EXPECTED LIFE CYCLE COST FOR SYSTEMS WITH REPAIRABLE COMPONENTS

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I would like to dedicate this research to my lovely wife.

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ABSTRACT

Life Cycle Cost (LCC) typically is specified as the total cost that arises during the mission life of a product. Life cycle cost analysis has been used as a strong tool to estimate the cost of various product life cycle stages and to provide cost trade of between these stages. This thesis intends to develop a generic mathematical model to estimate the life cycle cost of systems with repairable components. In addition the proposed model has the capability of providing cost trade-off between product validation and corrective maintenance by selecting the best target reliability level and confidence level and between preventive maintenance and corrective maintenance cost through finding the suitable preventive maintenance interval and improvement factor, the most advantage of preparing cost trade-off is reducing the total cost during mission life. Two sets of data were employed in order to evaluate the proposed model by using MathWork Matlab 2012. The first is the extension of a previous case study in the field of cost optimization and the other is data collected from a case study performed in an automotive industry company. Final results illustrate the capability of the proposed model to cost estimation and cost management.

ABSTRAK

Kos Kitaran Hayat (LCC) biasanya dinyatakan sebagai jumlah kos yang timbul semasa hayat misi produk. Analisis kos kitaran hayat telah digunakan sebagai alat yang kuat untuk menganggar kos peringkat kitaran hayat produk pelbagai dan untuk menyediakan kos perdagangan antara peringkat ini. Tesis ini bertujuan untuk membangunkan model generik matematik untuk menganggarkan kos kitaran hayat sistem dengan komponen dibaiki. Di samping itu, model yang dicadangkan mempunyai keupayaan untuk menyediakan kos perdagangan antara pengesahan produk dan penyelenggaraan pembetulan dengan memilih sasaran tahap kebolehpercayaan terbaik dan tahap keyakinan dan antara penyelenggaraan pencegahan dan kos penyelenggaraan pembetulan melalui mencari selang penyelenggaraan pencegahan dan faktor penambahbaikan yang sesuai, yang paling kesempatan menyediakan perdagangan kos mengurangkan jumlah kos sepanjang hayat misi. Dua set data telah digunakan untuk menilai model yang dicadangkan dengan menggunakan Mathwork Matlab 2012. Data pertama adalah lanjutan daripada kajian kes terdahulu dalam bidang pengoptimuman kos dan kedua ialah data yang dikumpul daripada kajian kes yang dilakukan keatas industri automotif syarikat. Keputusan akhir menunjukkan keupayaan model yang dicadangkan untuk kos anggaran dan pengurusan kos.

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LIST OF ABBREVIATION

LCC	-	Life Cycle Cost
WLC	-	Whole Life Cost
CBS	-	Cost Breakdown Structure
CM	-	Corrective Maintenance
PM	-	Preventive Maintenance

LIST OF PARAMETERS

C_D	-	Design cost
C_V	-	Validation cost
C_M	-	Manufacturing cost
C_O	-	Operation cost
C_{MD}	-	Total direct manufacturing cost
C_{MID}	-	Total indirect manufacturing cost
C_O	-	Operation cost
C_{Ma}	-	Maintenance cost
C_{PM}	-	Preventive maintenance cost
C_{CM1}	-	Corrective maintenance cost for parts without PM policy
C_{CM2}	-	Corrective maintenance cost for parts under PM policy
C_E	-	End of life cost
L_T	-	Hourly test labour rate
L_M	-	Hourly manufacturing labour rate
P_D	-	Hourly design professional rate
P_M	-	Hourly manufacturing managerial rate
t_D	-	Design time
E_D	-	Hourly design equipment and furniture cost
C_{PD}	-	Product development cost
$R(t)$	-	Reliability at time t

R	-	Target reliability
C	-	Test confidence level
n	-	Test sample size
β	-	Weibull slope or shape parameter of the failure
η	-	Weibull characteristic life or scale parameter
L	-	Number of mission lives that the product is tested for
N	-	Production volume during one year for product under study
t_{Bogey}	-	Product mission life
E_T	-	Hourly test equipment cost
n_{ET}	-	The number of test equipment
M_T	-	Test material cost for one sample
H_T	-	Test handling cost for one sample
M_M	-	Direct material cost for a unit product
t_M	-	Production time per labor per unit for product under study
t_{M_i}	-	Production time per labor for product for product i
t_Y	-	Production time in a year
t_H	-	Total yearly production time for product under study
t_{H_i}	-	Yearly production time for product i
z	-	Total number of products that the company produces
C_F	-	Yearly facility cost
E_O	-	Total energy cost during life time
I_O	-	Total insurance cost during life time
Cl_O	-	Total cleaning cost during life time
T_O	-	Total taxes during life time
V_j	-	Virtual age after jth simple preventive maintenance

V_t	-	Effective age at time t
t_P	-	Preventive maintenance interval
m	-	Improvement factor
C_{pm}	-	Level m preventive maintenance cost
n_{PM}	-	Number of preventive maintenance during the life time
$E(CR)$	-	Expected corrective repair cost for parts without PM policy
$E(CR2)$	-	Expected corrective repair cost for parts under PM policy
$\Lambda(t)$	-	Product failure intensity function
n_{LC}	-	Production volume during product life cycle
C_{EI}	-	Inspection cost
C_{ED}	-	Demolition cost
O_D	-	Hourly design overhead cost
O_M	-	Yearly manufacturing overhead cost
O_O	-	Operation overhead cost
O_{PM}	-	Preventive maintenance overhead cost
O_{CM}	-	Corrective maintenance overhead cost for parts without PM policy
O_{CM2}	-	Corrective maintenance overhead cost for parts under PM policy
O_E	-	End of life overhead cost

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Increasing global competition has changed the traditional attitude towards manufacturer responsibility from merely designing, producing and selling a product to offering integrated industrial product service and warranty systems. This new arrangement has significant effect on how to evaluate and select a product among many alternatives. From a cost point of view, traditional methods in which customers considered only the initial and investment costs while selecting a product are changed to life cycle cost methods in which, customers consider not only initial costs but also after sale service and support that the manufacturer can provide until product disposal.

Market pressure has forced manufacturer to take responsibility for after sale costs in addition to manufacturing costs. This resulted in a considerable shift in the business environment leading to the implementation of the life cycle cost concepts by the manufacturing companies. Life cycle costing analysis is a powerful technique, which helps manufacturer consider total cost of the product during the product life cycle and even reduce the cost during this period and finally help them preserve their profitability in long term.

This study intends to develop a generic model for estimating life cycle cost for systems with repairable components.

1.2 Background of the Study

Life Cycle Cost (LCC) is defined as the total cost incurred in the product life time, the main categories of LCC are design and development cost, construction or manufacturing cost, operation cost, maintenance cost, after sale and disposal cost (Du et al., 2009). First U.S. military proposed the life cycle cost method for the military equipment selection and procurement, later the life cycle cost method extended to the civilian and other areas as well (Zhang and Wang, 2012).

Life cycle costing aims to estimate the total costs of products and to compare costs of alternative products in their life cycle. Based on the cost estimation, it is possible to control and minimize the future costs by either planning the use of an asset or by improving the product or asset itself, which is a basis for life cycle costing (Markeset and Kumar, 2004). The anticipated life cycle cost can be used as an important source for decision making in product procurement, design optimization, maintenance scheduling and revamp planning.

Life cycle costing has obvious long term benefits, nevertheless its adoption pace has been quite slow (Lindholm and Suomala, 2004). Possible reasons for such a slow adoption rate could be dearth of standards and formal guidelines as well as dearth of reliable past data (Korpi and Ala-Risku, 2008). In addition, there is lack of cross-case studies in life cycle cost field; existing ones are limited in terms of studying a single industry (Sterner, 2000) and covering some superficial features of LCC such as adoption rate (Hyvönen, 2003).

Normally, the ownership cost during the life time of the product is substantially greater than the initial cost of acquisition. Depending on the system type, the ownership cost during the life time may vary from 10 to 100 times the initial cost of acquisition. Therefore, creating a cost effective maintenance policy to minimize the life cycle cost is a critical task. The reliability level of a system has a significant effect on systems' life cycle costs and maintenance costs, selecting an appropriate reliability level can reduce ownership cost and total cost of the product during the life time (Justino et al., 2012).

In the light of the important role of life cycle costing in decision making this research aims to develop a generic life cycle cost model by considering all the cost elements during a service cycle time.

1.3 Problem Statement

Usually, design and economic justifications have been undertaken as separate projects due to the intrinsic contrary goals. Although they share the aim of producing a competitive product, designing the best possible product is naturally opposite to minimizing costs. Life cycle costing techniques can be used as an effective method to overcome this problem and assist the decision maker and designer to consider economic aspects.

Operation and maintenance costs are among the most important elements of any system life cycle cost analysis. Researches in office building service systems have shown that life cost ratio covers expenses associated with initial capital costs, business operating and maintenance and building operating costs. Furthermore according to these researches during the life of a building, business maintenance and operating costs is possibly up to five times more than capital costs (Wu et al., 2006). Life cycle costing techniques that consider validation costs as one of the cost elements are also useful in reducing the maintenance and operation costs and minimizing total cost during the life cycle of the system.

Increasing reliability level has a significant effect on reducing the cost of corrective maintenance, but at the same time will increase the cost of product validation, so it seems to be necessary to find a target reliability level that minimize the total expected life cycle cost (Kleyner et al., 2004). To reach a high reliability level, it is necessary to perform a large amount of investment in the system. Therefore, the challenge of the system is to find the effect of this additional investment on the other life cycle costs (Justino et al., 2012).

Developing a life cycle costing model which considers all the costs related to the system and their relationship can define the effect of changing in one cost element on other cost elements which can minimize the total life cycle cost of a product or system. Figure 1.1 compares acquisition and operational costs in two systems: the first does not use reliability program and the later uses reliability program.

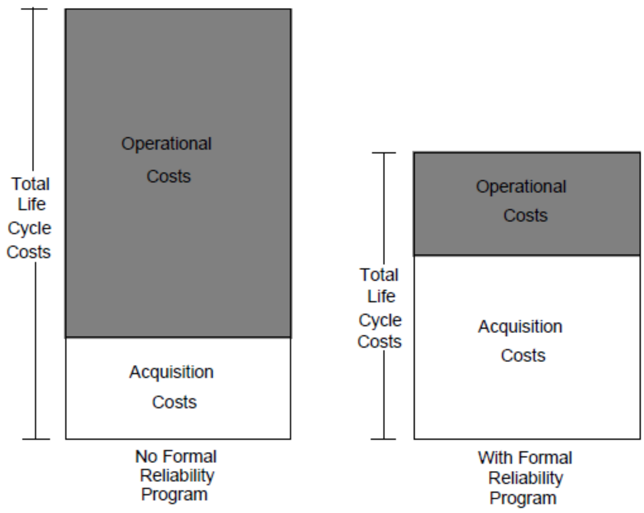

Figure 1.1 Acquisition and operational costs in different reliability policies
Source: Dhudsia, 1997

Most of the product life cycle models investigate in cost of design without considering the product validation cost which is an important cost element and also ignore preventive maintenance cost (Kleyner et al., 2004). This thesis aims to add cost of preventive maintenance to the life cycle cost model which is proposed by Kleyner and Sandborn, (2008). In addition this research intends to use parametric estimation method for predicting validation cost, preventive maintenance cost and corrective maintenance cost.

1.4 Objective of the Study

In order to carry out this project within the scope that is introduced in section 1.5, the objective of the study is:

To develop a generic model for expected life cycle cost for systems with repairable components.

1.5 Scope of the Study

The main focus of this research is on the use of cost breakdown structure and estimation techniques to project all the cost elements of a system with repairable components during its life cycle. Generic mathematical model to find the expected life cycle cost for systems with repairable components is considered by the research. In order to achieve the objective of the study, it involves adaption of a model by Kleyner and Sandborn (2008) by adding cost elements that was not considered in the model and the utilization of MathWorks Matlab R2012 and ReliaSoft Weibull ++8 to solve the mathematical model and to provide sensitivity analysis to overcome the uncertainty related to the random cost elements. An automotive industry factory is selected for the case study.

1.6 Significance of the Study

This study develops a mathematical model based on the cost elements related to systems with repairable components. This model will be used to identify and estimate all the cost elements of a system with repairable components during its life cycle. Furthermore, this model can be used by designer and decision maker in order to make the appropriate decision that can simultaneously minimize the cost during the system life cycle.

1.7 Study Outline

This research is comprised of six chapters. Chapter 1 presents some concepts and background of the study. Moreover, it states the objectives, problem statement, significance of the study, and also summarizes the study outline.

Chapter 2 reviews previous works on the existing methods of life cycle costing. The review starts with the life cycle costing approach and cost variables. Subsequently a brief description of reliability and warranty is presented. Afterwards life cycle cost for building industry is discussed. The existing models reviewed in this research include life cycle cost methodologies and frameworks, economic evaluation methods, cost estimation techniques, uncertainty reduction techniques. Finally a summary of the literature review is provided.

Chapter 3 presents the stages of this research. Furthermore, research methodologies and framework are discussed in this chapter. The overall research procedure is described in detail.

Chapter 4 presents the description and assumption of mathematical model, which can support the research to reach its objective. Model formulation, relevant parameter and variables are discussed in this chapter.

Chapter 5 presents the case example and the case study data for verifying and validating the formulated model. In addition, chapter five offers the results of solving the case example and case study and related discussions by using MathWorks Matlab R2012 software.

Chapter 6 presents the conclusions, limitation of the study, and recommended future research of the present study.

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