TOTAL PRODUCTIVE MAINTENANCE (TPM) AND SOCIO-TECHNICAL ASPECTS FROM MALAYSIAN MANUFACTURING INDUSTRIES PERSPECTIVE

by

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To family,
fiancé,
and friends, with love.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

		Page
PdM	Predictive Maintenance	1
RCM	Reliability-Centred Maintenance	1
TPM	Total Productive Maintenance	1
FMEA	Failure Modes and Effects Analysis	3
OEE	Overall Equipment Effectiveness	10
WCM	World Class Manufacturing	15
HRM	Human Resources Management	15
MRP	Material Resources Planning	15
MP	Maintenance Prevention	17
MI	Maintainability Improvement	17
AM	Autonomous Maintenance	17
JIPM	Japan Institute of Plant Maintenance	18
TQM	Total Quality Management	25
JIT	Just-In-Time	25
EI	Employee Involvement	25
TEEP	Total Effective Equipment Productivity	25
RPN	Risk Priority Number	38
α	Reliability Coefficient: Cronbach's Alpha	63
SMI	Small Medium Industries	72
N	Number of Sent Questionnaires	71
SPSS	Statistical Package for Social Science	64
MITI	Ministry of International Trade and Industry	72
r	Pearson Product-Moment Correlation coefficient	122

LIST OF APPENDICES

LIST OF PUBLICATIONS

1.1 Nurul Shahida Mohd Shalahim, Khairanum Subari, and Shahrul Kamaruddin (2005). A Study on Human Performance Measurement Based on Maintenance Policies and Total Productive Maintenance Using the Matrix Method. Proceedings of the 4th Mechanical Engineering Research Colloquium (MERC 2005/I), [CD Rom] School of Mechanical Engineering, Universiti Sains Malaysia, Penang, Malaysia, 27-29 January, p. 235-242.

1.2 Nurul Shahida Mohd Shalahim, Mazwan Noor, Noor Ain Ibrahim, Khairanum Subari, and Shahrul Kamaruddin (2004). A Preliminary Study on Facility Layout Design Development towards World Class Manufacturing Achievement. 2nd International Engineering Conference (IIEC). December 19-21 2004. Riyadh Kingdom of Saudi Arabia.

1.3 Mazwan Noor, Noor Ain Ibrahim, Nurul Shahida Mohd Shalahim, Khairanum Subari, and Zalinda Othman (2004). Adopting Lean Principles in Planning: A Case Study. 2nd International Engineering Conference (IIEC). December 19-21 2004. Riyadh Kingdom of Saudi Arabia.

PENYELENGGARAAN PRODUKTIF MENYELURUH (TPM) DAN ASPEK-ASPEK SOSIO-TEKNIKAL DARI PERSPEKTIF INDUSTRI PEMBUATAN MALAYSIA

ABSTRAK

Penyelenggaraan adalah suatu fungsi penting dalam sesebuah kilang pembuatan. Kilang pembuatan kini terdedah dengan perubahan paradigma yang baru dan pantas. Strategi penyelenggaraan seperti Penyelenggaraan Produktif Menyeluruh (TPM) harus diberi perhatian yang sewajarnya oleh industri pembuatan. Selain dari itu, aspek sosio-teknikal juga memainkan peranan penting di dalam sesebuah organisasi. Merujuk kepada perkara di atas, kajian ini menyelidik hubungan di antara dua praktis TPM iaitu Penyelenggaraan Autonomi (AM) dan Penyelenggaraan Terancang (PM) dengan sepuluh aspek sosio-teknikal iaitu: [1] keyakinan; [2] daya kepimpinan; [3] komunikasi; [4] motivasi; [5] kerja berpasukan; [6] sikap; [7] latihan; [8] pemberian kuasa; [9] kepunyaan; dan [10] pengkayaan tugasan. Kajian ini dijalankan secara tiga fasa. Pada fasa pertama, tahap pengetahuan dan pemahaman tentang praktis-praktis TPM telah dikaji melalui satu soal-selidik berpos yang dijalankan secara rawak kepada 200 kilang pembuatan di Malaysia. Kadar respon adalah 22.5%. *Spearman Rho Product-Moment Correlation Analysis* telah digunakan untuk ujian hipotesis. Keputusan menunjukkan bahawa tahap pengetahuan dan pemahaman tentang praktis-praktis TPM di kalangan responden adalah dalam kategori sederhana. Walau bagaimanapun, keputusan juga menunjukkan hanya 4.4% daripada responden telah dianugerahkan dengan anugerah *TPM Awards*. Maka ini menunjukkan tuntutan kualiti dalam praktis penyelenggaraan masih lagi jauh ketinggalan. Kekurangan format berstruktur tentang implementasi TPM diandaikan menjadi faktor major terhadap permasalahan di atas. Pada fasa kedua pula, iaitu kajian kes mengenai dua

praktis TPM iaitu AM dan PM dengan sepuluh aspek sosio-teknikal telah dijalankan di dalam sebuah kilang pembuatan yang terpilih berdasarkan markah tertinggi yang diperolehi dan telah dianugerahi dengan anugerah *TPM Awards*. Data diperolehi daripada pekerja-pekerja yang terlibat secara langsung dengan penyelenggaraan mesin melalui kaedah soal-selidik. 30 soalan kaji selidik telah diedarkan kepada pekerja-pekerja terbabit dan kadar respon adalah 83.3%. Keputusan menunjukkan konteks utama, iaitu AM dan PM, mempunyai hubungan korelasi yang penting dengan sepuluh aspek sosio-teknikal yang dikaji. Dalam kedua-dua fasa soal-selidik, data dianalisis menggunakan perisian komputer berstatistik iaitu Statistical Package for Social Science (SPSS) versi 12.0. Setelah data dianalisis dalam fasa kedua, fasa ketiga dijalankan iaitu pembentukan borang Analisis Mod Kegagalan dan Kesan (FMEA). Sebagai keputusannya, borang FMEA direka untuk disesuaikan dengan aspek-aspek sosial-teknikal untuk menambahbaikkan sistem penyelenggaraan di kilang-kilang pembuatan di Malaysia, khususnya.

TOTAL PRODUCTIVE MAINTENANCE (TPM) AND SOCIO-TECHNICAL ASPECTS FROM MALAYSIAN MANUFACTURING INDUSTRIES PERSPECTIVE

ABSTRACT

Maintenance is a vital function in manufacturing industries. Manufacturing industries are exposed to newer and rapidly changing paradigms. A well-conceived maintenance strategy such as Total Productive Maintenance (TPM) should deserve more attention by the manufacturing plants. Apart form that, the socio-technical aspects also play as an important role in the organisations. Referring to the above matter, this study investigates the interrelatedness between two TPM practises; Autonomous Maintenance (AM) and Planned Maintenance (PM) with ten socio-technical aspects which are: [1] confidence; [2] leadership; [3] communication; [4] motivation; [5] teamwork; [6] attitudes; [7] training; [8] empowerment; [9] ownership; and [10] job enrichment. This study was conducted in three phases. In the first phase, the level of knowledge and understanding of TPM practices was investigated via random postal survey of 200 Malaysian manufacturing companies. The response rate was 22.5%. Spearman Rho Product-Moment Correlation Analysis was used for the hypotheses testing. The results showed that the level of knowledge and understanding of TPM practices among the respondents is categorised as average mode. However, the results also showed that only 4.4% of the respondents were certified with TPM Awards certification. Thus, it shows that demanding quality in maintenance practices is still a far cry. Lack of structural format in TPM implementation is the major factor for this state. In the second phase, which is a case study, research on two TPM practices which are AM and PM and ten socio-technical aspects stated above was performed in a manufacturing company. The company was selected based on the highest

marks scored in the respondents rank and is awarded with TPM Awards certification. Data was gained from the employees whose directly involved with machine maintenance by using a questionnaire method. Thirty questionnaires were distributed to the employees and the response rate was 83.3%. The results showed that the main constructs, namely AM and PM are significantly correlated with ten socio-technical aspects studied. In both phases of questionnaire survey, data was analysed using statistical software called Statistical Package for Social Science (SPSS) version 12.0. The third phase which is the evaluation of Failure Modes and Effects (FMEA) form is executed after the data has been analysed in second phase. As for the result, the FMEA form is designed to correspond with socio-technical aspects mentioned above and to enhance maintenance systems in Malaysian manufacturing companies, particularly.

CHAPTER ONE

INTRODUCTION OF THE STUDY

1.0 Introduction

Maintenance is an inevitable function in manufacturing plants. Machine can operate to its maximum capacity by the use of a good maintenance system (Mobley, 1990). Over the past few decades, there are many maintenance policies have been developed and applied in the industrial organisations, for example, Preventive Maintenance, Predictive Maintenance (PdM), and Reliability-Centred Maintenance (RCM). However, most of the earlier policies do not emphasise on the socio-technical aspects. Providentially, the other maintenance policy that highlighted the importance of socio-technical aspects is Total Productive Maintenance (TPM) which is invented by Seiichi Nakajima in the year 1988 (Nakajima, 1988).

TPM is a manufacturing program designed primarily to maximise machine effectiveness throughout its entire life through the participation and motivation of the entire work force (Nakajima, 1988). While research that considers the mathematical modelling and statistical research base of machine maintenance has been extensive (McKone et al., 1999), least research has directly investigated the socio-technical aspects in TPM maintenance activities. McKone et al. (1999) added that TPM addresses machine maintenance through a comprehensive productive-maintenance delivery system covering the entire life of the equipment and involving all employees from production and maintenance personnel to top management.

Thus, this study hypothesises that there are significant relationship between socio-technical aspects and TPM practices in a company. This study investigates the effects of socio-technical aspects which are: [1] confidence; [2] leadership; [3] communication; [4] motivation; [5] teamwork; [6] attitudes; [7] training; [8] empowerment; [9] ownership; and [10] job enrichment on two TPM practices which are: [1] autonomous maintenance; and [2] planned maintenance. Socio means the study of the relationship between people living in groups. Thus, this research focuses on human behaviour towards TPM practices. Socio-technical is one of the crucial aspects in leading a good performance in manufacturing industries (Emery, 1990). Cua et al. (2001) also added that socio-technical aspects should be optimised to achieve the best possible performance.

This study proposes a theoretical framework integrating the abovementioned variables which are TPM and socio-technical aspects in an attempt to show how these two constructs depend on each other. It also explores the mediating role of each of socio-technical aspect in the relationship between each of the two TPM practices. Specifically, this study will provide a model in which the socio-technical aspects as intervening variables to help maximising the better TPM in one company. The main claim of this study is that socio-technical aspects will enhance the Total Productive Maintenance activity in a company.

The other main part of this research is to find a systematic way to documenting the socio-technical aspects that affect TPM activities. This research suggests the Failure Modes and Analysis Techniques (FMEA) to documenting the socio-technical aspects. This research studies the conventional FMEA technique to evaluate a new form to document the critical aspects of socio-technical in manufacturing plants.

This chapter generally contains the following subchapters: an overview of the originality of the research, followed by the discussion of the research problem, problem definition, objectives of the study, scope of the study, assumptions, research limitations, the significance and justification of the study, and the definitions and descriptions of terminologies used throughout this thesis. Finally, the disposition of this thesis is written at the end of this chapter.

1.1 Originality of the Research

According to Phillips and Pugh (2000) cited by Ahmad (2003), originality can comprise of any one or more of the following items:

i) Carrying out empirical work that hasn't been done before.

This study is the first empirical work in examine the linkage between TPM activities and socio-technical aspects.

ii) Taking a particular technique and applying it in a new area.

This study uses the widely used Failure Modes and Effects Analysis (FMEA) but with a new approach; which uses the socio-technical aspects as the functions in the form.

iii) Trying out something in this country that has previously only been done in other countries.

TPM is a broad study which has been done in several countries such as United Kingdom, United States, Japan and Nigeria; but still new in Malaysia.

iv) Looking at areas the people in the discipline haven't looked at before.

TPM is a broad study, but there is no research that examines TPM activities and socio-technical aspects in Malaysia, so far.

v) Adding to knowledge in a way that hasn't been done before.

This study is adding knowledge to the researchers in the same and different field.

1.2 Discussion of the Research Problem

The problem investigated in this study can be viewed from several dimensions. The maintenance departments are having maintenance failures according to previous researches and studies as discussed as follows.

In the UK, industry spends £14 billion on maintenance, 1/5 of the total value of all plant and equipment, to which must be added the cost of maintenance failures, usually downtime following breakdowns, and quality failures because equipment wasn't properly set up by the maintenance crew (Tudor, 1994).

The study by Thilander (1992) shows that the productivity of the companies is positively influenced by the well-defined areas of responsibility, of appointing one individual who holds the overall responsibility for the maintenance of a machine line, and of establishing direct contact between the operators and maintenance technicians.

A study by Chan et al. (2003) at a manufacturing company in Hong Kong shows that maintenance problem such as: [1] frequent problem repetition, [2] insufficient proactive maintenance, [3] paucity of predictive maintenance occurred because of several reasons

and one of the reasons is that the operator is not being responsible for the ultimate care of his/ her equipment.

Based on the previous researches stated above, it is clear that one of the reasons of the maintenance problems occurrence is because of human or maintenance crew's behaviour. Thus, the question then arises: Do socio-technical aspects affect maintenance activities, or in particular concern, TPM activities?

1.3 Problem Definition

Problem definition or problem statement is a clear, precise and succinct statement of the question or issue that is to be investigated with the finding of an answer or solution. Sekaran (2000) also added that problem definitions could pertain to: [1] existing business problems where a manager is looking for a solution; [2] situations that may not pose any current problems but which the manager feels can stand improvement; [3] areas where some conceptual clarity is needed for better theory building; or [4] situations in which a researcher is trying to answer a research question empirically because of interest in the topic. Thus, this study is focused on the fourth definition of the problem statement criteria. Hence, the main problem statement for this study is: *Do socio-technical aspects affect the TPM activity in a company?*

However, on the basis of extensive reviews on literatures and articles and the problem statement, the following research questions have been proposed related to Malaysian manufacturing companies and then will be investigated using the empirical data. The main objective of this study is to answer these questions, which are stated as follows:

Question 1: Is there a significant relationship between the autonomous maintenance and planned maintenance in a company?

Question 2: Is there a significant relationship between autonomous maintenance and socio-technical aspects in a company?

Question 3: Is there a significant relationship between planned maintenance and socio-technical aspects in a company?

1.4 Objectives of the Study

According to the problem definition defined in Section 1.3 above and the questions of the study, thus this study seeks to achieve the above objectives:

i) To explore the interrelatedness between autonomous maintenance and planned maintenance in Malaysian manufacturing industries.

ii) To explore the interrelatedness between autonomous maintenance and socio-technical aspects in Malaysian manufacturing industries.

iii) To investigate the interrelatedness between planned maintenance and socio-technical aspects in Malaysian manufacturing industries.

iv) To evaluate a new designed FMEA form to document the socio-technical aspects that affect the TPM activities in Malaysian manufacturing industries.

1.5 Scope of the Study

This study investigates the effects of ten widely studied socio-technical aspects which are employee's : [1] confidence; [2] leadership; [3] communication; [4] motivation; [5] teamwork; [6] attitude; [7] training; [8] empowerment; [9] ownership; and [10] job enrichment on two TPM practices which are: [1] autonomous maintenance; and [2] planned maintenance. Regarding to this, for a preliminary data gathering, i.e. the first

phase of questionnaire, a simple random sample of the Malaysian manufacturing companies was chosen from the SIRIM Directory 2004 for certified products and companies for this study. However, for the second phase questionnaire, the best practice company from the previous phase is selected. The best company scores the highest rank in the level of understanding and knowledge of TPM and has been awarded with TPM Awards which is a maintenance systems award from the first phase survey.

1.6 Assumptions of the Study

The following assumptions were taken into account in this study:

i) The respondents to the questionnaire have in-depth knowledge of maintenance activities in their companies.

ii) The perception of the respondents is representative of their organisation (Amjad, 2005).

iii) The respondents are answering the questionnaire based on their daily maintenance routine.

iv) It is assumed that the respondents are able and willing to provide accurate responses to the questions asked which is consistent with the assumption (Carr et al., 1997).

1.7 Research Limitations

There will always be limitations and weaknesses in any study, the same goes for this study. It is necessary to evaluate the study in the context of its limitations after the study has been completed. Hence, the refinement to the study could be made in the future. Thus, it can be argued that this study has some limitations as follows:

i) The limited sample size even though comparable with several studies (Shah and Ward, 2003; Sohail and Hoong, 2003; Zadry, 2004). This limitation usually means that the results of the findings cannot be generalised to the rest of the population, or to other population. However, according to Ahmad (2003), this in itself is not critical and the fact that the lack of external validity is a rather common limitation among the empirical studies.

ii) The survey was conducted during the first half of 2005. The sample data used in this study was therefore a cross sectional study. It does not account for changes over time. Several studies suffered from this limitation such as (i.e. Suwignjo et al. 2000; Rahman and Bullock, 2004).

iii) This study focuses on socio-technical aspects which studies the human behaviour, thus it is not always possible to conduct investigations that are 100 percent scientific, in sense that the results will not be exact and error-free. This is primarily because this study encounters with the collection of data in the subjective areas of perceptions and attitudes. However, still, to the extent that this study is designed to ensure the objectivity, precision and confidence, nevertheless this study has endeavoured to engage in scientific investigation.

iv) This study was conducted in one country only, which is Malaysia. Thus, the results of this study must be treated with caution and the generalisation is limited. In particular, the representative of one country will be called into question despite the several of countries.

v) There are also issues with self-reported performance data and possible single respondent bias. This is comparable with Shah and Ward (2003).

1.8 The Significance and Justification of the Study

This study is expected to contribute to the theory and practice of TPM and socio technical aspects. The proposed questions in this study are important for at least four reasons.

Firstly, this study explores the effects of the implementation of the two practices of TPM which are autonomous maintenance and planned maintenance on the companies' maintenance systems. In other words, these two practices will affects Malaysian companies to achieve better maintenance systems in terms of reducing machine's breakdowns, and other machines losses.

The second significant aspect of this study is related to the country to be studied. Most of the studies in both TPM practices and socio-technical aspects have been carried out in the western countries and Japan. Little research on TPM practices and socio-technical aspects are conducted in Asian countries, and to this study particular concern, in Malaysia as well.

Thirdly, this study is vital because it discusses and assesses the effects of socio-technical aspects on TPM practices in one company. The link between TPM practices and socio-technical aspects is represented by the proposed theoretical framework. Furthermore, this study is necessary since there are so many previous researches study the importance of TPM in one company.

Fourthly, this study discusses the importance of TPM practices itself. This study also list down all the reasons why most of the companies have abandoned the TPM practices. Hence, it is hope that this study will an 'eye opener' to the Malaysian

manufacturing companies, that maintenance is one of the important aspects to their companies.

It is hope that this study can contribute to the body of knowledge on TPM practices and socio-technical aspects as a whole. It is also hope that Malaysian companies will start to adopt the best new tools, techniques and practices in maintenance systems. Therefore, this research intends to contribute in the accumulated knowledge is this topic of research in the manufacturing industry.

1.9 Definitions and Descriptions of Terminologies

Following are the definitions and descriptions of terminologies that have been used in this study shown in Table 1.1.

Table 1.1 Definitions and Descriptions of Terminologies

Terminology	Definitions and Descriptions	Author(s)
Total Productive Maintenance (TPM)	A maintenance concept aimed at continuously decrease the equipment losses and to improve the availability.	Nakajima (1988); Rodriguez (1990); Sherwin (1999).
The Pillars of TPM	There are five pillars which underpin TPM; [1] attack upon the six big losses and improvement in OEE; [2] planned maintenance; [3] autonomous maintenance; [4] training and education; and [5] preventive maintenance.	Nakajima (1988).
Six Big Losses	The six big losses are the machine losses which are: [1] breakdown losses; [2] set-up and adjustments losses; [3] minor stoppage losses; [4] speed losses; [5] quality defect and rework losses; and [6] yield losses.	Tajiri and Gotoh (1992).
Overall Equipment Effectiveness (OEE)	An effective measurement to analyse the efficiency of a single machine or an integrated manufacturing system; and it is a function of machine's availability, performance rate, and quality rate.	Nakajima (1988).

Table 1.1 ... continued

Terminology	Descriptions	Author(s)
Planned Maintenance	A maintenance system which is performs on the machine at a scheduled time regardless of its actual state of deterioration.	Eti et al. (2004).
Autonomous Maintenance	A maintenance system which consists of the activities that carried out by operators with the technical assistance of maintenance crew.	Tajiri and Gotoh (1992).
Training and Education	A system to expose the maintenance and production staff to the new ways to deal with corporate physical assets.	Nakajima (1988).
Preventive Maintenance	A maintenance system to reduce maintenance costs and deterioration losses in new machine considering past maintenance data and the use of the latest technology when designing for higher reliability, maintainability, operability, safety, and other requirements.	Nakajima (1988).
Socio-technical	Socio-technical is one of the crucial aspects in leading a good performance in manufacturing industries.	Emery (1990).
Confidence	Confidence is measured by the employee's trust towards the machines that they operate and the maintenance system in the organisation.	Bisantz and Seong (2001).
Leadership	A process of giving purpose (meaningful direction) to collective effort and causing willing effort to be expended to achieve purpose.	Jacobs and Jaques (1990).
Communication	The process of a sender transmitting a message to a receiver with mutual understanding.	Lussier (1996).
Motivation	The term motivation means the internal process leading to behaviour to satisfy needs.	Lussier (1996).
Teamwork	Teamwork is two or more employees interacting to achieve an objective.	Lussier (1996).
Attitudes	A strong belief or feeling toward people, things, and situations.	Lussier (1996).
Training	Training is the systematic modification of behaviour through learning which occurs as a result of education, instruction, development, and planned experience.	Armstrong (1999).
Empowerment	Empowerment simply means giving the authority to make decisions to that level or place in the organisation which, by virtue of available knowledge and closeness to the activity concerned, is most able to make a correct, quick, and effective decision.	Kruse (1995).

Table 1.1 ... continued

Terminology	Descriptions	Author(s)
Job Enrichment	A process to increase the motivation and satisfaction of the employees and improve productivity in the process.	Hackman et al. (1975).
A Technique	Set of tools which has wider applications.	McQuater et al. (1995).
Failure Modes and Effects Analysis (FMEA)	A systematic technique using engineering knowledge, reliability, and organisational development techniques; in other words, teams to optimise the system, design, process, product, and/ or service.	Stamatis (1991).
Continuous Improvement	The never-ending pursuit of excellence.	Saylor (1996).

1.10 Thesis Disposition

This thesis contains seven chapters and is organised as follows. Chapter One describes about the study briefly. It provides an overview of the origins of the research, the problem statement, objectives of the study, scope of the study, assumptions, research limitations, the significance and justification of the study, definitions and descriptions of terminologies and finally thesis disposition.

Chapter Two provides rigorous literature reviews related to the variables of interest, which is Total Productive Maintenance which presented into two main activities which are autonomous maintenance and planned maintenance, and their association with socio-technical aspects, which are [1] confidence, [2] leadership, [3] communication, [4] motivation, [5] teamwork, [6] attitudes, [7] training, [8] empowerment, [9] ownership, and [10] job enrichment. Furthermore, this chapter also discusses the theories on two main Total Productive Maintenance activities which are autonomous maintenance and planned maintenance and how they are influenced by the socio-technical aspects that stated above. Theoretical framework proposed for this study is also presented in this chapter.

The third chapter describes the details of the research methodology used for the study. Chapter Three also includes the research design, data collection methods, survey instruments, assessment of measurement and statistical techniques used for inference of this study.

Chapter Four on the other hand discusses the findings of the first phase questionnaire. It includes the analysis of the respondent's background, descriptive statistics and the results of hypotheses testing using Spearman Rho Product-Moment Correlation Analysis.

Chapter Five presents the findings of the second phase questionnaire which is a case study in a company in Penang, Malaysia. The company for the case study was chosen based on the highest score in respondent rank that has been depicted in Chapter Four. The data obtained are the background of the company, TPM practices which are AM and PM and the socio-technical aspects that affect those two TPM practices.

Chapter Six discusses the FMEA approach used in this study. The developed FMEA in this study will be used to verify all the critical socio-technical aspects in the company. The FMEA is an important technique for evaluating the design and documenting the review process. All credible failure modes and the resultant effects of socio-technical aspects are identified and documented.

Chapter Seven presents the conclusions and recommendations for the future research. The developed framework based on the results is also been discussed in this chapter. Finally, the contributions of the study in term of theoretical and practical contributions have also been comprised in Chapter Seven.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The purpose of this chapter is to review the related literature on the maintenance concept and evolution. Nevertheless, this chapter emphasises literatures on TPM. Furthermore, Chapter Two also discusses the entire literature on socio-technical aspects. The definition, history, concepts, and components of FMEA are reviewed in the last section. This literature review provided the basis for designing and developing the research instruments and final analysis. The initial sources of this chapter came from books, journals, dissertations, proceedings, and information from the websites. The structure of this literature is illustrated in Figure 2.1.

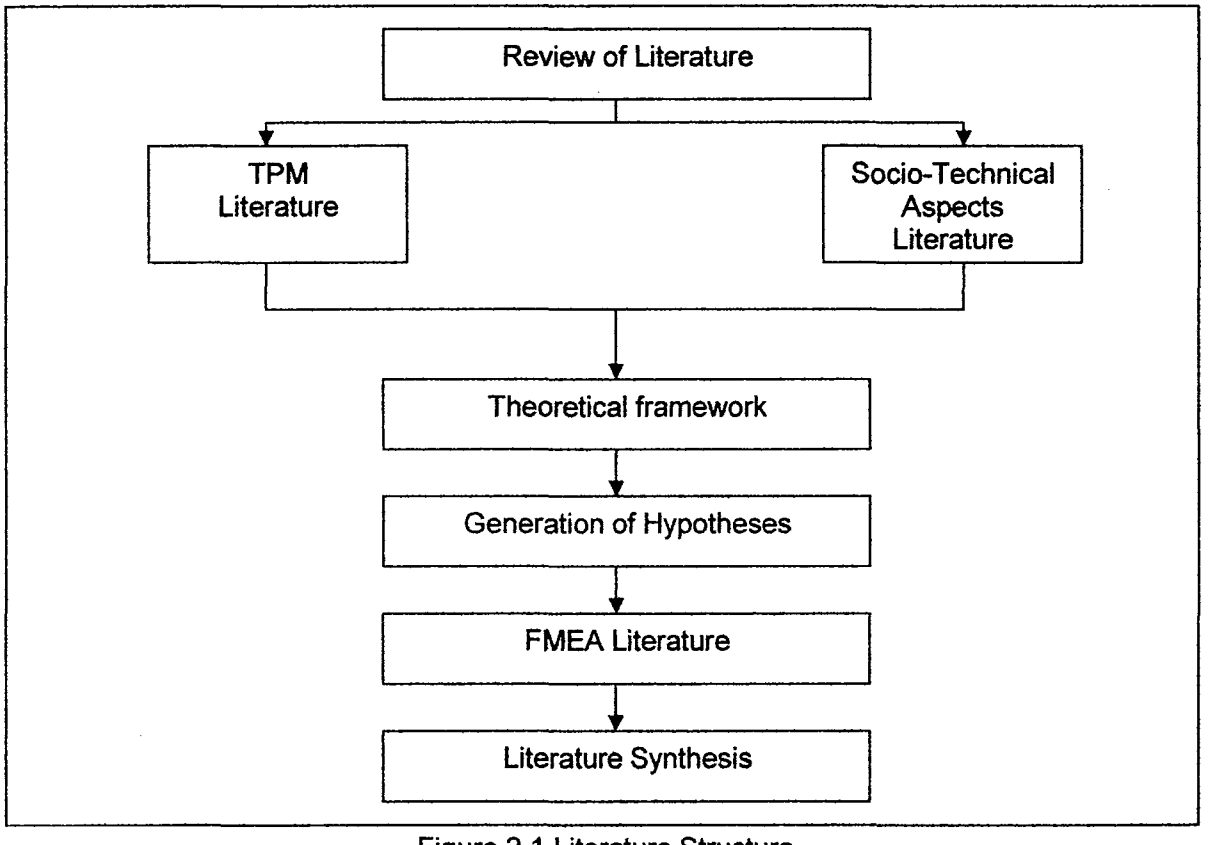
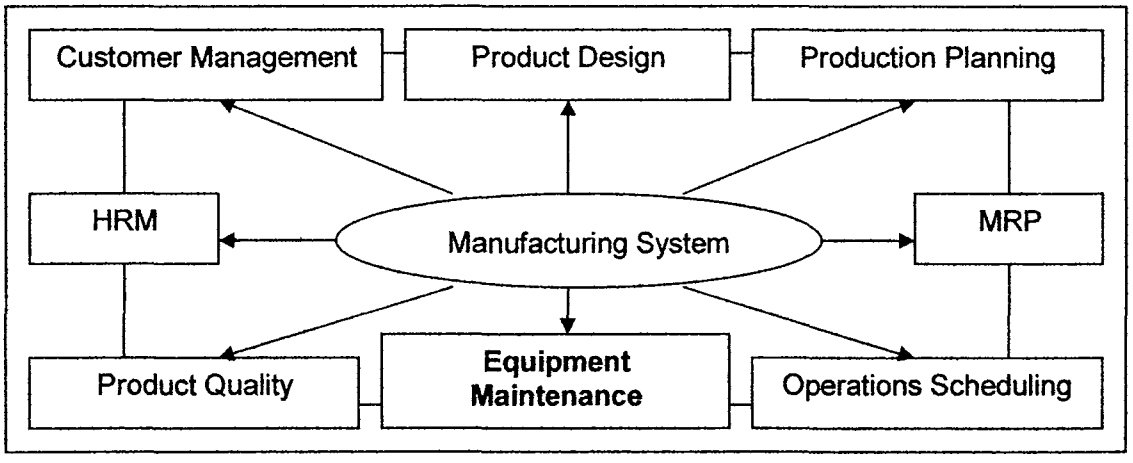


Figure 2.1 Literature Structure

2.1 Maintenance Concept

Maintenance is not an expense; it is an investment in improved manufacturing (Katila, 2000). Investment in maintenance, one of the basic functions of a firm, returns improved quality, safety, dependability, flexibility, and lead times (Teresko, 1992). Over the past few decades, there has been increased recognition that in a World Class Manufacturing (WCM), maintenance is not a separate, isolated function that makes repairs and performs assorted activities as needed (Katila, 2000). Katila (2000) also quoted Ettiene-Hamilton (1994), that maintenance is a full partner striving together with other functions to achieve the company's strategic goals.

Ahmed et al. (2002) added that maintenance is a major contributor to the performance and profitability of manufacturing systems (Figure 2.2). Its importance is increasing as there are increasing trends towards automation and integration of manufacturing systems, i.e., installation of advanced manufacturing technology (Maggard and Rhyne, 1992) Good maintenance is fundamental to a productive manufacturing (Besterfield et al., 1999) to discover a lot of potential working hours, and to reduce costs.



HRM = Human Resources Management;MRP = Material Resources Planning

Figure 2.2 Manufacturing Functional Areas

2.1.1 Maintenance Evolution

According to Deshpande and Modak (2002), the evolution of maintenance can be traced through three generations since 1930s as follows:

i) First Generation

It covers the period up to World War II. Industry was not highly mechanised, equipment was simple and over designed. Hence, the maintenance was easy, and the need for skills was also lower.

ii) Second Generation

By 1950s, due to increased mechanisation, complex machines were involved. Hence, concept of preventive maintenance was introduced. In 1960s, this consisted of mainly equipment overhauls at regular intervals. Maintenance planning and control systems were developed to control the maintenance costs.

iii) Third Generation

Since the mid-1970s, the changes in industry have gathered momentum and it is revealed that the six big losses (discussed in Section 2.2.1) actually occur in practice, hence, TPM was introduced.

Table 2.1 Maintenance Evolution

Generation	Maintenance Policy	Descriptions
First generation (1930s, 1940s)	Corrective Maintenance	Fix it when it broke
Second generation (1950s, 1960s)	Preventive Maintenance based on bathtub curve theory	Higher plant availability Longer equipment life Lower costs
Third generation (1970s, 1980s, 1990s, 2000s)	Condition monitoring, TPM RCM	Higher plant availability Greater safety and effectiveness Better product quality

2.2 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a maintenance programme which is developed in Japan by Seiichi Nakajima. According to Nakajima (1988) cited by Chan et al. (2003), the word 'total' in TPM has three meanings:

i) Total effectiveness indicates TPM's pursuit of economic efficiency and profitability.

ii) Total maintenance system includes Maintenance Prevention (MP) and Maintainability Improvement (MI), as well as PM. Basically, this refers to 'maintenance-free' design through the incorporation of reliability, maintainability, and supportability characteristics into the equipment design.

iii) Total participation of all employees includes autonomous maintenance (AM) by operators through small group activities. Essentially, maintenance is accomplished through a 'team' effort, with the operator being held responsible for the ultimate care of his/ her equipment.

There are so many benefits of the TPM implementation in one company, such as follows:

i) Increased productivity (Carannante and Haigh, 1996; Roberts, 1997; Chan et al., 2000; Al-Hassan et al., 2000).

ii) Machine's breakdowns occur rarely (McKone et al., 1999; Chand and Shirvani; 2000; Portela, 2000; Willmott and McCarthy, 2001; Chan et al., 2003).

iii) Cleanliness and pride improves the working environment (Carannante and Haigh, 1996; Roberts, 1997; Chan et al., 2000).

As can be seen, there are many benefits gained from TPM implementation in one company. TPM can also reduce equipment losses by investing in people who can then improve equipment availability, improve product quality, and reduce labour costs (Takashi, 1989). TPM system requires all employees working in autonomous small group to work together to eliminate equipment breakdown (Nakajima, 1989). Everyone is involved since every component of the manufacturing systems, including operations, product design, process design and management, impacts equipment maintenance (Nakajima, 1989).

2.2.1 History of TPM

Total Productive Maintenance (TPM) policy can be traced back its originality in the year of 1960s in Japan. Seiichi Nakajima, vice-chairman of the Japanese Institute of Plant Engineers (JIPE), the predecessor of the Japan Institute of Plant Maintenance (JIPM), promoted TPM throughout Japan and has become known as the father of TPM (McKone et al., 1999). In 1971, TPM was defined by JIPE as follows:

"TPM is designed to maximise equipment effectiveness (improving overall efficiency) by establishing a comprehensive productive-maintenance system covering the entire life of the equipment, spanning all equipment-related fields (planning, use, maintenance, etc.) and, with the participation of all employees from top management down to shop floor workers, to promote productive maintenance through motivation or voluntary small-group activities" (Tsuchiya, 1992).

To eliminate waste, Toyota was the first company to implement TPM (Nakajima, 1989). Toyota measures six categories of equipment losses throughout its production system. The six losses then were combined into one measure of overall equipment effectiveness (OEE). These are (Fredendall, 1996): [1] equipment failure; [2] setup and

adjustment; [3] idling and minor stoppages; [4] reduced speed; [5] defects in the process; and [6] reduced yield.

In the year 1995, there were about 800 companies or company units using the TPM in Japan (Johansson, 1996). Also the European companies have started to apply TPM (Katila 2000). One of the very first has been the Swedish car manufacturer Volvo in the Gent factory in Belgium.

2.2.2 Pillars of TPM

According to the inventor of TPM, Seiichi Nakajima (1988), TPM has five pillars as shown in Figure 2.3. However, this study only focuses on the two pillars which are autonomous maintenance and planned maintenance.

i) Pillar 1: An attack upon the six big losses and improvement in overall equipment effectiveness (OEE).

ii) Pillar 2: Planned maintenance that consists of scheduled planned inspections and service and entails major planned restoration of machine during a works shutdown phase.

iii) Pillar 3: Establish autonomous maintenance.

iv) Pillar 4: Training and education, which is the centre of TPM, with maintenance and production staff exposed to new ways of dealing with corporate physical assets.

v) Pillar 5: Continuous improvement in machine improvement and maintenance prevention which the goal is to reduce maintenance costs and deterioration losses.

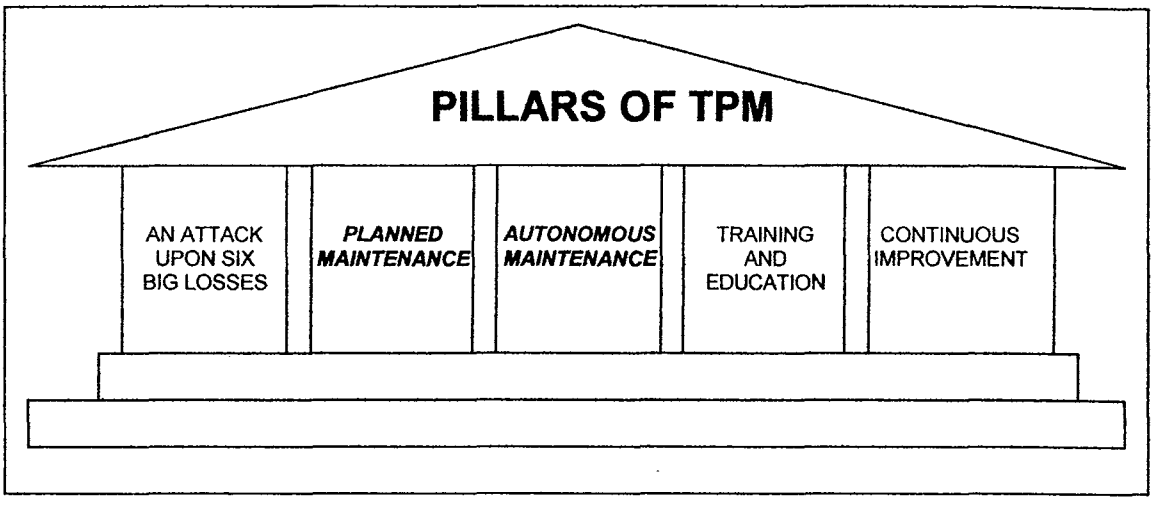


Figure 2.3 Pillars of TPM

2.2.2.1 Autonomous Maintenance

According to McKone et al. (1999), to achieve the goals of autonomous maintenance, it is obvious that the programme must involve teams of production and maintenance people, daily activities to maintain the condition of the equipment, cross-training to improve operator skills, and participation of operating personnel in the maintenance delivery process. The summary of each goal is presented in Table 2.2.

Table 2.2 Summary of Autonomous Maintenance Goals
Source: McKone et al. (1999)

Objective	Descriptions	Author(s)
Housekeeping (5S activities)	Housekeeping tasks include cleaning and inspecting, lubrication, precision checks, and other light maintenance tasks and can be broken into five S's: [1] *Seiri* (Organisation); [2] *Seiton* (Tidiness); [3] *Seiso* (Purity); [4] *Seiketsu* (Cleanliness); and [5] *Shitsuke* (Discipline). After these tasks are transitioned to operators, maintenance people can focus on developing and implementing other proactive maintenance plans.	1. Nakajima, 1988. 2. Tajiri and Gotoh, 1992. 3. Suzuki, 1992.

Table 2.2 ... continued

Objective	Descriptions	Author(s)
Cross-training	Cross-training allows operators to maintain equipment and to identify and resolve many basic equipment problems. TPM is designed to help operators learn more about how their equipment functions, what common problems occur and why, and how those problems can be prevented through early detection and treatment of abnormal conditions.	1. Nakajima, 1988. 2. Suzuki, 1992. 3.Tajiri and Gotoh, 1992.
Teams	The objective of the teams is to stabilise conditions and deterioration of equipment.	1. Nakajima, 1988. 2. Suzuki, 1992.
Operator Involvement	This is to prepare operators to become active partners with maintenance and engineering personnel in improving the overall performance and reliability of the equipment.	1. Tajiri and Gotoh, 1992.

2.2.2.2 Planned Maintenance

According to Nakajima (1988), cited by McKone et al. (1999), planned maintenance typically involves the work conducted by highly skilled maintenance technicians. As more tasks are transferred to operators through autonomous maintenance, the maintenance department takes a more proactive approach to maintenance and is able to develop a disciplined planning process for maintenance tasks, such as equipment repair or replacement, and on determining countermeasures for equipment design weakness. Typically, strong planning departments also have good information tracking systems that enable them to capture the process data, gather and disseminate data to operators, and identify trends or problems with equipment (Suzuki, 1992).

2.2.2.3 Attack upon the Six Big Losses

TPM is designed to eliminate the 'six big losses' and thereby to improve the effectiveness of the equipment (Tajiri and Gotoh, 1992). The 'six big losses' of the

equipment are: [1] breakdown losses; [2] setup/ adjustments losses; [3] idling and minor stoppages; [4] reduced capacity losses; [5] quality problems; and [6] startup/ restart losses.

2.2.2.4 Training and Education

Training and education are the systematic modification of behaviour through learning which occurs as a result of education, instruction, development, and planned experience (Armstrong, 1999).

2.2.2.5 Continuous Improvement

In this kind of maintenance policy, machines are replaced or restored to their optimal working condition before a failure is allowed to occur and it is widely accepted that it reduces random breakdowns, and unplanned downtime of facilities (Gupta et al. 2001).

2.2.3 Review of TPM Literatures

Numerous books on TPM have presented TPM improvement activities in plants and suggested steps for TPM implementation based on case studies (Hartmann, 1992; Suzuki, 1992; Tsuchiya, 1992; Tajiri and Gotoh, 1992; Varughese, 1993; Steinbacher and Steinbacher, 1993; Shimbun, 1995). According to McKone et al. (2000), the researches that consider the mathematical modeling and statistical research base of equipment maintenance have been extensive (McCall, 1965; Pierskalla and Voelker, 1976; Valdez-Flores and Feldman, 1989; Shaked and Shanthikumar, 1990). However, little research has directly investigated TPM activities. Table 2.3 depicts some of the studies that discussed the TPM implementation with respect to the various issues.

Table 2.3 TPM Literatures and Their Appearance in Key References

TPM Category	TPM Literature	Sources														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Implementation	Implementation	*		*				*	*	*			*			
	Comparison between different countries	*							*				*			
	Understanding of TPM concept	*						*					*		*	*
	Improvement activities	*												*	*	*
Benefits Gained	Overall Equipment Effectiveness (OEE)													*		
	Autonomous Maintenance	*													*	
	Planned Maintenance	*									*			*		
	Six big losses										*	*			*	
	Costs			*					*				*			
Difficulties	Abandonment				*	*	*									
	Difficulties in implementation			*	*	*	*	*								
	Satisfaction level		*								*	*				
Mathematical and Statistical Studies	Machine reliability and statistical											*				*
	Contextual issues	*	*													
	Mathematical modeling	*	*													

(1) McKone et al. (1999)
(2) Cua et al. (2001)
(3) Chan et al. (2003)
(4) Adam et al. (1997)
(5) Co et al. (1998)
(6) Jostes and Helmes (1994)
(7) Chand and Shirvani (2000)
(8) Carannante and Haigh (1996)
(9) Eti et al. (2004)
(10) Ahmed and Hassan (2002)
(11) Miyake et al. (1995)
(12) Wireman (1991)
(13) Shah and Ward (2002)
(14) Nakajima (1989)
(15) Suzuki (1992)

Table 2.3 shows the previous researches on TPM. Several studies have been done on TPM implementation (McKone et al., 1999; Chan et al., 2003; Chand and Shirvani, 2000; Carannante and Haigh, 1996; Eti et al., 2004; Wireman, 1991; and Al-Hassan et al., 2000). Their studies show that implementing TPM in ones company can give great benefits in terms of productivity and equipment effectiveness. Appropriate implementation of TPM offers tremendous potential in improving, not only the equipment efficiency and effectiveness, but in areas of quality, flexibility, and employee-work friendliness as well. Besterfield et al. (1999) wrote, "TPM is keeping the current plant and equipment at its highest productive level through cooperation of all areas of an organisation".

However, there are several studies present the difficulties in TPM implementation as in Chan et al., 2003; Adam et al., 1997; Co et al., 1998; Jostes and Helmes, 1994; Chand and Shirvani, 2000; and McAdam et al., 1996. Their studies show several difficulties in TPM implementation such as: [1] lack of management support; [2] lack of resources; [3] lack of structural format in TPM implementation; [4] TPM is a time-consuming programme which take two to three years to give the benefits to the company; and [5] TPM is a money-consuming maintenance programme.

Consequently, there are researches which compare the effectiveness of TPM programme between different countries (McKone et al., 1999; Carannante and Haigh, 1996; Wireman, 1991; and McAdam et al., 1996. For example, the study by Carannante and Haigh (1996) shows that Japanese manufacturing plant have better TPM programme compared to the manufacturing plants in the United Kingdom. The study also shows that Italian plants are in the third place after Japan and the UK plants. It is probably because