (200 FH) and the escalated interval (250 FH).

Existing interval:
The existing interval is the baseline. Only the direct maintenance cost is calculated and to be compared with the escalated interval.

Escalated interval:
It includes the effort to prepare the required data and to develop the escalation proposal, and the changes of the operating cost and the (opportunity) revenues.

J.4 Cost Breakdown Structure

Based on aforementioned scope of the investigation, the Cost Breakdown Structure (CBS) for each alternative is developed and shown in Figure J.1. The CBS is made by tailoring Fig. 6.1 in Chapter 6, where not relevant cost components are omitted. The description of the cost components are following.

Application of LCC-OPS for this case study is to calculate the required costs (investment) to escalate the interval and the changes of the operating costs as well as the changes of (opportunity) revenue.

The required costs or the investment consists of the cost to collect the maintenance data (routine, non-routine and unscheduled), the problem analysis cost, staff cost to process the data and the escalation proposal development cost. These costs are considered as investment because the activities are sub-contracted to a third party, under supervision of Garuda's engineers. Sometimes a modification is carried out to avoid drop-out of a maintenance task, but it is not applied in this case study.

The escalation will reduce the routine maintenance frequency and it will reduce the direct maintenance cost of the routine maintenance and increase the availability of the aircraft. Increase of aircraft availability will increase the (opportunity) revenue. But, the reduction of the scheduled maintenance frequency may increase the unscheduled maintenance, and as a consequence reduce aircraft availability and (opportunity) revenue. Therefore, it quite depends on the nature of the findings of scheduled maintenance and the occurrence of unscheduled maintenance with respect to the frequency of scheduled maintenance.

Changes of scheduled maintenance frequency may affect the required spares, but it doesn't for this case study. If the occurrence of some unscheduled maintenances can be attributed to a particular maintenance task in the package, then the changes of the scheduled maintenance frequency will affect the maintenance dependent cost.

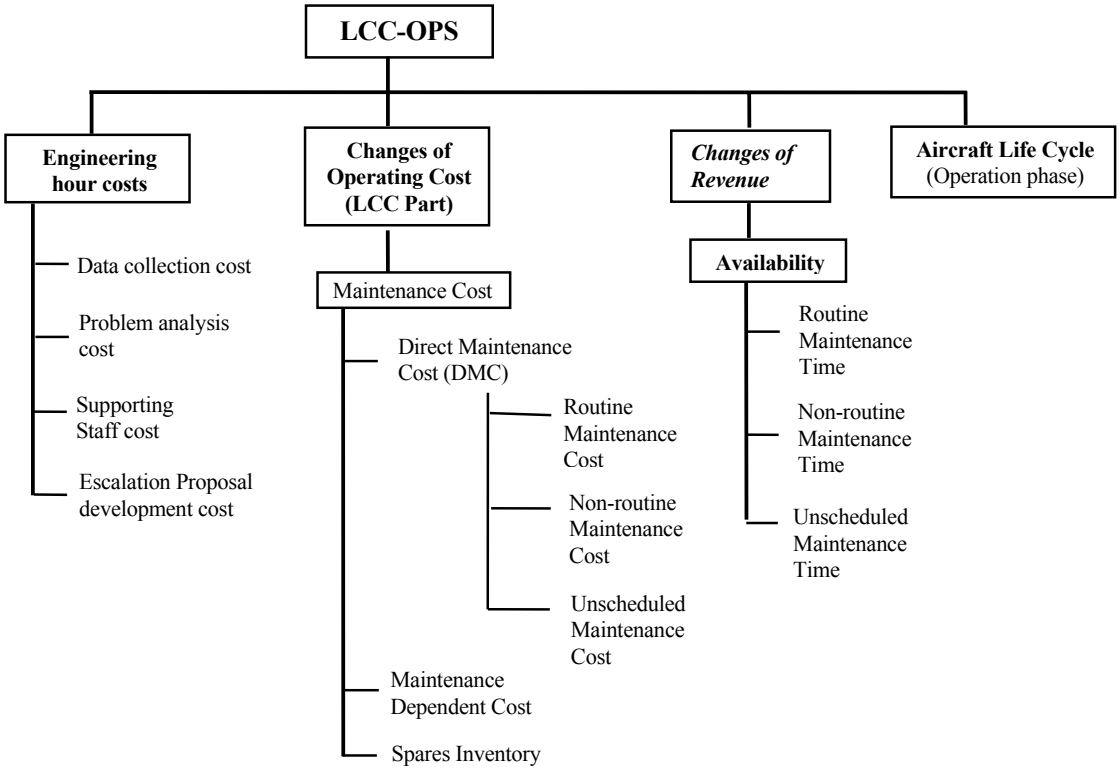


Fig. J.1 The CBS of the case study for maintenance program optimisation

J.5 Cost Components Estimation

After the included cost components are identified, estimation (calculation) of these cost components is conducted below. The staff rate used is USD 30/hour, the engineer hour rate is USD 40/hour. The end results of the calculation are presented in Table J.2. The process of calculation is following.

a. Existing interval

The engineering hour cost is zero for the existing interval, it is the baseline.

Maintenance costs, in the CBS above, consist of the Direct Maintenance Cost, Maintenance Dependent cost and Spares cost. There is no data available on the required spares, however this is relatively small as compared to C-check or D-check, therefore it is assumed to be zero.

Routine maintenance cost = (labour hours * labour rate + material cost) *
(flight frequency * block hour * annual operating days)/
(scheduled maintenance interval)
= (29 * 30 + 200)*(8*1.0833*285)/200 = USD 13,214.-

Non-routine maintenance cost = (labour hours * labour rate + material cost)*
annual frequency of findings.
Non-routine maintenance cost = (0.25* 30 + 100)* 2 = USD 215.-
(Note: labour hour and material cost for non-routine maintenance are rough estimates).

Opportunity revenue = number of passengers * load factor * flight distance / block hour*
Revenue Passenger Kilometre* (total down time of maintenance).
= 120 * 0.65 * 600 / 1.0833*0.13*(37.0489) = USD 208,073.-

b. Escalated interval

The engineering hour cost = data collection cost + problem analysis cost + staff cost +
proposal development cost
Rough estimate of this cost is following.
Data collection cost = Data collection time * Number of aircraft * Labour rate.
= 3 * 30 * 30 = USD 2,700.-

Problem analysis cost = Problem analysis time * Engineering rate
= 80 * 40 = USD 3,200.-

Proposal development cost = Proposal development time * Engineering rate
= 80 * 40 = USD 3,200.-

Staff cost = Staff time * Labour rate = 80* 30 = USD 2,400.-

Routine maintenance cost = (labour hours * labour rate + material cost) *
(flight frequency * block hours * annual operating days)/
(scheduled maintenance interval)
= (29 * 30 + 200)*(8*1.0833*285)/250 = USD 10,571.-

Non-routine maintenance cost = (labour hours * labour rate + material cost)*
annual frequency of findings.
Non-routine maintenance cost = (0.25* 30 + 100)* 3 = USD 323.-
(Note: labour hour and material cost are rough estimates). The number of non-routine maintenance is determined below.

Estimation of the number of findings:

The data of the non-routine maintenance is shown in Fig. 5.5 of Chapter 5. The findings in PK-GGF registration with the MRI Code 2760010100 and the MRI Code 2915070100 are a wrong reporting, because they are only a check. Therefore, only two findings can be taken into account. From the total 117 inspections, the average interval utilisation is 80.6%. It is much higher than the average of the intervals of the findings. Figure J.3 shows the distribution of the number of inspections as a function of the interval utilisation (two inspections were extended 24% than the normal interval, no further information concerning this ‘over’ extension).

The delay time is estimated based on the information of the number of inspections, number of findings, and the utilisation of the interval. Data censoring is not applied due to limitation of information. Based on Fig. J.3 and the interval utilisation of the discovered findings, the distribution of defect initiation must be random, because even though many inspections conducted at higher intervals, no findings were discovered.

For aircraft registration of GWN, the first *recorded* inspection on return filter difference pressure indicator was conducted at 11784 FH (see Fig. J.4). Inspection at 12395 FH (one inspection before the inspection at 12515 which discovered findings) did not detect any potential failure. There were 38 inspections conducted for the return filter difference pressure indicator of GWN registration, A-check interval, therefore Fig. J.4 is simplified.

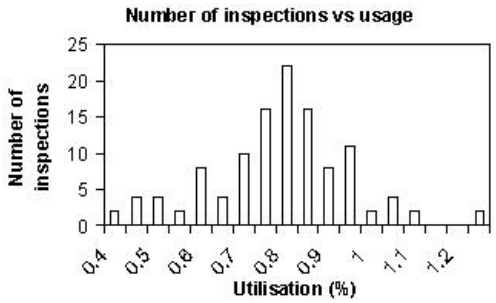


Fig. J.3 Distribution of number of inspection versus interval utilisation

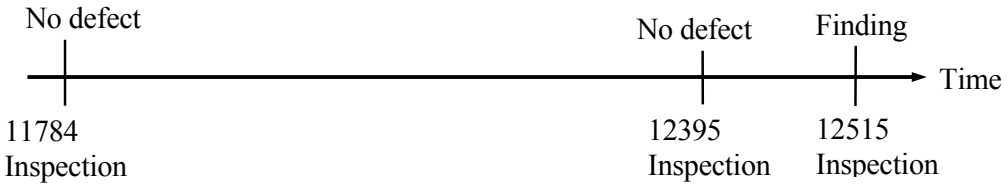


Fig. J.4 Inspection record of return filter difference pressure

Estimation of the escalated interval is addressed to the probability of defect detected during inspection. By assuming the average of the inspection interval utilisation represents all of the inspections and the defect initiation is *uniformly distributed*, with k=(2/117)/T, then the following calculation is made:

Average interval, T=0.806*200 = 161.2 FH.
Probability density of defect initiation, k= (2/117)/161.2 = 0.0106%
Probability of defect detected at T, P(d) = 2/117 = 1.71%

The proposed increase of interval is 25% from the existing interval (200 FH), or the escalated interval is 250 FH. It equals to 155.1% T (=250/161.2), or x=0.551. Therefore the probability of a defect to be detected in the escalated interval is:

P'(d) = 0.0106%*250 = 2.65% (rounded: **3 findings**).

Since the findings were only caused by the return filter difference pressure indicator and it is considered safe for this item for escalation, then **no** drop-outs is necessary.

The unscheduled maintenance data is collected from other documents than the routine maintenance report. **None** from the following information on ATA 29 can be addressed to the failure of the return filter difference pressure indicators:

a. 7 delays caused by ATA 29 in the last 12 months (from Technical Delay Report)
b. 5 Maintenance Reports, in the last six months (from Maintenance Discrepancy Report, Line Maintenance)
c. 26 PIREPS, in the last six months (from Aircraft Maintenance Log, already a digitised data).

Because no unscheduled maintenance is discovered (to estimate the length of delay time), at the escalated interval it is assumed there won't be any unscheduled maintenance. In other words, $h \geq T$ *and the inspections are considered perfect.* This assumption is valid only for the 200 FH A-check interval. Because there is no unscheduled maintenance, then the maintenance dependent cost is assumed zero.

Opportunity revenue = number of passengers* load factor * flight distance / block hours* Revenue Passenger Kilometre* (total down time of maintenance).
= 120 * 0.65 * 600 / 1.0833*0.13*(29.639) = USD 166,458.-

From Table J.1 the total annual operating costs savings at fleet level is:
USD (6,645,060 - 5,320,560) = USD 1,324,500.-

The investment required for the escalation is USD 11,500.-

Table J.2 shows the cash-flow for the period of evaluation at fleet level. The calculation is at a fleet level because the investment (USD 11,500) is at a fleet level. Total LCC-OPS savings at fleet level is USD 5,335,969.- (Present Value, to include the effect of time value of money). At aircraft level the LCC-OPS is USD 177,865.- for five years of evaluation period.

Table J.1 Maintenance cost due to A-check escalation (fleet level)

Cost component	Existing interval (200 FH) (USD)	Projected interval (250 FH) (USD)
Engineering hours cost (one time):	***Base line***	***11,500***
Data collection cost		2,700
Problem analysis cost		3,200
Staff cost		3,200
Proposal development cost		2,400
Maintenance costs (annual):	***13,429*30***	***10,894*30***
Routine maintenance cost	13,214*30	10,571*30
Non-routine maintenance cost	215*30	323*30
Unscheduled maintenance cost	0	0
Maintenance dependent cost	0	0
Opportunity revenue:	***208,073*30***	***166,458*30***
TOTAL (LCC-OPS)	**6,645,060**	**5,332,060**

Table J.2 Cash-flow for 5 years (fleet level)

Year:	Expenses (USD)	Savings (USD)	Total (USD, PV)
1	11,500	1,324,500	1,313,000
2		1,324,500	1,182,589
3		1,324,500	1,055,883
4		1,324,500	942,753
5		1,324,500	841,744
Total Savings (LCC-OPS)			**5,335,969**

Increase of 25% of the existing interval results in 55% increase of the findings probability, if the defect initiation is assumed uniformly distributed. However, the absolute value of the probability of defects detected is only 2.65%. *For this reason, 25% escalation of the existing interval* ***is justified.***

J.6 SENSITIVITY ANALYSIS

Sensitivity analysis of the LCC-OPS is concentrated on the change of the amount of unscheduled maintenance. The opportunity revenue mostly depends on the interval of routine maintenance, therefore it is not appropriate to conduct a sensitivity analysis for the opportunity revenue. The following calculates the changes of LCC-OPS savings by the change of the amount of unscheduled maintenance.

Changes of one unscheduled maintenance will change the LCC-MPS savings of the interval escalation for five years of:
Annual unscheduled maintenance cost = (labour hour * labour rate + material cost)*
annual frequency of unscheduled maintenance.
= (2* 30 + 200)* 1 = USD 260.-
Maintenance dependent cost = (delay and cancellation cost) * 60 *
(unscheduled maintenance downtime)
= (200) * 60 * 1 = USD 12,000.-
In total = 260 + 12,000.- = USD 12,260.-
For five years evaluation period and in Present Value the changes of the LCC-OPS when the unscheduled maintenance increase by one is:
= USD 49,902.-per aircraft.
Relative to the total LCC-OPS savings per aircraft this change of LCC-OPS is:
= 49,902.-/ 177,865 = 28,1%
It means that the LCC-OPS is sensitive to the change of the amount of unscheduled maintenance.

Figure J.5 shows the RESULTS worksheet of the LCC-OPS for the case discussed in this appendix.

J.7 CONCLUSIONS

Based on the results of calculation above, escalation of the A-check interval to 250 FH is beneficial, with **LCC-OPS** of **USD 177,865.-,** per aircraft (with PV) under the assumption that the escalation does not change the amount of unscheduled maintenance.

LCC-MOPS **RESULTS** by Edy Suwondo

Engineering hour costs :	11,500	USD		
Data Collection cost	2,700	USD		
Problem Analysis cost	3,200	USD		
Proposal Development cost	3,200	USD		
Supporting staff costs	2,400			
Modification Costs (fleet)	0	USD		
Resale value increase	0	USD		
Direct maintenance cost savings/yr	2,535	USD		
Maint. Dependent cost savings/yr	0	USD		
Inventory cost reduction/yr	0	USD		
Other cost reduction/yr	0.0	USD		
Opportunity revenue/yr	41,615	USD		
LCC-OPS per aircraft	177,865	USD		
Period of evaluation	5	years		
LCC-OPS at fleet level	5,335,955	USD		
ADDITIONAL CRITERIA:				
Payback Period (with interest)	0.0087	years		
Return On Investment (ROI)	11,517.4	%		
Internal Rate of Return (IRR)	Not applicable	%		

Fleet level calculation

Year	Expenses	Savings (USD)	Total (USD)
1	11,500	1,324,496	1,312,996
2		1,324,496	1,182,586
3		1,324,496	1,055,880
4		1,324,496	942,750
5		1,324,496	841,741

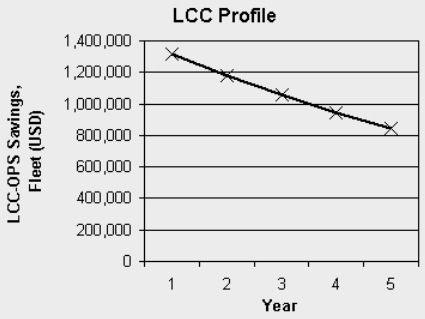


Fig. J.5 The RESULTS worksheet of the LCC-OPS for the case in this appendix.

Appendix K

LCC-OPS Case: Aircraft Selection

This appendix describes a case study of LCC-OPS model application for aircraft selection (LCC-SEL). The case study is selected because the author was assigned by a manager of GMF to perform analysis on aircraft fleet replacement. The objective of the application is LCC-OPS comparison between the existing Boeing 747-200 owned by Garuda and new Boeing 747-400. The period of evaluation is 2000-2005 with the route of Denpasar-Narita-Denpasar (DPS-NRT-DPS). Evaluation will use the past data (1998) of these two types of aircraft based on Garuda operation and maintenance.

K.1 Introduction

In 1998, Garuda's Boeing 747-200's are nearly 20 years old. The management of Garuda is considering to replace the aircraft with new ones. Currently Garuda has some B747-400 in its fleet, where this aircraft type is one of the candidates. In the first instance, comparison will be made between B747-200 and B747-400, where operation data is available.

K.2 Objectives

The objective of the analysis is to compare the LCC-OPS savings between B747-200 and B747-400 for the same route of operation by using past data of Garuda Indonesia Airlines. Other objective is to verify the LCC-OPS model for aircraft selection.

K.3 Scope

The scope of the analysis is on the investment and exploitation costs. The investment cost consists of depreciation for B747-200, while for B747-400 it consists of depreciation and financing cost. This is because the B747-200's fully belong to Garuda, while the new B747-400's still need to be acquired. The residual value is taken into account in the annual

depreciation calculation. The exploitation costs consist of fuel, maintenance, and delay and cancellation costs. These are cost components of Direct Operating Cost (DOC). The Indirect Operating Cost (IOC) is excluded from consideration because it has no direct relationships to aircraft type.

The crew costs (cockpit and cabin) for thee two aircraft can be equalised (very small difference), therefore it is not included in the calculation. Concentration will be on the relative costs of these aircraft. For the two aircraft, breakdown of LCC-OPS is shown in Fig. K.1.

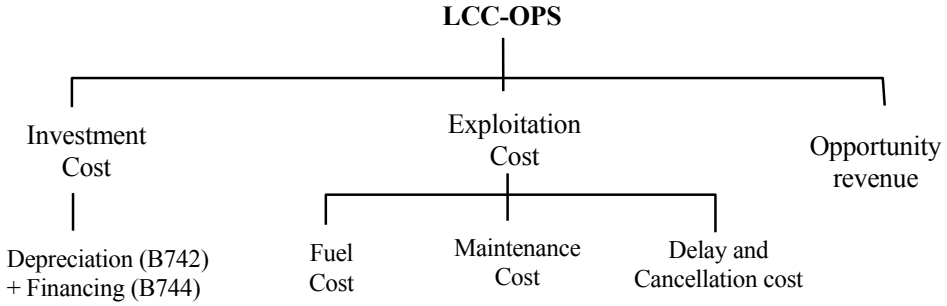


Fig. K.1 Breakdown of LCC-OPS into cost components

K.4 Calculation of Cost Components

Comparison will be made in annualised LCC, as in previous cases. At first, the cost components per block hour are calculated based on past data. The results are then multiplied by the annual block hours of the new route, i.e. DPS-NRT-DPS. Cost components per block hour are calculated by dividing the total of annual expenses for each cost category by the total block hour for that year (1998). The calculated annual cost of investment will be used directly, because this cost is independent from the flight hours or number of departures. For delay and cancellation cost, multiplication by relevant number of departures will be used. The method of calculation is shown directly in the calculation below.

The total of block hours for B747-200 during 1998 is 16202 for six aircraft (7.4 FH/day), except during December five aircraft. While for B747-400 the block hours is 12278 for three aircraft (11.2 FH/day). *It is assumed that the total flight hours made by these two types of aircraft are responsible for the exploitation costs which were made in that period.* The results of the calculation are presented in Table K.1 and K.2. The process of cost component calculation is following.

It is assumed that for the intended route of these two types of aircraft will fly **283** days annually (data of B747-400, Garuda) and **2 departures daily**, with total block hours per day equal to the past data, i.e. 14,01 hours for B747-200 and 13,84 hours for B747-400. Calculation of annual fuel and maintenance costs is using the assumption that fuel cost and maintenance cost per block hour are constant in the course of the evaluation period.

As mentioned earlier, calculation is made on annual basis. Based on the information above, number of flight hours (FH) per aircraft during 1998 are following:
B747-200: 16202/5.91667 = 2738.37 FH/year
B747-400: 12278/3 = 4092.67 FH/year

Bock hour data:
B747-200: DPS-NRT = 6.92, NRT-DPS = 7.09, Average = 7.005 hour
B747-400: DPS-NRT = 6.60, NRT-DPS = 7.24, Average = 6.92 hour

Projected flight frequency = 2 departures/day
Projected annual utilisation = 283 days/year.

Depreciation:
Depreciation is applied to include capital recovery in the exploitation cost. Therefore, purchase price of the aircraft is excluded from the evaluation. Depreciation is defined as the reduction of the purchase (selling) price of the aircraft (including engine, seats, avionics, etc.) due to the age of aircraft, during the study period (2000-2005). Depreciation is assumed equal to the depreciable price divided by the period of depreciation (straight line model).

B7470-200:
The market price of B747-200 until end of 1999 is about USD 10 million and in next five year is estimated about USD 5 millions [expert opinion]. Estimates of market prices from other sources is limited useable, due to wide range variations of aircraft condition. Based on the estimate above, the annual depreciation of B747-200 is USD 1,000,000.-
Depreciation per block hour = annual depreciation/(block hour * flight frequency * annual utilisation)
= 1,000,000/(7.005*2*283) = USD 252/block hour

B747-400:
The purchase price of a B747-400 in 1999 is USD 187 million [Boeing data]. If it is assumed that the aircraft design life is 20 years with 10% resale value, the annual depreciation is:
(187,000,000-18,700,000)/20 = USD 8,415,000.-
Depreciation per block hour = 8,415,000/(6.92*2*283) = USD 2,148/block hour.

Financing cost:
Financing cost is an additional cost to the purchase price of the aircraft given to the lender (bank). Financing cost has a range of 0.10 - 0.20, depending on the interest rate [Roskam, J., "Airplane Design", Part VIII, 1990]. Assuming the average value is applicable, i.e. 15%, then the financing cost per aircraft is:
= USD 187,000,000 * (0.15) = USD 28,050,000.-
Divided equally for 20 years = USD 28,050,000/20 = USD 1,402,500/year, or USD 358/block hour.

Fuel and oil cost:
Fuel cost calculation for the route of DPS-NRT-DPS is using actual data of 1998 for the same route and aircraft type [data from Directorate of Operation, Garuda]. By assuming fuel price of USD 0.1619/litre and specific gravity of 0.79 kg/litre, fuel cost per block hour is following. The difference of fuel burn for DPS-NRT and NRT-DPS is due to wind direction. Oil cost is about 0.10 of fuel cost [Roskam, 1991].

B747-200:
DPS-NRT: fuel burn = 77,785 kg; NRT-DPS: fuel burn = 79,394 kg
Average fuel and oil cost per block hour = (1.0+0.10) * average fuel burn/departure * fuel cost/kg /fuel density /block hour/departure
= 1.1 *(77,785+79,394)/2*0.1619/0.79/7.005
= USD 2,529.-/block hour
Fuel and oil cost per year = Average fuel and oil cost per block hour * block hour/departure * departures/day * operating days/year
= 2,529 * 7.005 * 2 * 283 = USD 10,027,055.-/year

B747-400:
DPS-NRT: fuel burn = 62,975 kg; NRT-DPS: fuel burn = 69,075 kg
Average fuel and oil cost per block hour = 1.1 *(62,975+69,075)/2*0.1619/0.79/6.92
= USD 2,151.-/block hour
Fuel and oil cost per year = 2,151 * 6.92 * 2 * 283 = USD 8,424,865.-/year

Maintenance cost:
Maintenance cost per block hour is calculated based on the total maintenance cost in 1998 divided by the total block hours in 1998. This maintenance cost includes the cost of Heavy Maintenance Visit (HMV) by amortising the HMV cost to the interval of HMV. Data from AVITAS [Aircraft Technology Engineering & Maintenance, Oct/Nov 1995] shows that the total maintenance of B747-200 is USD 2207 per block hour, while for B747-400 is USD 1000 per block hour. It means that maintenance costs per block hour of Garuda organisation, i.e. USD 1,500 for B747-200 and USD 700 for B747-400, are 'reasonable'. This is due the fact that labour rate at Garuda is lower than AVITAS data.

Maintenance cost per block hour:
B747-200: USD 1500.-
B747-400: USD 700.-
Maintenance cost per year = Maintenance cost per block hor * block time per departure * number of departures per day * operating days per year
B747-200: 1500 * 7.005 * 2 * 283 = USD 5,947,245.-
B747-400: 700 * 6.92 * 2 * 283 = USD 2,741,704.-

Delay & Cancellation costs:
Delay cost is calculated based on delay cost per minute, i.e. USD 200 (constant, data from Directorate of Operation, Garuda), multiplied by average delay duration in 1998. Cancellation cost is calculated based on cost per cancellation multiplied by the average number of cancellation per (thousand) departures in 1998. Cancellation cost per cancellation is assumed equal to delay cost with a duration of 24 hours. Delay and cancellation costs for these two aircraft are following [compared to another airline data, these delay cost and cancellation cost are 'reasonable']. Opportunity revenue due to delay reduction is excluded in the total of LCC-OPS because it is assumed that the average duration of a delay is too small for commercial use.

B747-200:
Total delay duration in 1998 = 401.85 hours; number of departures = 3171 [Monthly Reliability Report]

Delay cost per departure = total delay duration in minutes * delay cost per minute /number of departures in 1998 (fleet)
= 401.85* 60* USD 200/ 3171 = USD 1520.72
Delay cost per year (projected) = delay cost per departure * number of departures per year
= 1520.72 * 2 * 283 = USD 860,727.-
Delay cost per block hour (projected) = 1520.72/7.005 = USD 217.-
Revenue loss due to delays per year (excluded in the total LCC-OPS) = total delay duration in 1998 /number of departures in 1998 (fleet) * number of departures per year* number of passengers * load factor * revenue passenger kilometre * block distance /block hours
= 401.85/3171* 2 * 283 * 431 * 0.65 * 0.13 * 6000 /7.005 = USD 2,237,491.-
Revenue loss due to delays per block hour (excluded in the total LCC-OPS) = total revenue loss per year / block hour per year
= 2,237,491/(7.005* 2 * 283) = USD 564.-

Number of cancellations in 1998 = 2
Cancellation cost per departure = 2* 24 * 60 * 200/3171 = USD 181.65
Cancellation cost per year (projected) = 181.65 * 2 * 283 = USD 102,814.-
Cancellation cost per block hour (projected) = 181.65/7.005 = USD 26.-
Revenue loss due to cancellations per year = number of cancellations in 1998/number of departures in 1998 * number of departures per year * number of passengers * load factor * RPK * block distance
= 2/3171* 2 * 283 * 431 * 0.65 * 0.13 * 6000 = USD 78,007.-
Revenue loss due to cancellations per block hour = total revenue loss / block hour per year
= 78,007/(7.005* 2 * 283) = USD 20.-

B747-400:
Total delay duration in 1998 = 261.88 hours; number of departures = 2369
Delay cost per departure = 261.88* 60* 200/ 2369 = USD 1326.53
Delay cost per year (projected) = 1326.53 * 2 * 283 = USD 750,816.-
Delay cost per block hour (projected) = 1326.53/7.005 = USD 189.-
Revenue loss due to delays per year (excluded in the total LCC-OPS):
= 261.88/2369* 2 * 283 * 431 * 0.65 * 0.13 * 6000 /6.92 = USD 1,975,754.-
Revenue loss due to delays per block hour (excluded in the total LCC-OPS):
= 1,975,754/(6.92* 2 * 283) = USD 504.-

Number of cancellations in 1998 = 0
Cancellation cost per departure = 0
Cancellation cost per year (projected) = 0
Cancellation cost per block hour (projected) = 0
Revenue loss due to cancellations per year = 0
Revenue due loss to cancellations per block hour = 0

Table K.1 shows the results of the calculation in block hour because some costs (e.g. maintenance cost) are usually stated per block hour. Table K.2 presents the calculation in annual basis.

Table K.1 Cost components **per block hour**

Cost components	B747-200 (USD)	B747-400 (USD)
Investment *): Aircraft depreciation	252	2,148
Financing		358
Fuel and oil	2,529	2,151
Maintenance	1,500	700
Delay **)	217	189
Cancellation **)	26	0
Revenue loss due to cancellations	20	0
Revenue loss due to delays (excluded)	564	504
TOTAL	**4,544**	**5,546**

*) Investment cost is depreciation cost (B747-200) and plus the financing cost (B747-400).
**) Delay cost is assumed equal to USD 200,-/minute, while a cancellation is equivalent to 24 hour delay or USD 288,000,-/cancellation.

Table K.2 Cost components **per year**

Cost components	B747-200 (USD)	B747-400 (USD)
Investment *): Aircraft depreciation	1,000,000	8,415,000
Financing	---	1,402,500
Fuel and oil	10,027,055	8,424,865
Maintenance	5,947,245	2,741,704
Delay **)	860,727	750,816
Cancellation **)	102,814	0
Revenue loss due to cancellations	78,007	0
Revenue loss due to delay (excluded)	2,237,491	1,975,754
TOTAL	**18,015,848**	**21,734,885**

*) Investment cost is depreciation cost (B747-200) and plus the financing cost (B747-400).
**) Delay cost is assumed equal to USD 200,-/minute, while a cancellation is equivalent to 24 hour delay or USD 288,000,-/cancellation.

Annual LCC-OPS for the aircraft candidates above is:

= 18,015,848 - 21,734,885 = **USD -3,719,037.-**

It means the second candidate (B747-400) leads to a higher LCC-OPS. Although the second candidate has a low fuel consumption and a low maintenance cost, the required investment (depreciation and financing) is very high as compared with the savings from fuel and maintenance.

Table K.3 shows the LCC-OPS for each projected year, with Present Value and discount rate of 12%. The LCC-OPS for five years, with Present Value is:

USD 15,015,052.-

The difference of this value with the result in the MS Excel is due to round of error.

Table K.3 Present Value calculation of LCC-OPS

Year	0	1	2	3	4
PV of LCC-OPS	3,719,037	3,320,568	2,964,793	2,647,137	2,363,515

K.5 Cost Drivers Identification

Based on Table K.2 the highest cost contributors are following.

B747-200:
Fuel and oil costs, USD 10,027,055.-.
Fuel and oil costs depend on the thrust required, while the thrust required is equal to drag of the aircraft. To reduce fuel and oil costs the specific fuel consumption must be low, the total of drag coefficient is low and the flying speed of the aircraft is low. The flying speed is determined by market requirement. Therefore the cost drivers are the specific fuel consumption and the total drag of the aircraft.

B747-400:
Aircraft depreciation USD 8,415,000.- and fuel and oil costs USD 8,424,865.-
Aircraft depreciation depends on the aircraft initial price, which is determined by the market or by the manufacturers. Therefore, similar to B747-200, the cost drivers of this aircraft are the specific fuel consumption and the total drag of the aircraft.

K.6 Sensitivity Analysis and Risk Analysis

Sensitivity analysis of the LCC-OPS is concentrated on changes in the number of cancellations. Other cost components are less likely to change significantly. The following calculates the changes of LCC-OPS as a percentage by the increase of **one** cancellation per aircraft per year.

Increase of number of cancellations per year (in projected) = 1
Increase of cancellation cost per year (projected) = 1 * 24 * 60 * 200 = USD 288,000.-
Increase of opportunity revenue due to the increase of **one** cancellation per year:
= 1* 431 * 0.65 * 0.13 * 6000 = USD 218,517.-
Increase of **one** cancellation of B747-200 leads to the changes of LCC-OPS of
= 288,000 + 218,517 = USD 506,517.-
In percent : 506,517/3,719,037= 13,6%

It means that the LCC-OPS is **not too sensitive** to changes in the number of cancellations. Therefore risk analysis is not necessary.

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Summary

Observation of current practices in aircraft operations and maintenance shows limited consideration of cost savings applied by aircraft modifications, maintenance program optimisation and aircraft selection. This is due to hidden (maintenance dependent) costs and difficulties in quantifying the utilisation of a higher availability or reduction of revenue losses. Hidden costs can be a significant portion of operating costs and could be reduced by a better aircraft reliability. Most of the decisions for aircraft modification and maintenance program optimisation are made only to fulfil airworthiness or operational (technical delays and cancellations) requirements. The considerations for the impact of aircraft reliability and maintenance dependent costs on life cycle cost are limited during aircraft selection, because operational data is very limited and the methods to quantify technical delays and cancellations are not available.

This situation can be improved by a better quantification of the required investment and the savings achieved by a proper evaluation of the implemented modifications and maintenance program optimisations. In this thesis a Life Cycle Cost model is developed, called LCC-OPS, which visualises the hidden costs and quantifies opportunity revenues or losses. This model will provide an objective calculation and evaluation of the current and projected alternatives.

LCC-OPS, at the highest level, consists of the required investment for modifications or maintenance program optimisation, the reduction of operating costs and the increase of (opportunity) operating revenues. LCC-OPS supports calculation of these cost components. These are taken into account over the life cycle period for the aircraft or fleet. Proper implementation of LCC-OPS may lead to new Performance Indicators for the Engineering and Maintenance Organisation, i.e. life cycle cost savings per year.

In order to implement LCC-OPS an additional process is required, i.e. Cost Analysis, under responsibility of a Cost Management Unit. The process of Cost Analysis begins with recording operations and maintenance cost data, reporting and evaluation of aircraft operation and maintenance cost, continued by *analysis of the direct and indirect costs*. In order to support this process, a cost database must be established, with the data from the own operation and the manufacturer's data. However, manufacturer's data in Service Bulletins is currently not sufficient to support estimation of cost savings.

Current methods applied for escalating inspection intervals do not have a strong theoretical background. The author recommends the use of Delay Time Models as a basis theory for evaluating the results of inspections. Based on this theory, the most appropriate method to escalate inspection intervals is the application of provisional check intervals, before a new inspection intervals are established. This method is also recommended by Boeing. Application of this method requires estimation of delay time (HLA=How Long Ago and HML=How Much Longer), based on the identified potential failures or functional failures.

Samenvatting

In de huidige praktijk van vliegtuiggebruik en -onderhoud blijkt dat nauwelijks kostbesparingen beschouwingen worden toegepast bij vliegtuig modificaties, het optimaliseren van onderhoudsprogramma's en bij vliegtuigselectie. Dit is het gevolg van niet zichtbare (onderhoudsafhankelijke) kosten en van moeilijkheden bij het kwantificeren van de benutting van hogere beschikbaarheid of van inkomsten verliezen. De niet zichtbare of onderhoudsgerelateerde stilstandskosten kunnen een aanzienlijk deel uitmaken van de directe kosten voor de vliegoperaties en kunnen worden verminderd door een hogere bedrijfszekerheid van het vliegtuig. De meeste van de beslissingen over vliegtuigmodificaties en optimalisatie van het onderhoudsprogramma hebben betrekking op het waarborgen van de luchtwaardigheids- en operationele eisen (technische vertragingen en afgelastingen van vluchten). De beschouwing van de invloed van betrowbaarheid en onderhoudsafhankelijke kosten op de levencycluskosten zijn beperkt tijdens de vliegtuigselectie, door geringe beschikbaarheid van operationele data en methoden om vertragingen en afgelastingen van vluchten te kwantificeren.

Deze situatie kan worden verbeterd door een betere kwantificering van de vereiste investeringen en de te realiseren besparingen door evaluatie van de resultaten van de ingevoerde modificaties en van de geoptimaliseerde onderhoudsprogramma's. In dit proefschrift wordt een levenscycluskosten model ontwikkeld, aangeduid als LCC-OPS, waarmee onder andere bovengenoemde verborgen en niet zichtbare kosten kunnen worden bepaald en gebruikt. Hiermee is het mogelijk om de huidige situatie en voorgestelde alternatieven te berekenen en te evalueren.

LCC-OPS op het hoogste niveau, bestaat uit de noodzakelijke investeringen voor modificaties of optimalisering van het onderhoudsprogramma, uit verlaging van de operationele kosten en verhoging van de operationele inkomsten. LCC-OPS biedt ondersteuning om deze kosten komponenten vast te stellen. Deze worden beschouwd over de evaluatieperiode: de levenscyclus van het vliegtuig of de vloot. Toepassing van LCC-OPS kan leiden tot gebruik van nieuwe prestatie indicatoren voor de engineering en onderhoudsorganisatie, bijvoorbeeld jaarlijkse besparing van levenscycluskosten.

Voor de toepassing van LCC-OPS is een afzonderlijk werkproces vereist, kostenanalyse, onder verantwoordelijkheid van een organisatie element kostenbeheer. Het proces kostenanalyse begint met registratie van operationele en onderhoudskosten, gevolgd door analyse van de directe en indirecte kosten. Om dit proces te ondersteunen, is het noodzakelijk te kunnen beschikken over een kostenbestand, bestaande uit zowel gegevens vanuit de eigen operatie en die van de fabrikant. Echter de huidige gegevens van Service Bulletins is niet toereikend voor het schatten van kostenbesparingen.

De huidige methoden die worden toegepast voor escalatie van onderhoudsintervallen ontberen een degelijke theoretische basis. De auteur beveelt het gebruik aan van "Delay Time Models" als basis-theorie voor het evalueren van inspectieresultaten. Één van de onderdelen van deze theorie, is het gebruik van voorlopige inspectie intervallen, voordat een nieuw inspectie interval wordt vastgesteld. Deze methode wordt eveneens aanbevolen door

Boeing. Toepassing van deze methode vereist het schatten van de tijdsvertraging of Delay Time (HLA: How long Ago en HML How Much Longer), gebaseerd op geïdentificeerde potentiële of functionele storingsvormen.

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Curriculum Vitae

The author was born on 20 of July 1965, in Banyuwangi, Indonesia. After finishing his basic school and middle school in 1984, he went to Institut Teknologi Bandung to take his university study. He got his 'Sarjana Teknik' degree in 1991 with final thesis in optimisation of composite structures for aircraft wing panels.

Since 1991 until 1992 he gave lectures in aircraft loads and composite structures at Aerospace Engineering Department, Bandung Institute of Technology. In the same period he worked also as a part-timer at IPTN, the Indonesian Aircraft Manufacturer.

In 1992 he left for the Netherlands to get a one year trainingship at Delft University of Technology, Faculty of Aerospace Engineering. In the beginning he studied aircraft systems, but then he 'incidently' moved to the group Aerospace Industrial Engineering and Management of Prof.ir. K. Smit.

Since 1994 until 1997 he conducted a literature survey in Life Cycle Costing, at the Delft University of Technology. This activity was finished in 1997, where at the same year he started his Ph.D. research. He travelled several times to Jakarta (Indonesia) to collect data and information at the Engineering and Maintenance Division of Garuda Indonesia Airlines for his research. His Ph.D. research was under guidance of Prof. ir. K. Smit from Delft University of Technology and Prof. ir. O. Diran from Bandung Institute of Technology. In 2007 he finished his research and got his doctor degree from Delft University of Technology.

The author is married with Suci Resmiwati and has three daughters: Yusrina Nur Dini, Hasna Nur Karimah and Marha Nur Amalina.