MAINTENANCE MANAGEMENT PERFORMANCE OF MALAYSIAN PALM OIL MILLS

NAZIM BALUCH

DOCTOR OF PHILOSOPHY
UNIVERSITI UTARA MALAYSIA
August 2012

MAINTENANCE MANAGEMENT PERFORMANCE OF MALAYSIAN PALM OIL MILLS

By

NAZIM BALUCH

Thesis Submitted to
Othman Yeop Abdullah Graduate School of Business
Universiti Utara Malaysia
In Fulfillment of the Requirement for the Degree of Doctor of Philosophy

CERTIFICATION OF THESIS

"I hereby verify that this thesis is my own work except for those reviews for which I have discussed the sources"

09 August 2012

Nazim Baluch
(Metric # 92963)

PERMISSION TO USE

In presenting this thesis in fulfillment of the requirements for a Post Graduate degree from the Universiti Utara Malaysia (UUM), I agree that the Library of this university may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or in their absence, by the Dean of Othman Yeop Abdullah Graduate School of Business where I did my thesis. It is understood that any copying or publication or use of this thesis or parts of it for financial gain shall not be allowed without my written permission. It is also understood that due recognition given to me and to the UUM in any scholarly use which may be made of any material in my thesis.

Request for permission to copy or make other use of materials in this thesis in whole or in part should be addressed to:

Dean of Othman Yeop Abdullah Graduate School of Business
Universiti Utara Malaysia
06010 UUM Sintok
Kedah Darul Aman

ABSTRACT

Performance of an organization should be appraised simultaneously, both in terms of its efficiency in resource utilization process and effectiveness in realizing the pre-determined goals. Measuring performance provides the required information to the management for effective decision making and is used by industries to assess progress against set goals and objectives in a quantifiable way. Deficient maintenance management can severely affect competitiveness of an organization by reducing throughput, increasing inventory, and leading to poor performance. Applying Overall Equipment Effectiveness, this research study, has evaluated maintenance management performance in Malaysian palm oil mills, highlighted how it helps to identify the factors causing poor performance and demonstrates how to improve and perpetuate company's productivity, profits, and sustainability by adopting world class maintenance strategies such as Total Productive Maintenance. This research study supplicated data by mail survey questionnaire sent to all Malaysia palm oil mills, validated data through triangulation, and analyzed using descriptive statistics. The research exalts practitioner's perspective and has determined that Scientific Management Theory axioms and Total Productive Maintenance principles are not being applied to optimize productivity in palm oil mills. The research also identified theory and practice gaps pertinent to maintenance management in palm oil mills and provided shop-level solutions to bridge those gaps. Research findings established how efficient and effective maintenance management offers, besides substantial cost savings, a wide scope of improvements for the palm oil industry. In order to ensure competitiveness and sustainability in the 21^{st} century, it is obligatory for Malaysian palm oil mills to adopt best management practices in processing, manufacturing and maintenance.

Key Words: Maintenance management, Total Productive Maintenance, Measuring performance, Overall Equipment Effectiveness, Scientific Management Theory

ABSTRAK

Prestasi sesebuah organisasi perlu dinilai secara serentak, kedua-duanya dari segi kecekapan dalam proses penggunaan sumber dan keberkesanan dalam merealisasikan matlamat yang telah ditentukan. Pengukuran prestasi memberi maklumat yang diperlukan kepada pihak pengurusan untuk pembuatan keputusan yang berkesan dan ia digunakan oleh pihak industri untuk menilai pencapaian berbandingkan matlamat dan objektif yang ditetapkan dengan cara yang boleh diukur. Pengurusan penyelenggaraan yang lemah boleh menjejaskan daya saing sebuah organisasi dengan mengurangkan pengeluaran, meningkatkan inventori, dan menyebabkan prestasi yang merosot. Dengan menggunakan Keberkesanan Peralatan Keseluruhan, kajian penyelidikan ini telah menilai prestasi pengurusan penyelenggaraan dan menengahkan cara ia boleh membantu mengenal pasti faktor yang menyebabkan prestasi yang lemah dan memberi peluang untuk mengekalkan dan meningkatkan produktiviti, untung, dan kelestarian sebuah syarikat dengan mengguna pakai strategi penyelenggaraan bertaraf dunia seperti Penyelenggaraan Produktif Keseluruhan. Kajian telah memperolehi data melalui borang soalselidik yang dihantar kepada semua kilang minyak sawit di Malaysia, mengesahkan data melalui penyegitigaan, dan menganalisis data menggunakan statistik deskriptif. Penyelidikan ini meninggikan perspektif pengamal dan telah menentukan bahawa teorem Teori Pengurusan Saintifik dan prinsip Penyelenggaraan Produktif Keseluruhan tidak dilaksanakan untuk mengoptimumkan produktiviti di kilang minyak kelapa sawit. Kajian ini telah mengenal pasti jurang antara teori dan amalan yang penting untuk pengurusan penyelenggaraan di kilang minyak kelapa sawit dan menyediakan penyelesaian tahap-kedai untuk merapatkan jurang tersebut. Penemuan penyelidikan telah menunjukkan bagaimana pengurusan penyelenggaraan yang cekap dan berkesan boleh memberi, selain penjimatan kos yang besar, penambahbaikan dalam skop yang agak luas bagi industri minyak sawit. Bagi memastikan daya saing dan kelestarian industri minyak kelapa sawit di abad ke-21, ianya satu kewajipan untuk kilang minyak sawit di Malaysia menerima pakai amalan pengurusan terbaik dalam pemprosesan, pembuatan, dan penyelenggaraan.

Kata Kunci: Pengurusan Penyelenggaraan, TPM, OEE, SMT

ACKNOWLEDGEMENTS

First and foremost, I am highly grateful to God Almighty for blessing me with the strength, honor, and encouragement to complete this PhD.

I would like to express my gratitude and sincere thanks to my advisors: Prof. Ir. Dr. Che Sobry Abdullah and Prof. Madya Dr. Shahimi Mohtar for allowing me great flexibility during my studies and for their continuous guidance and support to my research. I will always be proud as a graduate of the Universiti Utara Malaysia.

I dedicate this thesis to my parents (deceased) who have been an inspiration role model for me throughout my life, and to the two persons I love most, my wife Fadia Baluch and my son Asim Baluch. I want to thank my lovely wife, Fadia for providing her encouragement, support and understanding throughout the years, as I worked endless hours on my doctorate, so I could fulfill my lifelong dream.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABI	American Business Institute
ABAC	Asia Business Advisory Council
ADB	Asian Development Bank
AGVs	Automated Guided Vehicles
AIA	American Institute of Accountants
AICPA	American Institute of Certified Public Accountants
APEC	Asia Pacific Economic Cooperation
APOC	American Palm Oil Council
BDM	Break Down Maintenance
BOD	Biochemical Oxygen Demand
CBM	Condition Based Maintenance
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CI	Continuous Improvement
CIMA	Chartered Institute of Management Accountants
CM	Corrective Maintenance
CMMS	Computerized Maintenance Management System
CO_2	Carbon Dioxide
CPKO	Crude Palm Kernel Oil
CPO	Crude Palm Oil
CSR	Corporate Social Responsibility
DCS	Distributed Control Systems
DV	Dependent Variable
EFB	Empty Fruit Bunch
EPD	Environment Protection Department
ERV	Equipment Replacement Value
ETP	Economic Transformation Program
EU	European Union
EU-RED	European Union Renewable Energy Directive
FAO	Food and Agriculture Organization
FBM	Failure Based Maintenance
FDI	Foreign Direct Investment
FELCRA	Federal Land Consolidation & Rehabilitation Authority
FELDA	Federal Land Development Authority
FFB	Fresh Fruit Bunch
FMEA	Failure Mode Effect Analysis
FMS	Flexible Manufacturing Systems
FRBD	Federal Reserve Bank Dallas
GAP	Good Agricultural Practices
GE	General Electric
GHG	Green House Gas
GMO	Genetically Modified Organism
GRI	Global Reporting Initiative
HACCP	Hazard Analysis Critical Control Points

HSE	Health Safety & Environment
ICAS	Institute of Chartered Accountants of Scotland
ICM	Integrated Crop Management
ICT	Information & Communication Technology
IEC	International Electro-technical Commission
ILO	International labour Organization
IPM	Institute of Personnel Management
ISO	International Organization for Standardization
IT	Information Technology
IV	Independent Variable
JIPM	Japan Institute of Plant Management
JIT	Just in Time
KPI	key Performance Indicator
LCC	Life Cycle Costing
LED	Light Emitting Diodes
LM	Lean Manufacturing
LTP	Long Term Program
MACC	Malaysian Anti Corruption Commission
MCC	Milling Certificate of Competency
MDG	Millennium Development Goal
MESA	Maintenance Engineering Society of Australia
MFF	Mesocarp Fruit Fiber
MIAC	Malaysian International Aerospace Centre
MIDA	Malaysian Industrial Development Authority
MIER	Malaysian Institute of Economic Research
MMIS	Maintenance Management Information Systems
MMPM	Maintenance Management Performance Model
MPM	Maintenance Performance Measurement
MPOA	Malaysian Palm Oil Association
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council
MQA	Malaysian Qualification Agency
MRO	Maintenance Repair & Overhaul
MTBF	Mean Time between Failures
MTTR	Mean Time to Repair
MV	Moderating Variable
NEM	New Economic Model
NGO	Non Governmental Organization
NKEA	National Key Economic Areas
O&M	Operations & Maintenance
OA	Operational Availability
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturers
OER	Oil Extraction Rate
OLE	Overall Labour Efficiency
OPIEJ	Oil Palm Industries Economic Journal

O&R	Operations & Reliability
OR	Operations Research
PAM	Physical Asset Management
PKS	Palm Kernel Shells
PM	Preventive Maintenance
POME	Palm Oil Mill Effluent
POMTEC	Palm Oil Mill Technology Center
PORIM	Palm Oil Research Institute of Malaysia
PORLA	Palm Oil Registration and Licensing Authority
QOS	Quality Operating Systems
R&D	Research and Development
R&M	Reliability and Maintainability
RAV	Replacement Asset Value
RCM	Reliability Centered Maintenance
RF	Radio Frequency
RISDA	Rubber Industry Small Holders Development Authority
ROI	Return on Investment
RONA	Return on Net Assets
RPGDC	Remote Power Generating Diagnostics Centre
RSPO	Roundtable Sustainable Palm Oil
SALCRA	Sarawak Land Rehabilitation & Consolidation Authority
SCM	Supply Chain Management
SKU	Stock Keeping Unit
SLDB	Sabah Land Development Board
SME	Small & Medium Enterprises
SMI	Small & Medium Industries
SMT	Scientific Management Theory
SS	Six Sigma
TBL	Triple Bottom Line - People, Planet, Profit
TEEP	Total Equipment Effectiveness Performance
TOC	Theory of Constraints
TPM	Total Productive Maintenance
TQM	Total Quality Management
TSS	Total Suspended Solids
UBM	Use Based Maintenance
UK	United Kingdom
UN	United Nations
UNCED	United Nations Conference on Environment & Development
UNEP	United Nations Environment Program
USA	United States of America
USDA	United States Development Agency
USDOC	United States Department of Commerce
USITC	United States International Trade Commission
VBM	Vibration Based Maintenance
WCM	World Class Manufacturing
WO	Work Order

LIST OF APPENDICES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Introduction to the Study

Management is obliged to measure performance of their organizations for effective decision making to ensure sustainable profits. This research study espousing practitioner's perspective will employ Overall Equipment Effectiveness (OEE), key performance indicator (KPI) of Total Productive Maintenance (TPM), to evaluate maintenance management performance in Malaysian palm oil mills and accent poor performance stimulating determinants. The study will discuss moderating effects of maintenance strategy, TPM, to improve palm oil mills' productivity, profits, and sustainability. Adopting world class maintenance strategy, TPM, would enable to establish palm oil sectors' competitiveness in the 21st century.

1.2 Background

1.2.1 Strategic Importance of Maintenance

Intense competitive pressure is triggering many companies to look for every possible source of competitive advantage. To achieve this, the ingenuity of each company lies in understanding the potential of each function – say, for example, manufacturing or maintenance. Once understood, it requires a proper strategy to exploit such potential. Strategy at any level, say at a business and functional level will provide the company with a sense of direction, integrity and purpose (Pintelon, Pinjala, & Vereecke, 2006). Tsang (2002) reported that maintenance plays a vital role in any organization using machinery and should be incorporated into an organizations' business model.

Since 1990s there has been a steady increase in acknowledgement of the strategic importance of maintenance. One of the driving factors has been the continued pressure on costs attributable to maintenance. There has also been a growth in the awareness of the part played by maintenance in managing the risk exposure of a corporation. In some instances, this is driven by legislative changes in the areas of safety and environment. In other instances, it is driven by the increasing understanding of the dramatic effect that maintenance management can have on end product quality and overall organization's profitability. While cost is the issue that generally receives the majority of attention at a corporate level, the issues associated with risk management are equally important and vital to the responsible management of physical assets. Today maintenance is considered as a strategic and integral part of the business process and it is an established fact that "It creates additional value" (Liyanage & Kumar, 2003). As the understanding of the strategic importance of maintenance has risen, so too has, the efforts to control, measure, and better manage this function.

1.2.2 Maintenance Performance Measurement (MPM)

For nearly 30 years, the performance measurement literature has focused on developing relevant, integrated, balanced, strategic and improvement-oriented performance measurement systems (Bititci, Mendibil, Martinez, & Albores, 2005). Performance measurement and evaluation is the process of quantifying the efficiency and effectiveness of actions; it is a systematic, rigorous, and meticulous application of scientific methods to assess the design, implementation, improvement or outcomes of a program (Neely, Neely, Gregory, & Plats, 1995; Rossi, Lipsey, & Freeman, 2004).

Performance measurement provides the required information to the management for effective decision making and is used by industries to assess progress against set goals and objectives in a quantifiable way for effectiveness and efficiency. Efficiency and effectiveness are the central terms used in assessing and measuring the performance of organizations (Mouzas, 2006). Research results demonstrate that companies using integrated balanced performance systems perform better than those who do not manage measurements (Lingle & Schiemann, 1996; Kennerly & Neely, 2003). Poor organisational competencies in managing the maintenance function effectively can severely affect competitiveness by reducing throughput, increasing inventory, and leading to poor due-date performance (Patterson, Fredendall, Kennedy, & McGee, 1996; Ashayeri, 2007).

The business imperative for organizations seeking to achieve performance excellence demands that these organizations continuously enhance their capability to create value for customers and improve the cost-effectiveness of their operations. There are vast numbers of methods, tools, and computerized systems available that claim to be able to optimize maintenance, improve performance, or reduce costs associated with maintenance management. It is not possible to manage what you cannot control and you cannot control what you cannot measure (Drucker, 1994). Drucker (1977) distinguished efficiency and effectiveness by associating efficiency to "doing things right" and effectiveness to "doing the right things." In his terminology, a measure of efficiency assesses the ability of an organization to attain the output(s) with the minimum level of input(s). Efficiency is not a measure of a success in the marketplace but a measure of operational excellence in the resource utilization process. More precisely, efficiency is primarily concerned with minimizing the costs and deals with the allocation of resources across alternative uses (Achabal, Heineke, & McJntyre, 1984).

1.2.3 Performance Measurement - an effective management tool

Measuring performance is important because it identifies performance gaps between current and desired performance and provides indication of progress towards closing those gaps. Carefully selected KPIs identify precisely where to take action to improve performance (Weber & Thomas, 2005). Performance measurement is also an effective management tool to measure the direction and speed of change implemented by the company and plays an important role in the improvement of progress (change) towards a better performing organization. Therefore, we need to formulate appropriate performance indicators that are directly linked with company's strategic objectives (Gasperz, 2003). Measuring maintenance performance helps us identify the factors causing poor performance, and provides an opportunity to improve company's profits. Besides, performance measurement is also a way for the management to evaluate the condition of its systems and make a decision relating to maintenance policy adapted by the company. Therefore, improving the effectiveness of maintenance function will play a critical role in a company's ability to compete on the basis of cost, quality and delivery performance (Pintelon Gelders, & van-Puyvelde, 2000).

1.2.4 Driving Factors behind Maintenance Performance Measurement

Maintenance works as an important support function in business operations with significant investment in physical assets and plays an important role in achieving organizational goals (Tsang, 2002). The issues and challenges associated with MPM concern relevance, interpretability, timeliness, reliability, validity, cost & time effectiveness, ease of implementation, and maintenance for regular use by stakeholders. Some of the important driving factors behind demands on maintenance performance measures are:

I. Measuring value created by the maintenance: The most important reason for implementing maintenance performance system is to measure the value created by maintenance process. One must assess that what is being done is what is needed by the business process, and that the maintenance output is contributing/creating value for the business.

II. Justifying investment: The second basic reason for measuring maintenance effectiveness is to justify the organization's investment made in maintenance function, in order to verify if the investment made is producing proper return on the resources that are being consumed.

III. Revising resource allocations: The third basic purpose for measures of effectiveness is to determine if additional investment is required and to justify the investment made; management needs to maximise the use of resources allocated.

IV. Health safety and environmental (HSE) issues: The fourth reason is to understand the contribution of maintenance towards HSE issues. A poor maintenance performance can lead to accidents (safety issue) and pollutions (health hazards and environmental issues), besides encouraging an unhealthy work culture and environment.

V. Focus on knowledge management: Many companies are focused on effective management of knowledge in order to stay competitive. Furthermore, technology is ever changing and is changing faster in the new millennium. This has brought in new sensors and embedded technology, information and communication technology (ICT), and condition-based inspection technology such as vibration analysis, spectroscopy, thermography and others, which is replacing preventive maintenance with predictive maintenance. This necessitates a systematic approach for the knowledge growth in the field of specialization.

VI. Adapting to new trends in operation and maintenance strategy: New operating and maintenance strategy is adopted and followed by industries in quick response to market demand, for the reduction of production loss and process waste. MPM system measures the value created by the maintenance.

VII. Organizational structural changes: Today organizations are trying to adopt a flat and compact organizational structure. A virtual work organization, and empowered, self-managing, knowledge management work teams and workstations. All these innovations need to integrate the MPM system to provide a rewarding return for maintenance services.

1.2.5 OEE – TPM’s Key Performance Indicator

The efficiency and effectiveness of the maintenance system, now, play a pivotal role in the organization's success and survivability. Traditional accounting based measures to evaluate performance have been replaced by KPIs; therefore, the maintenance management system's performance needs to be measured using appropriate KPIs.

KPIs are the metrics (a metric is a standard of measure) that an organization chooses to use as their measures of process performance. They can vary among industries and among individual processes. Some typical KPIs for manufacturing and maintenance include; operating cost, asset availability, lost time injuries, number of environmental incidents, OEE, operational availability, return on investment (ROI), and asset utilization. In this research study, OEE will be used in order to evaluate the efficiency and effectiveness of maintenance management performance, in Malaysian palm oil mills. OEE has been selected for ease of grasp, understanding, and interpretation by the maintenance management and technicians alike. Most other maintenance optimising models, such as Markov decision processes, are stochastic in nature, which are not only difficult to grasp but also difficult to understand and interpret and are barely practitioner friendly.

OEE is a hierarchy of metrics which evaluates and indicates how effectively a manufacturing operation is utilized. The results are stated in a generic form which allows comparison between manufacturing units in differing industries. It is not however an absolute measure and is best used to identify scope for process performance improvement, and how to get the improvement. If for example the cycle time is reduced, the OEE can also reduce, even though more products are produced for less resource. Another example is if one enterprise serves a high volume, low variety market, and another serves a low volume, high variety market. More changeovers (set-ups) will lower the OEE in comparison, but if the product is sold at a premium, there could be more margins with a lower OEE. OEE measurement is also commonly used as a KPI in conjunction with lean manufacturing efforts to provide an indicator of success.

The goal of TPM is to maximize equipment effectiveness, and OEE is used as a measure (Waeyenbergh & Pintelon, 2002). Nakajima (1988) believed that OEE measurement is an effective way of analyzing the efficiency of a single machine or an integrated manufacturing system, and it is a function of availability rate, performance rate, and quality rate. TPM helps raise the value of OEE by supplying a structure to facilitate the assessment of losses, and subsequently giving priority to dealing with the more serious offenders (Eti, Ogaji, & Probert, 2004). Section 1.2.6 explains the relevance of the preceding emphasis on importance of evaluating maintenance management performance in Malaysian palm oil mills.

1.2.6 Malaysian Palm Oil Industry – an overview

Globalization has expanded the Malaysian palm oil market to over 150 countries. Malaysia in 2011, with 18.9 million tons production and 17.99 million tons of export, accounted for 46% of world exports (Figure 1.1). However, over the years, Malaysia has been losing her market share to her closest rival, Indonesia (MPOB, 2012).

Though, palm oil is predominantly used for food applications, its non-food use is growing at a fast pace. Non-food uses of palm oil and palm kernel oil (PKO) are either directly or through the oleo-chemical route. Direct applications include; the use of crude palm oil (CPO) as a diesel fuel substitute, drilling mud, soaps and epoxidised palm oil products, polyols, polyurethanes, and polyacrylates.

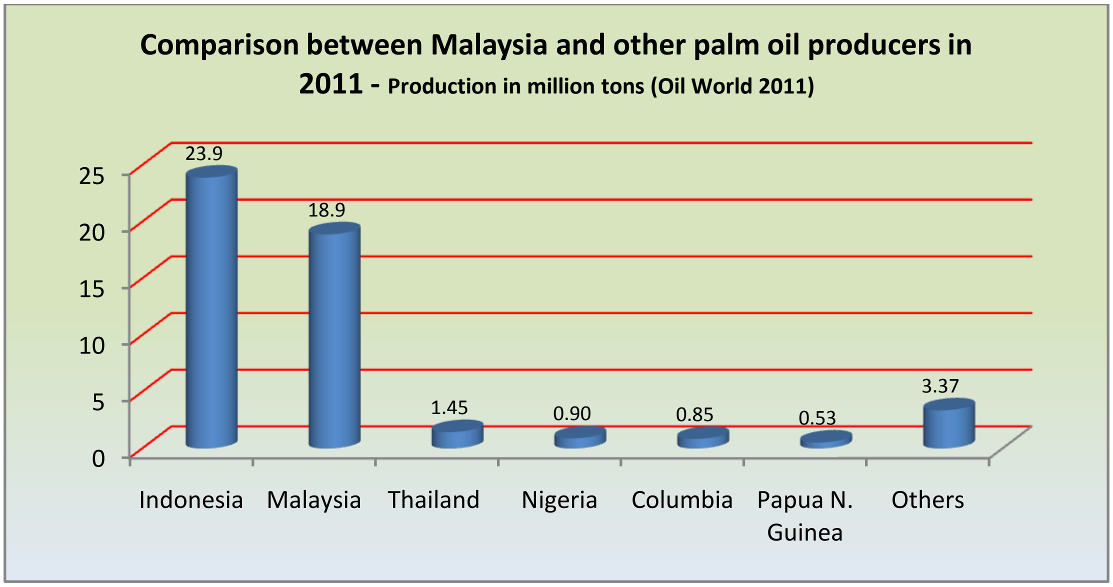


Figure 1.1
Global Palm Oil Production
Source: Oil World 2011

Currently, the emerging growing demand for palm oil is due to its relatively cheap price, compared to other vegetable oils, and versatile advantage both in edible and non-edible industrial applications. In terms of supply, it will be factored by continued yield improvement in Malaysia and increase in palm oil plantation areas in Indonesia (Carter, Finley, Fry, Jackson & Willis, 2007).

In the US, a recent wave of dietary focus on the trans-fat (common name for unsaturated fat with trans-isomer fatty acid) issues has led to increased consumption of palm oil. In addition to being less expensive, palm oil is semi-solid at room temperature, making it ideal for baking and food production. Though, several blends have been developed to produce solid fats with a zero content of trans-fatty acids (Basiron, 2008). Many food manufacturers are trying to find alternatives to trans-fat partially hydrogenated oils, which contribute to heart disease and other health problems. Although, palm oil is not without its own contribution to heart disease, the focus on the trans-fat issue has resulted in palm oil being considered more healthful than some other fats (USDA, 2008).

1.2.7 Industrial – biofuel use of palm oil

The industrial use of palm oil has also continued to grow dramatically; while the rapid growth in the industrial use of palm oil before 2003/2004 was due to the expansion of the oleo-chemical industry in Southeast Asia, recent increases were linked to the rise in petroleum prices beginning in 2004. Palm oil is increasingly used as a fuel, especially in the EU, though, food use still dominated the overall use of palm oil at 73.5% of production for 2010 (USDA, 2010).

The major factor for growth in palm production is its role in sustainable energy campaigns around the globe. European countries have promoted the use of palm oil by injecting hundreds of millions of dollars into national subsidies towards bio-diesel. Europe is now a leading importer of palm oil. Through the subsidizing of bio-fuels, European governments have accelerated the demand for palm oil in Europe (USDA, 2008).

1.2.8 Sustainability and the Round Table on Sustainable Palm Oil

In response to the urgent and pressing global call for sustainably produced palm oil, the Roundtable on Sustainable Palm Oil (RSPO) was formed in 2004. RSPO is a not-for-profit association that unites stakeholders from seven sectors of the palm oil industry; oil palm producers, palm oil processors or traders, consumer goods manufacturers, retailers, banks and investors, environmental or nature conservation non-governmental organizations (NGOs) and social or developmental NGOs in order to develop and implement global standards for sustainable palm oil. The RSPO Principles and Criteria for Sustainable Palm Oil Production (RSPO P&C) are the global guidelines for producing palm oil sustainably. RSPO certification ensures that the palm oil so certified meets the UN sustainability criteria; the triple bottom line, people, planet, and profit. 2011 figures indicate that 2.4 million tons, 13% of Malaysian palm oil production has been RSPO certified (MPOB, 2012).

1.2.9 EUREPGAP, GAP and EU-RED Protocol

The Scope of the EUREPGAP protocol is defined in its document "EUREPGAP protocol document version September 2001", that sets out a framework for Good Agricultural Practice (GAP) on farms which defines essential elements for the development of best-practice for the global production of agricultural & horticultural products. It defines the minimum standard acceptable to the leading retail groups in Europe, however, standards for some individual retailers and those adopted by some growers may exceed those described. This document does not set out to provide prescriptive guidance on every method of agricultural production.

Objectives of EUREPGAP are to: Promote a clear understanding for implementing GAP in the framework of integrated production with a food chain approach to assure quality and safety of fresh fruits and vegetables; Analyze the scope of private certifications to facilitate access of exports to high-value markets; Provide examples of implementing country programs to meet the quality and safety requirements of import markets; and Identify opportunities and difficulties in the horticultural sector to meet the quality and safety requirements of import markets.

EU-RED Protocol - In April 2009, the Council of the European Union adopted directive setting a common EU framework for the promotion of energy from renewable sources. The aim of this legislative act is to achieve by 2020 a 20% share of energy from renewable sources in the EU's final consumption of energy and a 10% share of energy from renewable sources in each member state's transport energy consumption.

The European Union Renewable Energy Directive (EU-RED) and its sustainability criteria have come into effect on December 5, 2010. The sustainability criteria are related to two issues; Green House Gas (GHG) emissions of biofuels and the land used to produce the biofuels. On palm-based biodiesel, the general default value for palm oil defined in the EU directive is 19% (savings of GHG emissions as compared with fossil fuels) which is below the 35% threshold for eligibility set in the EU-RED. All local suppliers would need to show the data supporting that their biofuels have a greater GHG) savings than the threshold value and they will be eligible. However, biofuels without the sustainability criteria would not receive tax exemptions, subsidies or other incentives from the EU 28-member states. Of Europe’s total vegetable oils import, palm oil accounted close to 60% in 2007.

1.2.10 Concern over GMO Food

The consumer concerns against Genetically Modified Organism (GMO) will be an area that will generate great interest in the near future. Results from a survey across the 15 EU countries showed that the general consumer concern about the GMO is high with 71% stating that they would not buy GMO products and 56% felt that GMO-based foods are a danger to the environment. From the same survey, 95% of the consumers want the right to choose whether or not to eat GMO based foods and 86% require information on labelling to enable them to make a choice. This has forced food manufacturers to avoid GMO soybean oil and provides an opportunity for palm oil. Thus far, all particular shipments of palm oil from Malaysia are certified to be GMO free. This will in no way jeopardize the current research in using biotechnology to modify the composition of palm oil towards higher oleic content.

1.2.11 Loss of Market Share

Market Share is the yardstick to benchmark competitive strength in a sector by comparing competing companies. If only the element of sales is used to measure performance, it will not take into account the market conditions. Sales may increase due to product popularity or decline in sales of CPO due to drought or recession. However, by measuring market share, a company can exist with competitive strength. Increasing market share is the most important objective of the corporate world. In terms of palm oil competitiveness, Malaysia can assess her trading position compared to other countries by continuously monitoring of her market share in key markets; China, European Union, Pakistan, India, and USA (MPOB, 2008). Malaysia accounted for 46% of the world exports production in 2011. However, over the years, Malaysia has been losing her market share to her closest rival, Indonesia (Simeh & Kamarudin, 2009).

1.3 Problem Statement

1.3.1 Particular research has not been done in the field of "Maintenance Management Performance Evaluation in Palm Oil Mills"

Thorough review, of local and international literature including Malaysian Palm Oil Journals, shows that particular research has not been done in the field of "Maintenance Management Performance Evaluation in palm oil mills". A world class maintenance department enhances the organization's ability to provide their product or service (Kutucuoglu, Hamali, & Sharp, 2002; Mishra, Anand, & Kodali, 2007). Given the strategic importance of effective maintenance management, it is imperative that palm oil mills recognize the maintenance management role. The following sections identify some of the gaps that exist and discuss the problematic areas that have the potential for the palm oil mills to become more competitive, sustainable, and generate savings through better performance; there is room for improvement.

1.3.2 SMEs poor contribution to Malaysian GDP

SMEs make up 99.2% of businesses in Malaysia, or over 567,480 business establishments; 73.4% of the palm oil mills belong to SMEs (MPOB, 2010). Malaysian government reiterated that it will carry on its efforts to promote SMEs which should, as per government estimates, contribute 37% in the gross domestic product (GDP) of Malaysia by 2020 as compared to 32% in the current financial year 2010 (SME News, 2010).

1.3.3 Maintenance a low priority in Malaysian SMIs

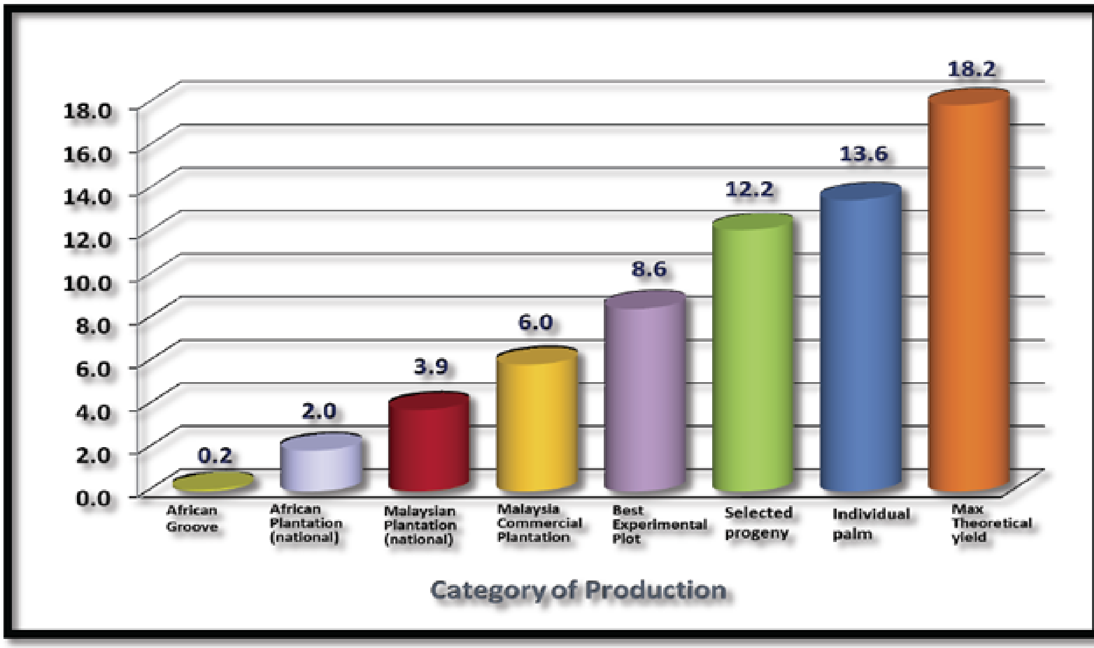
Though there are several maintenance strategies being practiced in the industrial world, such as preventive maintenance (PM), TPM, condition based maintenance (CBM), reliability centered maintenance (RCM); TPM is one the most practiced maintenance strategy in the industrial world. Recent researchers (Shamsuddin, Masjuki, Hassan, & Zahari, 2004) investigated the level of maintenance practices in SMEs in Malaysia and remarked; it is evident from the data and information that equipment maintenance is still a low priority. From the derived information, it can be inferred that lack of understanding about the importance of equipment in organizational performance is one of the main obstacles. Palm oil mills can improve their performance dramatically by adopting globally practiced maintenance strategies, like TPM. TPM initiatives are focused upon addressing major losses and wastes associated with the production systems by affecting continuous and systematic evaluations of production system, thereby inducing significant improvements in production facilities (Ravishankar, Burczak, & Vore, 1992; Gupta, Gunalay, & Srinivasan, 2001a; Gupta, Sonwalker, & Chitale, 2001b; Jurice, Sanchez, & Goti, 2006).

1.3.4 Low Productivity in palm oil mills hampering competitiveness

The global demand for palm oil is growing, thus prompting an increase in production in Malaysia and Indonesia. Besides industrial use, the increasing demand for palm oil is also ascribed to the increasing demand for biofuel as an alternative source of energy particularly in Europe having a mandated biofuel utilisation target. The growth in palm oil consumption has resulted in palm oil dominating the current global oil market. To meet this growing demand, palm oil industry needs to better utilize maintenance function to enhance productivity.

Malaysian Palm Oil Board (MPOB, 2010) and American Palm Oil Council (APOC, 2010), in a joint presentation entitled “Palm oil development and performance in Malaysia” to the United States International Trade Commission (USITC), showed palm oil productivity in Malaysia. National average yield of 3.66 tons / hectare of CPO is less than half of those companies that have adopted best management practices (Figure 1.2). Ineffective and inadequate implementation of good estate practices leads to low quality output. A notable example is the poor control in the harvesting standards which results in many unripe and under-ripe bunches being cut, leading to low oil extraction rate (OER). The category of ripe bunches has been known to be as low as 68% although the standard is set usually at over 90% (OPIEJ, 2002).

However, by adopting better maintenance and manufacturing management practices and using better yielding species, much higher yields (10-15 tons/hectare) and OER (up to 30%) can be achieved. Present average OER is 20% of fresh fruit bunches (FFB) where as best performers have reported OER as high as 30%. Biodiesel has a potential of 18 tons / hectare (MPOC, 2010). 40% of the total palm oil planted hectarage is with smallholders farms; their productivity is even lower than the national average, part due to lack of resources and managing skills at their disposal (MPOC, 2010).



Palm oil yield potential – ton/Ha.

Figure 1.2
Crude Palm Oil yield potential in tons/ha/yr

1.3.5 Sustainable Increase in Productivity

The production of palm oil is not without problems or challenges. The whole industry is partly blamed as a culprit for loss of forest cover and forested areas (deforestation). It is also blamed for loss of biodiversity, endangering wild animals and species, environmental pollution, chemical contamination, as well as for land disputes and social problems in Malaysia (also in Indonesia). At the milling factories, the problems of waste and pollution particularly of the palm oil mill effluents (POME) are also of growing concern.

With all such consequences and impacts highlighted in the media, the palm oil industry is currently under heavy scrutiny putting the producers, mill owners and operators, governments, NGOs and communities in a big battle of varying interests.

While the increasing trend on global demand for palm oil continues and with economic benefits being weighed against the intensifying environmental and social problems, the palm oil industry is now getting redressed through the lens of sustainable development. Improved methods of palm oil production along with new and efficient technologies, sound environmental and social policy measures, and greater stakeholders' engagement are among the new line of approaches to sustainable palm oil. Any growth to meet the global demand will have to be met through a sustainable increase in productivity.

1.3.6 Elevating Maintenance Function - The Financial Business Case

In 2005, a study was conducted by Management Resources Group Inc., USA, (DiStefano, 2005). Statistics from the United States Department of Commerce (USDOC) were studied, including their measurement of what they call "Net Stock of Private Fixed Assets" in various industries. This measurement is a close proxy of Replacement Asset Value (RAV). In 2003, the latest statistics available from the USDOC, there were $4.9 Trillion of physical assets on the ground in United States industry. Four Quartile Benchmark Statistics of Maintenance Spend as a percentage, 2-3%, of RAV was applied to dollarize the value of elevating Fourth, Third, and Second Quartile plants to the First Quartile plants (top performers) in maintenance spend. Industry wastes approximately $183 billion in excess maintenance spend annually in the United States alone! Further, we can safely assume from numerous published case studies that three to seven times the maintenance spend reduction benefit is accomplished in operational benefits including increased uptime, improved quality, more efficient production scheduling, reduced waste, reduced energy consumption, and reduced inventories.

Taking the conservative end of that statistics, three times maintenance spend reductions, one can see there is another $553 Billion in "Productivity Losses" that can be re-claimed through the maintenance and reliability improvements; making the financial business case in the United States alone $736 Billion in annual, recurring benefits (15% of the RAV). With the total assets of Malaysian palm oil sector quoted (MPOC, 2010) at RM 93.3 billion (US$ 29.6 b); at 15% benefits recoverable rate, palm oil milling estimated at 10% of the sector, can potentially recover RM 1,399,500,000 (US$ 0.47 billion). It is, therefore, crucial that Malaysian palm oil industry evaluates and improves the maintenance management performance in order to re-claim this amount of maintenance overspend.

1.3.7 Malaysian Development Plan 2020

Malaysian government unveiled its economic blue print for the next ten years in May, 2010, and identified six National Key Economic Activities (NKEAs) to be the engines of growth to generate high growth rates including oil and gas, electronic and electrical, tourism, agriculture and financial services. NKEAs identified will define the industrial areas where the country has the greatest opportunity to maintain competitiveness. Malaysia must complement on-going efforts to further develop sectors in which it has competitive advantage and to build and capitalize on new and emerging sectors crucial to its long-term growth. The Government emphasized that Malaysia cannot afford to continue stale policies that do not address current and future economic imperatives. All strategies and plans in the future need to be based on sustainable methods while taking into account climate changes and food security. Under the New Economic Model, The Economic Transformation Program (ETP) will provide mechanisms to strengthen the capability of the bottom 40% of Malaysian population, 77.2% of them are "Bumiputras", so that they can take advantage of opportunities to secure better jobs raise their productivity and grow their income. NKEA will help increase the per capita income, with the ultimate goal of raising it to US$ 15,000 per annum by 2020 from the present level of US$ 7,230 per annum (Figure 1.3). It will also target elimination of subsidies, decrease urban migration and ensure social stability. Elevating maintenance management to strategic business level will certainly help Malaysian palm oil industry in particular, and industrial and agriculture sector in general, to achieve the above stipulated goals.

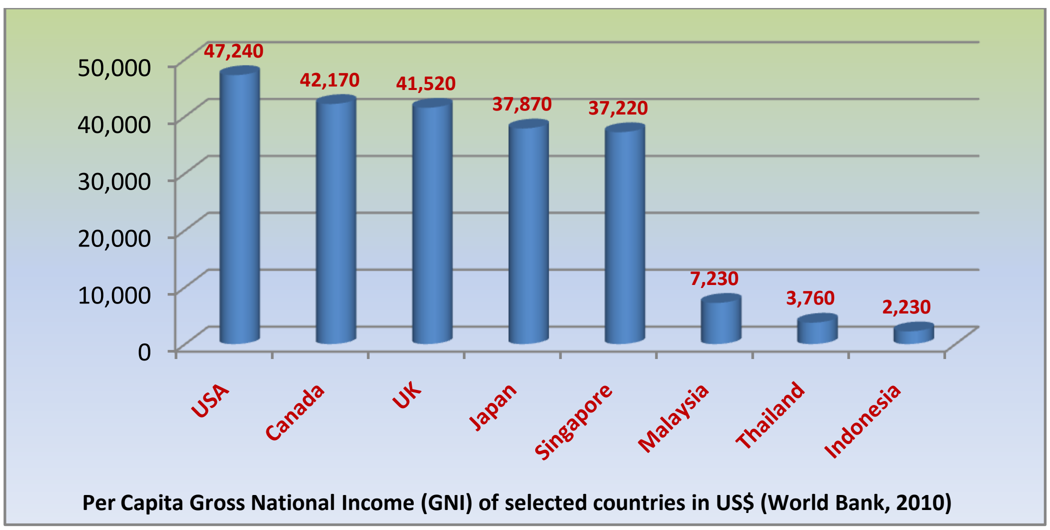


Figure 1.3
Per Capita GNI in US $ of selected countries

1.4 Research Questions

1. Why is the maintenance management performance of industrial organisations evaluated?
2. What role an "efficient & effective" maintenance system management can play in making Malaysian palm oil industry competitive in the 21st century?
3. What are the inefficiencies that plague the maintenance system management in Malaysian palm oil mills?
4. Is Malaysian palm oil industry's POME disposal practice sustainable?
5. Is there a knowledge gap between theory and practice in Malaysian palm oil mills' maintenance system management?

1.5 Research Objectives

1. To evaluate performance of maintenance system management at Malaysian palm oil mills by measuring OEE
2. To assess process performance of CPO production in Malaysian palm oil mills
3. To identify and quantify cost savings in the maintenance system management of Malaysian palm oil mills by benchmarking OEE with world class performers
4. To identify and quantify POME generated during CPO processing and evaluate disposal practices for sustainability and environmental impact
5. To identify theory and practice knowledge gap in Malaysian palm oil mills' maintenance system management

1.6 Scope of this Research Study

Palm Oil sector currently contributes 5-6% to the Malaysian GDP and provides employment for 1.4 million workers (direct employment of 570,000). It triggers upstream (oil palm plantations and relating equipment businesses) and downstream activities (CPO refining, oleo chemicals, and oleo chemical derivatives industries) and brings in revenues for national development and stability, with significant foreign exchange earnings. It covers 68% of the cultivated area of Malaysia; oil palm plantation industry is one of the few examples of an Agri-sector in the Developing World which, with limited Government subsidies (extended only to farmers under 5 hectare land), can successfully compete with the highly protected farmers in the G7 countries.

1.6.1 Malaysian Palm Oil Mills

Out of the 434 registered palm oil mills, 373 are operating in Malaysia (MPOB, 2010). The processes used are broadly similar and primarily involve; transportation of FFBs, sterilization, stripping, digestion and pressing, clarification, nut/fibre separation, nut conditioning and cracking, cracked mixture separation, and kernel drying. The oil extraction process, in summary, involves the harvesting of FFBs from the plantations, sterilising and threshing of the FFBs to free the palm fruit, crushing the fruit and pressing out the CPO. The crude oil is further treated to purify and dry it for eventual storage and export. Large-scale plants, featuring all stages required to produce palm oil to international standards, are generally handling from 3 to 60 tons (90 tons/h in larger mills) of FFB/h. The large installations have mechanical handling systems (bucket and screw conveyers, pumps and pipelines) and operate continuously, depending on the availability of FFB. Boilers, fuelled by fibre and shell, produce superheated steam used to generate electricity through turbine generators. Appendix - F shows list of palm oil mill equipment (Ismail, Zulkifli, Makhtar, & Deros, 2009), and Figure 1.4 depicts the CPO production process at MPOB's palm oil mill at Labu in Negeri Sembilan.

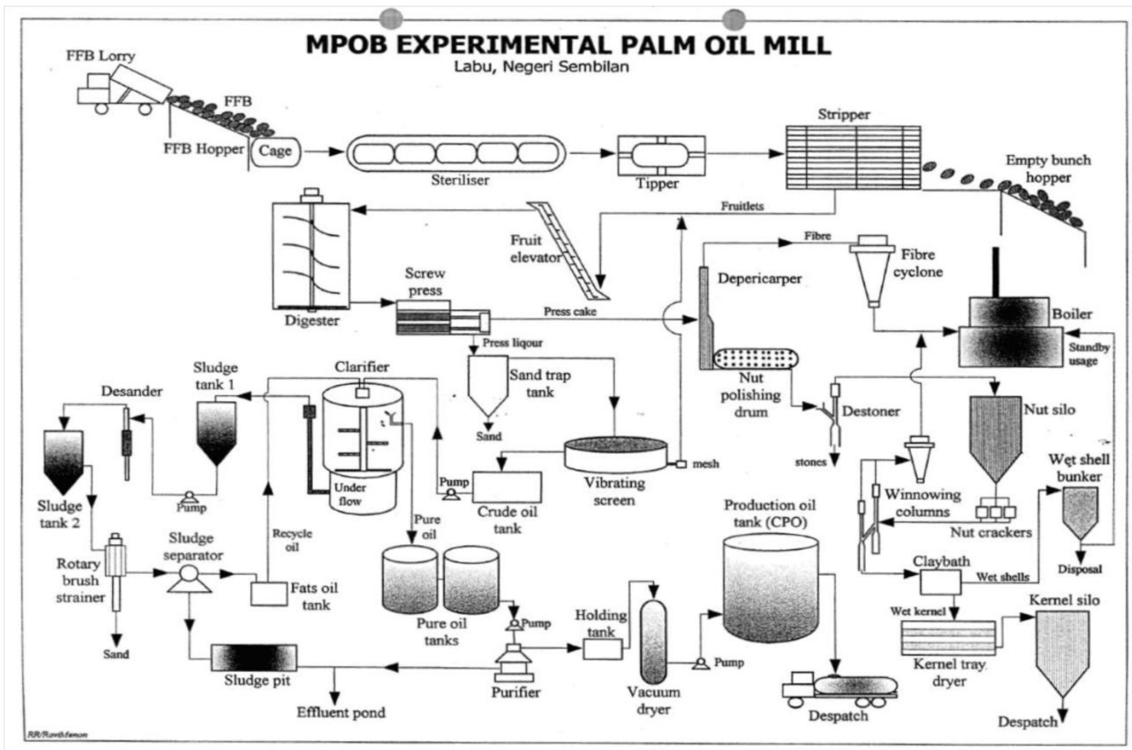


Figure 1.4
CPO Processing at MPOB mill (MPOB, 2011)

The lower pressure steam from the turbine is used for heating purposes throughout the factory. Latest processing operations are automatically controlled and routine sampling and analysis by process control laboratories ensure smooth, efficient operation. Although such large installations are capital intensive, OER of up to 30% can be achieved from good variety of oil palms and quality FFBs.

Conversion of CPO to refined oil involves removal of the products of hydrolysis and oxidation, colour and flavour. After refining, the oil may be separated (fractionated) into liquid and solid phases by thermo-mechanical means (controlled cooling, crystallisation, and filtering), and the liquid fraction (Olein) is used extensively as a liquid cooking oil in tropical climates, competing successfully with the more expensive groundnut, corn, and sunflower oils. Extraction of oil from the palm kernels is generally separated from palm oil extraction, and often carried out in mills that process other oilseeds such as groundnuts, rapeseed, cottonseed, shea nuts or copra. The stages in this process comprise grinding the kernels into small particles, heating (cooking), and extracting the oil using an oilseed expeller or petroleum-derived solvent.

The oil then requires clarification in a filter press or by sedimentation. Extraction is a well established industry, with large numbers of international manufacturers able to offer equipment that can process from 10 kg to several tons per hour. Palm oil processors of all sizes go through these unit operational stages. They differ in the level of mechanisation of each unit operation and the interconnecting materials transfer mechanisms that make the system batch or continuous. The scale of operations differs at the level of process and product quality control that may be achieved by the method of mechanisation adopted (Panapanaan, Kujanpää, Soukka, Heinimö, & Linnanen, 2009).

1.6.2 Upstream Producers

Included in this category are the plantation companies and private estates, producers under the government schemes, and the smallholders. Most of the 4.5 million hectares (area planted by the end of 2009) of oil palm planted in Malaysia are under private ownership, majority of which are by plantation companies (MPOC, 2010). The private sector has been the main driver for growth in the development and production of palm oil for more than two decades already as reflected by the increased plantation areas. The sizes of plantation companies vary considerably from a few hundred hectares to more than 100,000 hectares (Teoh, 2002). As such, plantation ownership area, as per 2009 MPOC data, stands to 60% for private estates (2.70 million hectares), 29% for government/state schemes (1.30 million hectares), and 11% for smallholders (0.50 million hectares). The main producer under the government schemes is the Federal Land Development Authority (FELDA) which operates 70 palm oil mills (MPOB, 2012).

1.6.3 Downstream Producers

Downstream producers can broadly be grouped under plantation-based companies; FELDA, independent manufacturing companies, and subsidiaries or associates of multinational companies. Plantation companies are involved in the downstream processing activities as kernel crushing, palm oil refining, palm-based products processing (e.g. for shortening, vanaspati, margarine, dough fat), and manufacturing of cooking oils, specialty fats and oleo-chemicals. Besides being the largest upstream producer FELDA is a major player in downstream processing, operating seven refineries, six kernel crushing plants and two margarine plants. Currently, there are 60 palm kernel crushing plants and more than 50 refineries operating in Malaysia (MPOB, 2012). Majority of the operating refineries are, in one way or another, associated with oil palm plantation and milling sectors, or both. Some of the refineries have also tied up with manufacturers of specialty products and oleo-chemicals. Today, the palm oil refining industry is one among the most important manufacturing sectors in Malaysia.

1.7 Significance of the Study

1.7.1 Palm Oil Mills and Clean Development Mechanism (CDM) Projects

Most CDM projects in palm oil mills are on waste-to-energy, co-composting, and methane recovery with the latter being the most common. The study on GHG in the milling process points that biogas collection and energy utilisation has the greatest positive effect on GHG balance. On the other hand, empty fruit bunches (EFB) end-use as energy and high energy efficiency of the mill have the least effect on GHG balance of the mill. According to the UNEP – Year End (2008) Snapshot of the CDM, Malaysia secured 145 out of 4237 projects, representing 3.5% of the total and ranking 5th in securing the number of CDM projects. Some of these projects include renewable energy projects, hydro and biomass from oil palm industry. Currently, only 20 out of 434 registered palm oil mills nationwide are involved in CDM-related projects. There is huge CDM potential waiting to be explored. The renewable energy is not only cheaper but also more efficient and environment-friendly than fossil fuels. The carbon credits derived under the CDM Kyoto Protocol increase the economic viability of palm diesel as a renewable fuel. As Malaysia is the world's largest exporter of palm oil, it produces some massive 168 million tons of palm oil biomass annually, the equivalent of about 330 million barrels of oil. Palm oil biomass offers great opportunities to be CDM projects under the Kyoto Protocol. If this potential is fully tapped, the future promise will be far and wide for Malaysia and for our climate.

1.7.2 Improve Foreign Exchange Earnings

Oil palm is the most productive oil crop (Figure 1.5) that has helped Malaysia to achieve the high production target yet. Production of CPO increased to 18.9 million tons in 2011 (MPOB, 2012) that helped Malaysia to increase her export earnings to a record RM 83.4 billion, in 2011. World oil & Fat demand will grow by 17 % by 2020 and that the export of palm oil products is expected to exceed RM100 billion in 2020 following initiatives to effectively enhance production.

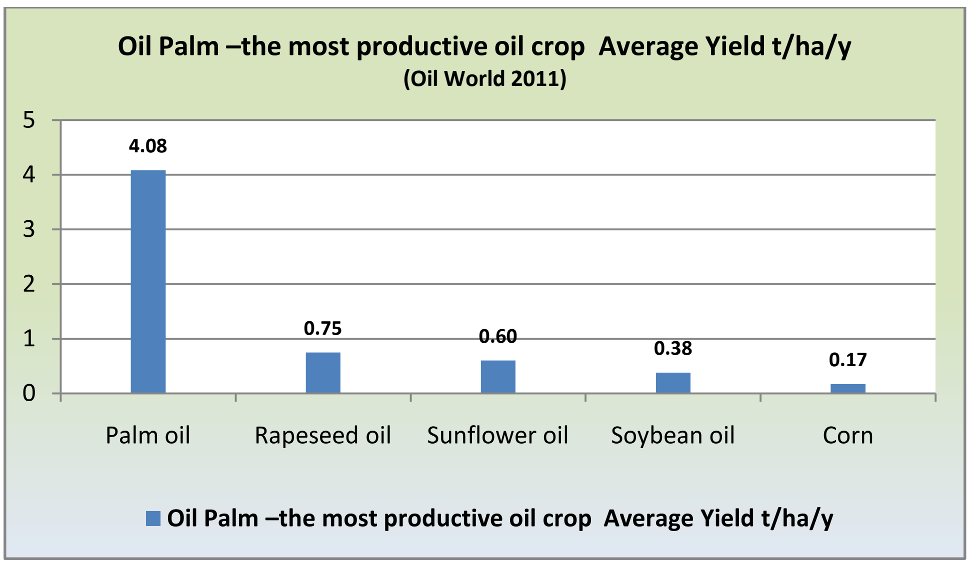


Figure 1.5
Oil Palm – the most productive oil crop

However, by using better planting material, adopting latest technologies this figure could improve dramatically. Yield could be increased from 4 tons/ha, present average, to 8 tons/h, reported for the industries implementing best practices, in Malaysia (Figure 1.2). A yield of 15 tons/ha has been claimed by Australian Palm Plantations; this is almost four times the Malaysian average.

1.7.3 Improve Sustainability – triple bottom line

The concept of sustainability received worldwide recognition as a result of a report that was published in 1987 by the World Commission on Environment and Development, known as the Brundtland Commission, entitled "Our Common Future". The commission, chaired by Norway's Prime Minister Gro Harlem Brundtland, developed today's generally accepted definition of sustainability, stating that sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Basically, therefore, it is a question of inter-generational equity. Sustainability demands that we pass on to our children a world that is virtually no worse than the one we inherited. The private sector is one step ahead of the public one in this respect. Sustainability must become a firmly entrenched, mandatory component of all political and social decisions. This is the only way to move on from theory to practice (Eisenberger, 2008).

The first United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro focussed on the question of the relationship between environmental and developmental goals. Both the Rio Declaration and, above all, Agenda 21 were adopted at this conference. Agenda 21 is an action program for global sustainable development that made the concept of sustainability a formal political principle. It was now recognized that global environmental protection is only possible if economic and social aspects are also taken into consideration. The EU formulated the three pillars of sustainability at its Copenhagen Summit and with the Treaty of Amsterdam of 1997. Known as the "three-pillar model of sustainability", the principle states that sustainability not only comprises the natural heritage we pass on to the next generation but also the economic achievements and social institutions of our society, such as democratic political participation or peaceful conflict resolution. Sustainable development thus rests on an ecological, an economic and a social pillar. If one of the pillars gives way, the 'sustainability building' will collapse. As the result of the growing pressure on the environment and increased scarcity of natural resources, sustainability is increasingly understood so as to mean that the environment is not only on a par with the other two pillars but also the basis of sustainability. Economic and social development can only take place if fundamental ecological functions are secured. The triple bottom line (TBL), also known as “people, planet, profit” or “the three pillars” of sustainability, captures this expanded spectrum of values and criteria for measuring organizational and societal success; economic, ecological, and social.

In the private sector, a commitment to CSR implies a commitment to some form of TBL reporting. The concept of TBL demands that a company's responsibility be to stakeholders rather than shareholders. In this case, "stakeholders" refers to anyone who is influenced, either directly or indirectly, by the actions of the firm.

The oil palm is one of the richest sources of fat-soluble antioxidants such as carotenoids, tocopherols, and tocotrienols; while much attention has been focussed on these fat-soluble components, little emphasis has been given to the water-soluble components, most of which are discarded during extraction of palm oil. For every ton of CPO produced, mills’ generate 2.4 tons of POME which is currently considered industrial waste and it requires extensive treatment before discharge. Though Malaysia enforces stringent regulatory environmental standards, the challenge of converting such agricultural / industrial waste to high value products has remained elusive until now.

1.7.4 Re-distribution of Wealth among Rural Population

Currently, Malaysia has about 18.55 million hectares of forest, compared to 4.5 million hectares of land under oil palm. Oil palm covers 68% of agricultural land, the sector employs 15 % of the workforce, 40% of palm planted acreage is by smallholders. As stated earlier, palm oil currently contributes about 5-6% to Malaysian GDP and provides employment for 1.4 million workers (direct employment of 570,000).

Oil palm cultivation has become a means to overcome rural poverty, FELDA managed plantations provide employment for over 112,635 farmers. The land schemes are provided with basic amenities such as piped water, electricity, communications, roads, schools and health care, and offer further employment opportunities in these economic activities. The New Economic Model (NEM) unveiled, recently, by the present Malaysian government, will generate benefits for all Malaysians, irrespective of race under its inclusive growth goal and approach. Agriculture is one of the six NKEAs that are to be the engine of growth. This increase in income of rural Malaysians will help the government to phase out the subsidies that are threatening the financial stability of the country and help to meet its target of raising Malaysian 'Gross National Income' (GNI). FELDA settlers' income in 2008 was reported at RM 3865 / m (US$ 14,500/y) compared to National Poverty Limit of RM 753 / m (US$ 2824/y). This has created redistribution of wealth, peace, and stability in the country and has reduced migration from the rural to the urban areas (Malaysian population is 70% urban and 30% rural).

1.7.5 Reduce Environmental Footprint – Green House Gases

Most industrialised countries have committed to significantly decrease GHG emissions as a response to the challenge of climate change. The EU, as an example, aims to decrease its GHG emissions by 20% from the level of 1990 by the year 2020. One means of attaining this goal is by increasing the share of transport biofuels to 10%. Thus, the markets of transport biofuels in the EU is expected to develop rapidly for the next 10 years. Palm oil is becoming a more important raw material for transport biofuels. Compared to other oil plants cultivated in Europe, palm oil has several advantages such as remarkably higher annual oil yield and lower production costs. Along with the rapidly increasing interest on palm oil use for transport fuels, serious concern about the sustainability of palm oil production has also increased and has stirred up new debates. However, palm oil industry is committed to guidelines of the RSPO protocol. Based on Nikander's (2008) study, the fossil carbon dioxide (CO_2) emission from palm oil mills is '19.77 gCO2e/MJbiofuel', if emissions are allocated by mass. The production of 'NExBTL-diesel' meets the EU requirement of 35 % GHG reduction with palm oil.

The carbon footprint study carried out by Nikander (2008) stated that over 50% of life cycle GHG emissions from the palm oil material chain arise from the raw material processing in palm oil mill. Since palm oil is used as the main raw material for 'NExBTL-diesel', there is a need to focus on this product chain. To identify further life cycle GHG reduction potential for palm oil-based diesel, this raw material processing phase needs to be studied. It is the phase where the CPO is extracted from the fruit bunches in a mill close to the oil palm plantation. Various studies on CPO milling point to the high methane emission from POME treatment and the possibilities for GHG reductions exist in mill co-product end-use as well (Schmidt, 2007; Yusoff & Hansen, 2007). Based on current typical industry practices for palm oil production in Malaysia, using palm oil for bio-fuel applications renders an average net CO_2 reduction of approximately 60%. In other words, the CO_2 emissions incurred in the palm oil supply chain are only around 40% of the CO_2 emissions generated by fossil fuels (Figure 1.6).

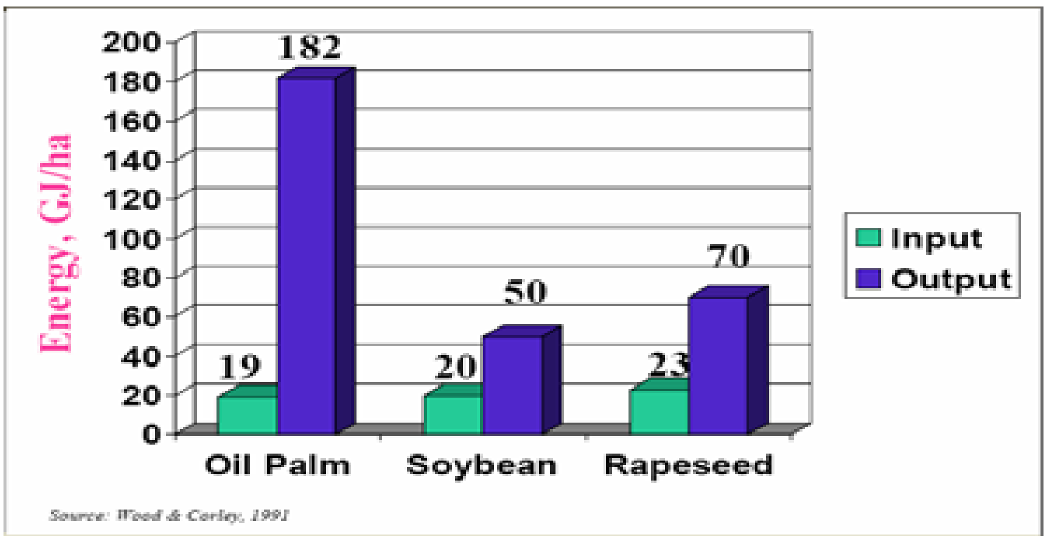


Figure 1.6
Carbon Dioxide (CO_2) footprint of palm oil

Depending on production techniques, palm oil can reach even higher GHG savings of between 80 and 90%, comparable with second generation bio-fuels. With further improvements in yield and waste management, and by taking into account carbon sequestration by the oil palm, this figure can be expected to go beyond 90% in the future.

1.7.6 Contribution to knowledge

Knowledge based competition is an area of intense interest to both strategic management scholars and practitioners alike. Researchers investigating this topic have typically anchored their work in the resource-based theory of the firm, which reasons that distinct knowledge should give the firm a competitive advantage. When a firm holds distinct knowledge stock that is hard to imitate, it must also enjoy sustained above normal returns (Reed & Fillipi, 1990; Barney, 1991). Globalization has afforded Malaysian palm oil mills to enterprise beyond its national borders, becoming multinational in their operations. They are a global source of ‘Foreign Direct Investment’ (FDI) for several nations; part of the one third of worlds’ trade that occur intra-firm (Antras, 2003). The terms ‘outsourcing’, ‘slicing up the value chain’ and ‘disintegration of production’ have been coined to label the increasing interconnection of production processes in a vertical trading chain that touches many countries, with each country specializing in a particular stage of production (Hummels, Ishii, & Yi, 2001).

Export-led economy in Malaysia was affected significantly in 2009 by overseas declines in demand for consumer goods brought about as a result of the Global Financial Crisis, though the country managed to bounce back in 2010. Malaysia’s GDP reached US$305.83 billion in 2011 with agricultural production share of 10.3% in rubber, palm oil, timber, and rice. The government is noticeably dependent on the state-owned oil company PETRONAS to fill its coffers, as it contributes roughly 44% to the government’s revenue. Malaysia in 2011 ranked 18th overall out of 183 economies in the International Finance Corporation’s Doing Business rankings in terms of the ease of doing business. For Malaysia to remain competitive, it is exigent that its resources are utilized efficiently and effectively to produce goods and services. Effective planning, implementation, and control of industrial production processes can ensure smooth and efficient operations. Production management responsibilities include the traditional, efficient and effective, use of “four M's”; men and women, machines, methods, materials & money. Managers are expected to maintain an efficient production process with a workforce that can readily adapt to new equipment and schedules. They may use industrial engineering methods, such as time-and-motion studies, to design efficient work methods. They are responsible for managing both physical (raw) materials and information materials (paperwork or electronic documentation). Of their duties involving money, inventory control is the most important. This involves tracking all component parts, work in process, finished goods, packaging materials, and general supplies. The production cycle requires that sales, financial, engineering, and planning departments exchange information such as sales forecasts, inventory levels, and budgets, until detailed production orders are dispatched by a production-control division. Managers must also monitor operations to ensure that planned output levels, cost levels, and quality objectives are met. Practitioners are obliged to make use of various modes that Theory provides, through TPM and Lean concepts, to conduct manufacturing operations efficiently and effectively.

This research study contributes to knowledge by identifying theory-practice gaps in maintenance management performance in Malaysian palm oil mills pertaining to 4Ms {man (labor), machines (equipment), methods (processes) materials (spares and materials)}and offers realistic shop level solutions to bridge those gaps.

1.8 Thesis Organization

Chapter one elaborates on strategic importance of maintenance and TPM's performance indicator OEE. It discusses how measuring performance identifies gaps between current and desired performance and affords solutions towards closing those gaps. It also defines palm oil industry's significance and its predicaments. Research scope, and research questions and objectives are also elaborated.

Chapter two cites literature that qualifies history of maintenance management, its strategies and performance measurement revolution. It accounts for Malaysian palm oil industry's scope, importance and challenges, sustainability and RSPO and TPM & OEE via referencing a critical review and obstacles to their implementation. The chapter also discusses 'Scientific Management Theory' (SMT), the underpinning theory for this research, and theoretical framework.

Chapter three discusses research framework, model and methodology and gap between theory and practice in maintenance management system at palm oil mills. It summarizes data collecting issues and challenges, explains MMP Model and variables in this research study and examines measuring instrument; its design, testing and validation.

Chapter four analyzes collection, enumeration, validity & reliability of data; critically reviews maintenance inputs (labour, spare-parts, materials, & tools, and maintenance contracted out); examines their correlation with OEE; and explains moderating variable, maintenance strategy, TPM.

Chapter five presents conclusion, recommendations and contributions. It identifies theory practice gaps in maintenance management performance at Malaysian palm oil mills and defines shop-level solutions to bridge those gaps. Chapter also presents the designs of generic, OEE calculating and maintenance daily service log template and provides an *e*-maintenance system concept for power generating equipment in palm oil mills.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Most companies view production/operations as the sole customer of maintenance. The end product consumer, however, is only viewed as a customer of maintenance when equipment performance affects final product quality. This is the business environment in which maintenance managers, through the maintenance function, contemplate to improve equipment effectiveness and reliability. It is a recognised fact that maintenance function is not just a cost center but a valuable business partner that can drive both operating efficiencies and top-line growth. As organizations increase their investment in capital intensive industries, the efficient and effective performance of maintenance function offers a unique opportunity for reliable equipment performance leading to cost savings and sustained profits. The maintenance organization's management needs to be transparent. To drive continuous improvement, corrective actions and remedies should be apparent. Proper KPIs, such as OEE, should be used to assess maintenance performance and to create transparency of the interdepartmental relationships; KPIs that do not do this are useless and should be discarded.

The first part of the chapter defines the maintenance function, its history of management, and maintenance strategies. It is followed by a review of the theory and practice of measuring organizational performance; in particular maintenance performance evaluation. The chapter, then, discusses Malaysian palm oil sectors' scope, importance and challenges. Subsequently, it elaborates underpinning theory, SMT, and theoretical framework.

2.2 Scope of Maintenance Management

The manufacturing industry has experienced an unprecedented degree of change in the last three decades, involving drastic changes in management approaches, product and process technologies, customer expectations, supplier attitudes as well as competitive behaviour (Ahuja, Khamba, & Choudhary, 2006). The changes in the current business environment are characterized by intense competition on the supply side and heightened volatility in customer requirements on the demand side. Increased customer demands, generated by the process of constant change of the international and national competitive environment, have affected the manufacturing organizations globally. Confronted with stiff global competition, organizations are under great pressure to enhance their competencies to create value for the customers and improve the cost effectiveness of their operations on a continuous basis. Organizations that want to survive in today's highly competitive business environment must address the need for high quality, lower costs and more effective, swifter research and development (R&D) (Gotoh, 1991; Hipkin & Cock, 2000). Moreover, need to attain shorter lead times, shorter innovation times and reduced inventories have led to increasing demand on an organization's preparedness, adaptability, versatility and flexibility (Schonberger, 1968; Al-Najjar & Alsyouf, 2000). These changes have left their unmistakable mark on the different facets of manufacturing organizations (Gomes, Yasin, & Lisboa, 2006). Competitive pressures and changing production management paradigms, in recent years, have increased the importance of reliable and consistent production equipment. The equipment technology and development capabilities have become major factors that demonstrate the strength of an organization and set it apart from others (Tsuchiya, 1992; Schuman & Brent, 2005; Braglia, Carmignani, Frosolini, & Grassi, 2006).

With the trend to JIT production, lean, flexible and agile manufacturing, it is vital that maintenance becomes integrated with corporate strategy to ensure equipment availability, quality products, on-time deliveries and competitive pricing (Wireman, 1990; Luxhoj, Riis, & Thorsteinsson, 1997). Maintenance, being an important support function in enterprise operations with significant investments in plants and machinery, plays an important role in meeting this tall order. The inefficiencies in equipment management have significant impact on organization's throughput, operating expense, inventory, and profitability. As a result, managing equipment performance becomes a challenging task for managers in manufacturing organizations; maintenance has thus emerged as an essential core function in the manufacturing and processing industries.

The changing needs of physical assets and equipments over time have been putting tremendous pressures on the enterprises to adapt proactive strategies for meeting the fast changing requirements of the production systems (Teresko, 1992). The wave of change has drastically transformed role of maintenance function in the organizations. The competitiveness in world markets now drives the changes in how top management views maintenance for growth and survival. It is evident from the literature that maintenance is a strategic function, the impact of which influences almost all aspects of an organisation's performance, including competitiveness (Madu, 2000), productivity (Raouf, 1994), quality (Ben-Daya & Duffuaa, 1995) and safety (Holmgren, 2005). Thus, improving the effectiveness of maintenance is crucial.

It is believed that what an organisation should measure depends on what it is trying to achieve (Neely & Austin, 2002; Johnston & Pongatichat, 2008) and the continual updating of relevant measures is viewed as essential (Bourne, Mills, Bicheno, Hamblin, Wilcox, Neely, & Platts, 2000; Kuwaiti, 2004; Wouters & Sportel, 2005). In case of palm oil mills, maintenance performance measurement is the focus of this research study, that's where the resources were deployed to get the pertinent data.

Several approaches have been proposed to evaluate maintenance performance in order to improve its effectiveness (De Groote, 1995; Pintelon & Puyvelde, 1997; Dwight, 1999; Tsang, 1998; Tsang, Jardine, & Kolodny, 1999; Yam, Tse, Ling, & Fung, 2000; Kutucuoglu, Hamali, Irani, & Sharp, 2001). Yet, the impact of some of these approaches has been limited, because convincing top management of the necessity to implement these approaches in their organisations is not easy when the results expected from the improvement of the maintenance effectiveness, are not assessed in terms of financial profit. This evaluation is difficult to realize, furthermore, because of the time-lag effect characterizing the nature of maintenance, which is a support function of production and operations (Pintelon & Puyvelde, 1997). In addition to the aforesaid constraints, there is a lack of literature on scientific work evaluating the contribution of maintenance to an organisation's profit creation (Oke, 2005). In order to avoid these problems and to convince the top management, it is necessary to highlight these losses caused by the ineffectiveness of maintenance management. However, to be able to recommend necessary improvements to maintenance, it is not sufficient to demonstrate just the negative impact of ineffective maintenance management on a company; it is also essential to identify its causes and offer practical solutions. Section 2.3 elaborates on definition of maintenance function as it is supported in literature.

2.3 The Maintenance Function

Maintenance has been defined as the combination of all the technical and administrative actions, including supervision, intended to retain an item, or restore it to a state in which it can perform a required function (IEC, 2006); whereas, maintenance management is the process of directing maintenance organization effectively. The scope of maintenance management should, therefore, cover every stage in the life cycle of technical systems (plant, machinery, equipment, and facilities); specification, acquisition, planning, operation, performance & evaluation, improvement, and disposal (Murray, Fletcher, Kennedy, Kohler, Chambers, & Ledwidge, 1996).

Maintenance is considered as a process that monitors a technical system's capability to deliver services, records problems for analysis, takes corrective/adaptive/perfective or preventive actions, and confirms restored capability (Coetzee, 1998; Campbell & Jardine, 2001; Soderholm *et al.*, 2007; ISO, 2008; IEC, 2008). The purpose of the maintenance process is to sustain the capability of a system to provide a service and thereby achieve customer satisfaction (Liyanage & Kumar, 2003; Soderholm, Holmgren, & Klefsjo¨, 2007; ISO, 2008; IEC, 2008).

A generic maintenance process consists of phases for management, support planning, preparation, execution, assessment, and improvement (IEC, 2004). Hence, maintenance is multidisciplinary and involves a wide range of actors, such as managers, process owners, maintenance technicians, maintenance planners, and logistic managers. Therefore, to be efficient and effective, the maintenance process should be horizontally aligned with both the operation and modification processes and vertically aligned with the requirements of external stakeholders (Liyanage & Kumar, 2003; Soderholm *et al.*, 2007).

The Maintenance Engineering Society of Australia (MESA) defines the maintenance function as “the engineering decisions and associated actions necessary and sufficient for the optimization of specified capability.” Capability in the MESA definition is the ability to perform a specific action within a range of performance levels. The characteristics of capability include function, capacity, rate, quality, responsiveness, and degradation. When perceived in the wider context, the maintenance function is also known as physical asset management (PAM), and should be well aligned with the business strategies. Major maintenance strategies are discussed in section 2.5.

2.4 History of Maintenance Management

Prior to the early 1900s, maintenance was considered as a necessary evil. Technology was not in a state of advanced development, there was no alternative for avoiding failure, and the general attitude to maintenance was, “It costs what it costs.” With the advent of technological changes and after the Second World War, maintenance came to be considered as an important support function for operations, production, and manufacturing. During 1950-1980, with the advent of techniques like preventive maintenance and condition monitoring, the maintenance cost perception changed to: “It can be planned and controlled.”

Therefore importance of the maintenance function has never been greater, due to its role in maintaining and improving availability, performance efficiency, quality products, on-time deliveries, the environment, safety requirements, and overall plant productivity (Ahlmann, 1984; Al-Najjar, 1997; Riis & Thorsteinsson, 1997; Ahlmann, 1998; Mckone & Wiess, 1998; Bevilacqua & Braglia, 2000; Al-Najjar & Alsyouf, 2003).

The approach to maintenance has changed dramatically over the last century (Blischke & Murthy, 2000). Up to about 1940, maintenance was considered an unavoidable cost and the only maintenance carried out was corrective maintenance (CM). Maintenance was neither incorporated into the design of the system, nor was the impact of maintenance on system and business performance duly recognized. The evolution of operations research (OR) from its origin and applications during the Second World War to its subsequent use in industry led to the widespread use of PM.

Since the 1950s, Operations and Reliability (O&R) models for maintenance have appeared at an ever-increasing pace. These can be found in many books (Niebel, 1985; Gertsbakh, 1997) and many review papers on the topic (Jardine & Buzzacot, 1985; Gits, 1986; Valdez-Flores & Feldman, 1989; Scarf, 1997; Cho & Parlar, 1991; Dekker, Wildeman, & van der Duyn, 1997). These models deal with the effect of different maintenance policies and optimal selection of the parameters of the policies. However, the impact of maintenance actions on the business performance is not addressed.

In the 1970s, a more integrated approach to maintenance evolved in the government and private sectors. New costly defence acquisitions by the US government required a Life Cycle Costing (LCC) approach, with maintenance cost being a significant portion. The close linkage between reliability (R) and maintainability (M) was recognized. The term

“R&M” became more widely used in defence-related systems. This concept was also adopted by manufacturers and operators of civilian aircraft through the methodology of RCM in the USA. In the RCM approach (Moubray, 1991) maintenance is carried out at the component level and the maintenance effort for a component is a function of the reliability of the component and the consequence of its failure under normal operation. The approach uses failure mode effects analysis (FMEA) and to a large extent is qualitative. At the same time, the Japanese evolved the concept of TPM in the context of manufacturing (Tajiri & Gotoh, 1992). Here, maintenance is viewed in terms of its impact on the manufacturing through its effect on equipment availability, production rate and output quality. Lean Maintenance is another maintenance concept that takes its lead from lean manufacturing. Lean Maintenance is a relatively new term, coined in the last decade of the twentieth century, but the principles are well established in TPM. It applies some new techniques to TPM concept, to render it a more structured implementation path. Lean seeks to eliminate all forms of waste in the manufacturing process including waste in maintenance.

Many changes in the internal environment of certain companies are taking place. These changes include the increased use of mechanisation and automation of operations, such as flexible manufacturing systems (FMS); robots; automatic warehousing systems; automatic guided vehicles (AGVs); and the increasing trend of using the just-in-time (JIT) and TQM philosophy (Yamashina, 1995; Luxhoj *et al.,* 1997; Suito, 1998). These changes tie up much invested capital. For example, companies within process industries and chemical industries, such as oil mills, paper mills and refineries use extremely expensive and fully automated production lines (Swanson, 2003). Furthermore, there is increasing pressure to protect the ecological environment from the danger of harmful industrial waste and pollution. Palm oil processing generates 2.4 tons of POME for every ton of CPO produced. This is a large amount of waste that needs to be treated before it is released to the environment. It also puts pressure on the palm oil mills that the manufacturing plant should be used efficiently and effectively. The plant should provide high quality products at a competitive price in addition to showing concern for the environment and safety (Alsyouf, 2004). Furthermore, an increasing awareness of maintenance and its influence on both industrial enterprises and society as a whole can be recognised. Many researchers and practitioners have highlighted the total losses that are caused by maintenance omission or ineffectiveness in maintenance (Ahlmann, 1984, 1998; Jardine, Fan, & Hong, 1996; Al-Najjar, 1997; Davies, 1998; Ljungberg, 1998; Luce, 1999; Vineyard, Amoako-Gyampah, & Meredith, 2000; Holmberg, 2001). Nevertheless, maintenance is still considered as a cost centre; 70 per cent of the respondents of a survey conducted on 118 Swedish manufacturing companies considered maintenance as a cost centre (Alsyouf, 2004). Furthermore, little research has been done to highlight the impact of the maintenance function on overall plant performance, i.e. productivity and profitability (Ahlmann, 1984&1998; Russell, 2001; Kutucuoglu *et al*., 2001; Al-Najjar & Alsyouf, 2004). This lends an opportunity for the research to be carried out for the palm oil sector. The following section briefly describes various maintenance strategies which currently might be practiced by the industry.

2.5 Maintenance Strategies

In the highly competitive globalized scenario the maintenance function is being looked on by manufacturing organizations as a potential source of cost savings and competitive advantage. The effective integration of maintenance function with engineering and other manufacturing functions in the organization can help to save extensive amounts of time, money and other useful resources in dealing with reliability, availability, maintainability and performance issues (Moubray, 2003). This has provided the impetus to the leading organizations worldwide to adopt effective and efficient maintenance strategies such as condition-based maintenance (CBM), RCM, TPM, over the traditional firefighting reactive or breakdown maintenance (BDM) approaches (Sharma, Kumar, & Kumar, 2005). These maintenance strategies are discussed in the following sections.

2.5.1 Reactive or Breakdown Maintenance (BDM)

In reactive maintenance, which is also known as BDM, repairs are done to bring the equipment back from failure stage to operational stage. It results in fluctuation in production, higher down time and increase in the scrap and rework rate. Thus, the ultimate effect is an increase in overall maintenance costs. No action is taken to detect the onset or how to prevent frequent failures, which accounts for usually high maintenance related costs. In a situation where customer demand exceeds supply and profit margins are large, BDM is a feasible approach, as its main objective is to keep the process running in order to maximize the availability. Traditionally, this type of strategy was mainly practiced as an action-oriented or fire-fighting approach that solved production problems. However, today stiff global competition and small profit margins have forced maintenance managers to think and adapt cost effective and reliable maintenance strategies (Pintelon & Gelders, 1992; Sheu & Krajewski, 1994). Kumar, Antony, Singh, Tiwari and Perry (2006) impress upon the manufacturing organizations to adapt lean and 'Six Sigma' (SS) principles, and business process improvement strategies for achieving dramatic results in cost, quality and time by focusing on process performance.

2.5.2 Preventive Maintenance (PM)

The main objective of carrying out PM is to reduce the frequent and sudden sporadic failures by performing repairs, replacement, overhauling, lubrication, cleaning and inspection at a specific predetermined interval of time say weekly, monthly, bi-monthly, half-yearly or annually regardless of the condition of the equipment/component (Gits, 1992). Thus, PM reduces the probability of equipment breakdown by proper planning of interval (age-based or calendar based), for carrying out PM tasks (Dekker, 1996). For successful implementation of PM and assessment of the time for action, a decision support system is required.

2.5.3 Condition Based Maintenance (CBM)

Predictive or CBM strategy reduces the probability of sudden sporadic failures with the aid of diagnostics and timely intervention. Vibration-based maintenance (VBM) involves periodic (VBMp) and continuous (VBMc) collection and interpretation of data, which is based on deterministic and probabilistic models. Thus, it provides useful information for diagnoses and prognoses. For instance, diagnostic equipments are used to measure the physical conditions such as temperature, vibration, noise, corrosion, etc.

about the root cause(s) and failure mechanisms. Vibration technique is always preferred in condition monitoring applied on rotating and reciprocating machines, but limitations and deficiency in data coverage and quality reduces its effectiveness and accuracy (Tsang, 1995; Yang, Liang, & Danyluk, 1999; Moubray, 2000). Nowadays, application of CBM has become popular in process industries, such as paper mills, oil-refineries, sugar mills and thermal power plants. In order to achieve an effective implementation of "zero-failure" strategy the condition monitoring system helps to discover failure causes, potential failures and mechanisms of failure. For instance, spectral analysis, one of the most useful fault diagnostics tool, provides a basis for identification of failure mechanisms, failure causes and failure modes in mechanical systems, such as rotating and reciprocating machines.

2.5.4 Reliability Centered Maintenance (RCM)

Moubray (2000) defined RCM as a systematic approach used to optimize preventive and predictive maintenance programs to increase equipment efficiency (uptime, performance and quality) while targeting on minimizing the maintenance cost.

In RCM methodology the focus is on maintaining system function rather than restoring equipment to an ideal condition. Earlier RCM methodology was restricted to the airline and nuclear industries. But today it offers tremendous opportunities in areas such as fossil power plants, oil-refineries, and other process industries. The primary objective of RCM is to preserve system function. To attain this objective various failure modes that cause functional failure are identified, then prioritized accordingly to reflect their importance in system functioning and consequences of failure. Tools such as FMEA and fault tree analysis (FTA) are used in RCM analysis. The process of RCM helps determine the maintenance requirements of any asset and helps conduct analysis to ensure the asset continues to perform the task without loss of function. It combines several well-known risk-analysis tools and techniques such as FEMA and FTA that can identify failure to identify problematic areas (Backlund & Akersten, 2003; Delzell & Pithan, 1996; Fleming, 2006; Toomey, 2006).

2.5.5 Total Productive Maintenance (TPM)

TPM took root in the automobile industry and rapidly became part of the corporate culture in companies such as Toyota, Nissan and Mazda as well as their suppliers such as Nippondenso. It has also been introduced by other industries such as consumer appliances, microelectronics, machine tools, plastics and many others.

Having introduced Preventive Maintenance, the process industries then began to implement TPM. Since, there have been a few studies done in the area of TPM to investigate the TPM relationship with manufacturing performance and business performance, for instance: Brah & Chong (2004); Seth & Tripathi (2005); Tsarouhas, 2007; Ahuja & Khamba, 2007; Ahuja & Kumar, 2009; and Damiana & Ghirardo, 2010. Moreover, some studies have been done that deal with the TPM implementation issues; studies were related to the benchmarking of implementation practices to explore key areas (Damiana & Ghirardo, 2010), identification of critical factors (Seth & Tripathi (2005), strategies to support its implementation (Seng, Jantan & Ramayah, 2005), and organization's inability to obviate resistance to change (Ahuja & Khamba, 2008b). The relationship of TPM with business performance has also been addressed in some studies (Bamber, Sharp & Hides, 1999; Cooke, 2000; Tsang & Chan, 2000; Jurice *et al.*, 2006).

Initially, corporate TPM activities were limited to departments directly involved with equipment such as production. However administrative and support departments, while actively supporting TPM in production, are now applying TPM to enhance the effectiveness of their own activities.

TPM as the name suggests consists of three words. Total signifies to consider every aspect and involving everybody from top to bottom. Productive emphasises on trying to do it while production goes on and minimize troubles for production. Maintenance means keeping equipment autonomously by production operators in good condition; repair, clean, grease, and accept to spend necessary time on it. Nakajima (1989), a major contributor of TPM, has defined TPM as an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns, and promotes autonomous maintenance by operators through day-to-day activities involving the total workforce. According to Shirose (1995) an autonomous maintenance (AM) program is held with an objective of accomplishing three purposes. First, to bring the production and maintenance people together to accomplish a common goal that is to stabilise equipment conditions and halt accelerated deterioration. Secondly, to help operators learn more about their equipment functions, what common problems can occur and why, and how those problems can be prevented by the early detection and treatment of abnormal conditions. Thirdly, AM helps to prepare operators to be active partners with maintenance and engineering personnel in improving overall performance and reliability of equipment. TPM can be thought being integral to a World Class Manufacturing Strategy that also involves JIT, TQM and employee involvement (McKone, Schroeder, & Cua, 2001). There have been studies done in the area of TPM to investigate the TPM relationship with manufacturing performance and business performance (Brah & Chong, 2004; Seth & Tripathi, 2005). In addition, some studies have also been done concerning implementation issues of TPM related to the benchmarking of implementation practices to explore: key areas (Ireland & Dale, 2001); and identification of critical factors (Tsang, 2002). The relationship of TPM with business performance has also been addressed in some studies (Bamber, Sharp & Hides, 1999; Cooke, 2000; Tsang & Chan, 2000). More importantly, Tsang and Chan (2000) revealed the importance of management leadership, employee involvement, education and training, strategic planning and communication for TPM in a high-precision machining company, located in Pearl River Delta, China. Cooke (2000) also identified top management support, alignment of management initiatives and change, employee training, autonomy to employees and communication as important factors for the success of TPM in a European context.

TPM is not a maintenance specific policy. It is a culture, a philosophy and a new attitude toward maintenance. According to Chaneski (2002) TPM is a maintenance management program with the objective of eliminating equipment downtime.

TPM describes a relationship between production and maintenance, for continuous improvement of product quality, operational efficiency, capacity, assurance and safety (Nakajima, 1988). It is an aggressive strategy that focuses on actually improving the function and design of the production equipment (Swanson, 2001). TPM has been accepted as the most promising strategy for improving maintenance performance in order to succeed in a highly demanding market arena (Nakajima, 1988). Ahuja *et al.*

(2006), report that TPM implementation can significantly contribute towards improvement in organizational behaviour in the manufacturing enterprises leading to world class competitiveness. It is also considered to be an effective strategic improvement initiative for improving quality in maintenance engineering activities (Ollila & Malmipuro, 1999; Pramod, Devadasan, & Jagathy, 2007). There are three ultimate goals of TPM; zero defects, zero accident, and zero breakdowns (Willmott, 1994; Noon, Jenkins, & Lucio, 2000).

TPM has been widely recognized as a strategic mechanism for improving manufacturing performance by enhancing the effectiveness of production facilities (Dwyer, 1999; Dossenbach, 2006). Wireman (1991) suggests that TPM is maintenance improvement strategy that involves all employees in the organization and includes everyone from top management to the line employee. It encompasses all departments including, maintenance, operations, design engineering, project engineering, inventory and stores, purchasing, accounting finances, and plant management. Strategic TPM implementation programs have revealed a significant realisation of manufacturing performance achievements leading to improved core competitiveness of organisations. TPM involves everyone in the organisation, from top-level management to production mechanics, and production support groups to outside suppliers (Ahuja & Khamba, 2008a, b). Nakajima (1988) emphasizes that TPM comprises of a companywide equipment maintenance program that covers the entire equipment life cycle and requires participation by every employee. It is a production-driven improvement methodology that is designed to optimise equipment reliability and ensure the efficient management of plant assets (Robinson & Ginder, 1995). Another strategic outcome of TPM implementations is the reduced occurrence of unexpected machine breakdowns that disrupt production and lead to losses, which can exceed millions of dollars annually (Gosavi, 2006). The basic practices of TPM are often called the “pillars” or “elements” of TPM. The entire edifice of TPM is built and stands on eight pillars (Sangameshwran & Jagannathan, 2002). The eight-pillar model of TPM implementation is depicted in Figure 2.7, below.

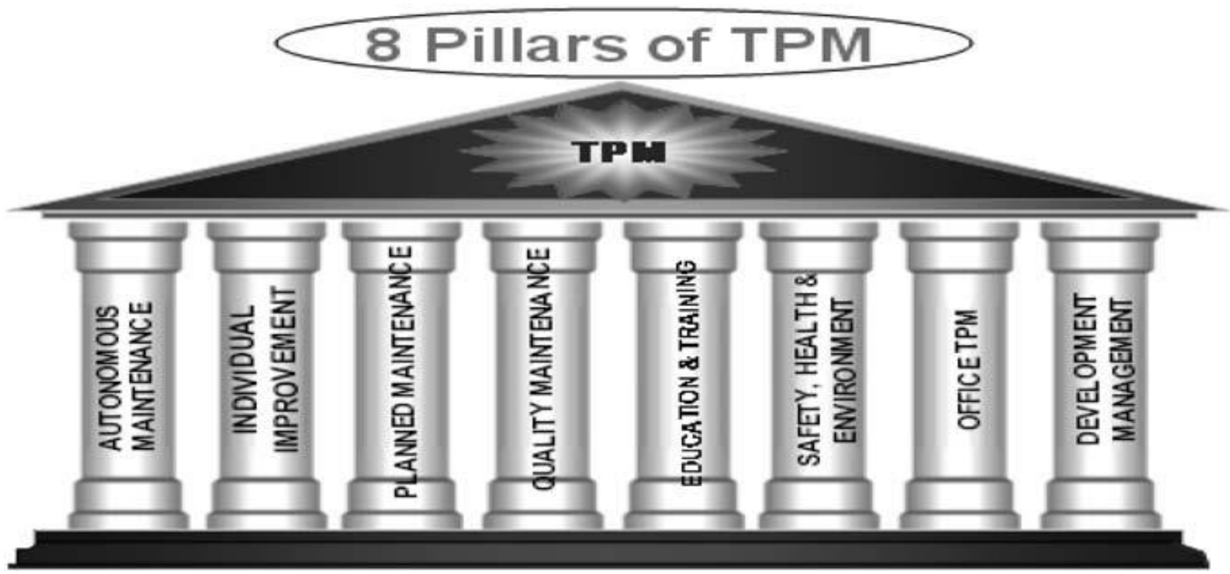


Figure 2.7
Eight Pillars of TPM
Source: Japan Institute of Plant Management

Nakajima (1989) has suggested that there are key implementation factors of autonomous maintenance such as progressive education and training, cooperation between departments, group activities, and prompt equipment problems treatment by maintenance department.

The benefits of TPM and autonomous maintenance have been addressed by several other authors (Nakajima, 1988; Jantan, Jantan, Nasurdin, Ramayah, & Ghazali, 2003;

Ahmed, Masjuki & Taha, 2005; Bamber,Sharp & Hides, 1999; Brah & Chong, 2004; Cooke, 2000; McKone, Schroeder, & Cua, 2001; Seng Jantan & Ramayah, 2005).

I. Obstacles to TPM Implementation

It has been reported in the literature that TPM implementation is not an easy task by any means. The failure of an organization to successfully implement a TPM program has been attributed to the various obstacles including lack of management support and understanding, lack of sufficient training, and failure to allow sufficient time for the evolution (Bakerjan, 1994).

Another significant contributor for failure of TPM implementation program is the organization's inability to obviate resistance to change. The resistance to change takes a number of forms, that is, reluctance of individuals to change roles (Riis *et al.*, 1997; Cook, 2000), inability to create dissatisfaction with the present situation (reason to change) (Maggard & Rhyne, 1992; Ireland & Dale, 2001), and inability to change organizational roles and culture (Patterson, Kennedy, & Fredendall, 1995; Lawrence, 1999). Moreover, Cook (2000) has attributed the failure of TPM implementation program to the inability of management to holistically implement the TPM practices at the workplace and highlights that serious deviations have been observed between officially laid out TPM policies and actual practices employed at workplace. Maintenance has been treated as an unnecessary evil and seen as an uncontrollable black box in the operation and development of manufacturing systems. Maintenance has been considered as a low profile job with its scope limited to breakdown and preventive maintenance. It has also been viewed as a reactive problem fixing and an operating expense to be minimized (Tripathy, 2005; Seth & Tripathi, 2005). In another study, Ahmed *et al.*, (2005) observed that the level of maintenance practices in Malaysian's SMI is still low priority due to lack of understanding of the importance of equipment in organizational performance, lack of technology and funding, and training, etc. (Ahmed, Hassan, & Taha, 2005). Section 2.6 explains the evolution of performance measurement.

2.6 Evolution of Performance Measurement

Performance measurement has its roots in early accounting systems. Johnson (1981) quotes the Medici accounts as an excellent example of how a pre-industrial organisation could maintain a good account of external transactions and stock without recourse to higher-level techniques, such as cost accounting.

However, as industrial organisations developed, so did their needs for measures and Johnson (1972) provides a detailed account of how current management accounting developed in the USA between the 1850s and 1920s as industrial organisations moved from piece-work to wages (Johnson, 1981), single to multiple operations (Johnson, 1975 & 1981), individual production plants to vertical integrated businesses (Johnson, 1975) and individual businesses to multi-divisional firms (Johnson, 1978). As a result, following the First World War, companies such as Du Pont, Sears, Roebuck, and General Motors were starting to use sophisticated budgeting and management accounting techniques (Chandler, 1962) such as standard costing, variance analysis, flexible budgets, return on investment and other key management ratios. From these beginnings, the use of budgets spread. A study showed that by 1941, 50% of well established US companies were using budgetary control in one form or another (Holden, Fish, & Smith, 1941) and by 1958, budgets appeared to be used for overall control of company performance by 404 out of 424 companies (just over 95%) participating in the study (Sord & Welsch, 1962).

However, between 1925 and the 1980s, there were no significant developments in management accounting (Johnson & Kaplan, 1987) and by the 1980s traditional accounting measures were being criticised as inappropriate for managing businesses of the day. Criticism focused on the dysfunctional behaviour traditional accounting based performance measures encouraged (Fry & Cox, 1989) especially when used inappropriately (Miller & Vollmann, 1985; Johnson, 1992).

In particular, they were criticised for encouraging short-term decision making (Banks & Wheelwright, 1979; Hayes & Garvin, 1982; Kaplan, 1984; and Pearson, 1985), their inapplicability to modern manufacturing techniques (Turney & Anderson, 1989; Kaplan, 1984; and Kaplan, 1986) and the damage they were causing to business and, therefore, the US economy (Hayes & Abernathy, 1980).

Traditional accounting based performance measures have been characterised as being financially based, internally focused, backward looking and more concerned with local departmental performance than with the overall health or performance of the business (Johnson & Kaplan, 1987; Keegan, Eiler, & Jones, 1989; Neely *et al.*, 1995; Olve, Roy, & Wetter, 1999). As a consequence, in the late 1980s and early 1990s there was a great interest in the development of more balanced performance measurement systems with the creation of frameworks such as supportive performance measures matrix (Keegan *et al.*, 1989), the SMART pyramid (Fitzgerald & Moon, 1996), the Results/Determinants

Matrix (Fitzgerald *et al*., 1991; Fitzgerald & Moon, 1996) and the Balanced Scorecard (Kaplan & Norton, 1992).

These frameworks overcame many of the shortcomings of traditional financially based accounting systems. However, despite criticisms (Argenti, 1997), with the recent growth of the concept of measuring the satisfaction of all the stakeholders (Ward, 1997; Doyle, 1994; Feurer & Chaharbaghi, 1995; Atkinson, Waterhouse, & Wells, 1997; Neely, Adams, & Kennerley, 2002) new frameworks are still emerging such as the Performance Prism (Neely *et al*., 2002). Otley (1998) points out those frameworks, on their own, are not a complete solution. Frameworks do provide different perspectives for categorising performance measures, allowing one to consider the balance between the demands on the business. But, they do not tell a company what to measure (Neely, Mills, Gregory, Richards, Platts, & Bourne, 1996) and there is no mechanism for specifying the objectives which should be met (Ghalayini & Noble, 1996). Performance measurement needs to be integrated into the management of the business (Lingle & Schiemann, 1996) and there are now management processes developed to do just this.

2.7 The Performance Measurement Revolution

Maintenance, a support function of production, is an integral part of operations, which in turn plays an important strategic role in business enterprise. So to appreciate the importance of maintenance performance measurement, one has to understand the broader concept of business performance measurement. What is it that makes the topic so relevant to management today? After all, it has long been recognised that performance measures are an integral part of the planning and control cycle (Barnard,

1962) and managers must have been planning and controlling the deployment of resources since the first organisation was established. Indeed, Chandler (1977) argues that most of the basic methods used to manage big businesses today were in place by 1910. In 1903, three Du Pont cousins consolidated their small enterprises with many other small single-unit family firms. They then completely reorganised the American explosives industry and installed an organisational structure that incorporated the "best practice" of the day. The highly rational managers at Du Pont continued to perfect these techniques, so that by 1910 that company was employing nearly all the basic methods that are currently used in managing big business (Chandler, 1977).

Given that the "basic management techniques" have been used for so long and that business performance measurement is undoubtedly one of these techniques, then surely most organisations should have had well developed performance measurement systems in place for many years by now. Even the most cursory examination of the academic and practitioner literatures would confirm that this is not the case (Ashton, 1997; Geanuracos & Meiklejohn, 1993; Kaplan, 1984; Neely, 1998; Neely *et al*., 1995). Numerous authors discuss the problems with the performance measures used by organisations today.

2.7.1 Financial Measures

Traditional financial measures are criticised because they:

i. Encourage short-termism, for example the delay of capital investment (Banks & Wheelwright, 1979; Hayes & Abernathy, 1980).
ii. Lack strategic focus and fail to provide data on quality, responsiveness and flexibility (Skinner, 1974).
iii. Encourage local optimisation, for example "manufacturing" inventory to keep people and machines busy (Goldratt & Cox, 1986; Hall, 1983).
iv. Encourage managers to minimise the variances from standard rather than seek to improve continually (Schmenner, 1988; Turney & Andersen, 1989).
v. Fail to provide information on what customers want and how competitors are performing (Camp, 1989; Kaplan & Norton, 1992).

The same measures are criticised for being historically focused (Dixon, Nanni, & Vollmann, 1990). Sales turnover, for example, simply reports what happened last week, last month or last year, whereas most managers want predictive measures that indicate what will happen next week, next month, or next year. However, with the advent of sophisticated forecasting measures of consumer and production trends, managers can now plan ahead to avoid surprises; the tools are out there that can be used to do just that.

Numerous managers suffer from data overload. Most firms have information systems which generate at least some redundant performance reports. Comments such as "we measure everything that walks and moves, but nothing that matters" are common. Yet another problem with the performance measures used in many organisations is that they are rarely integrated with one another or aligned to the business processes (Lynch & Cross, 1991). Performance measures are also often poorly defined.

In 1951, GE established a "Measurement Project" which "was intended to develop performance metrics that could be applied on a decentralised basis" (Meyer & Gupta, 1994). Johnson (1992) argues that "management by remote" control, i.e. managing by the financials, only became popular after the 1950s, before which time senior managers used the financial figures for planning, rather than control.

By the mid-1980s there were many vocal and well-respected critics of traditional measures (Berliner & Brimson, 1988; Goldratt & Cox, 1986; Hiromoto, 1988; Hopwood, 1984; Johnson & Kaplan, 1987; Miller & Vollmann, 1985; Richardson & Gordon, 1980; Schmenner, 1988; Turney & Anderson, 1989). The question this raises, however, is why now? What is it about managers in the late 1980s and early 1990s that has made them so receptive to the message that their performance measurement systems are obsolete? Why have these problems come to the fore today? Why have they captured management's attention? What sparked the performance measurement revolution? What has been the impact of this revolution? Where and when will it end?

Between 1994 and 1996, according to the American Business Institute (ABI) database, some 3,615 articles on performance measurement were published. This is equivalent to one new article on business performance measurement appearing every five hours of every working day. In 1996, new books on the subject appeared at a rate of one every two weeks in the USA alone. Between 1950 and 1991, the membership of AIA

(American Institute of Accountants) and AICPA (American Institute of Certified Public Accountants) grew from 16,062 to 301,410 - an increase of 1,877 per cent (Meyer & Gupta, 1994).

Chartered financial analysts did not exist before 1963. Through 1971, about 3,000 financial analysts were chartered. From 1972 through 1981, some 3,800 more analysts were chartered, but from 1982 through 1992 more than 8,200 new chartered financial analysts were added (Meyer & Gupta, 1994).

2.7.2 Reasons for Redesigning Business Performance Measures

To be effective, every company has to redesign how it measures its business performance. There are seven main reasons:

I. The changing nature of work - Traditional accounting systems allocate overheads on the basis of direct labor. In the 1950s and 1960s this was appropriate because direct labor often constituted in excess of 50% of the cost of goods sold. By the 1980s, however, direct labor rarely constituted more than 5 or 10% of the cost of goods sold, because of the massive investments that had been made in process automation. The net effect of this was that allocating overheads on the basis of direct labor resulted in wildly erroneous product costs, which in turn meant that managers made the wrong decisions (Kaplan, 1983; Schmenner, 1988). These arguments were so widely and vocally publicised that they resulted in the development of alternative methods of product costing, most notably activity-based costing and through-put accounting (Cooper, 1987a, b; Galloway

& Waldron, 1988a, b; 1989a, b). During the late 1980s and early 1990s, most of the major consultancies were selling services based on these new methods of costing. The associated marketing programs and the popularity of books such as Johnson & Kaplan's *Relevance Lost* meant that few in business could avoid being exposed to the message. That, given today's operating environment, the assumptions underpinning the traditional methods of cost accounting were fundamentally flawed.

II. Increasing competition - There can be little doubt that the level of competition that firms face is increasing on a global basis. Businesses all around the world are under continual pressure to reduce costs and enhance the value they deliver to their customers. Manufacturing businesses, such as Toyota, have revolutionised the way people think about operations through their search for greater efficiency and effectiveness (Monden, 1993). The widespread acceptance of so-called "Japanese manufacturing practices" demonstrate how successful they have been, but the net effect is a continual rise in global performance standards and customer expectations, which in turn lead to ever greater levels of competition (Womack, Jones, & Roos, 1990).

In terms of performance measurement, these changes have had two impacts.

First**,** many organisations now seek actively to differentiate themselves from their competitors in terms of quality of service, flexibility, customisation, innovation and rapid response. They have been forced to do so because they now find themselves competing in markets where value rather than cost is the primary driver. Competing on the basis of non-financial factors means that these organisations need information on how well they are performing across a broad spectrum of dimensions. If a business bases its strategy around its ability to customise products, then knowing whether it really is customising products, and whether it is customising them rapidly and cheaply enough, is essential. The traditional measures used to assess business performance simply do not provide this insight. Hence businesses have been forced to change their measures because they have changed their strategies. In doing so, many organisations have realised one of the hidden benefits of matching measures and strategies - namely that measures can encourage the implementation of strategy (Neely, Mills, Platts, Gregory, & Richards, 1994). It is widely accepted that performance measures influence behaviour. One only has to look at the academic obsession with refereed journal papers to see evidence of this. Accepting Mintzberg's (1978) thesis that when an organisation realises that the strategy is a function of the "pattern of decisions and actions" it takes, it then becomes clear that appropriately designed performance measures can encourage the implementation of strategy.

The second way in which the changing basis of competition has affected business performance measurement is in the tendency for organisations to downsize. Most organisations have achieved their downsizing goals by eliminating middle management and "empowering" the remaining employees. Anecdotal evidence suggests that empowering people can be very compelling, but only if those people know the overall direction in which the business is heading. Middle managers used to ensure that this was the case by translating strategic plans into operational targets, monitoring progress and generally co-ordinating the efforts and activities of their subordinates. Today, few organisations find themselves with sufficient human capacity to operate in this way. Hence they need new ways of communicating to their employees where the business is heading. Business performance measures provide one such means of communication.

III. Specific improvement initiatives - In response to increased competition, numerous organisations have embarked upon specific improvement initiatives. Some of these have come and gone, although most have been swept up into generic themes, such as TQM, lean production, WCM. Few would dispute that, of these, TQM has been one of the most pervasive. Open any undergraduate text on this topic and you will find discussions of continuous improvement, Deming (plan-do-check-act) cycles, statistical process control, Taguchi methods, and quality costing. All of these tools and techniques have one thing in common. They rely on performance measurement. The essence of continuous improvement, for example, is to seek constantly ways in which products and processes can be improved, so that greater value can be delivered to customers at ever greater levels of efficiency. Before any organisation can determine what it needs to improve, however, it has to establish where and why its current performance falls short, hence the need for performance measures. Similar arguments apply to statistical process control. Control charts provide a means of checking whether processes, generally repetitive manufacturing processes, are under control. That is whether the outputs they are producing vary only as much as would be expected, given the norms of statistical variation. Answering this question requires performance data to be collected. Without these data statistical process control quite simply cannot be introduced. Of course, TQM is not the only specific improvement initiative that has put performance measurement on the agenda. The widespread business interest in benchmarking has been another important driver. Xerox, largely through the efforts of Bob Camp, has been particularly vocal on this topic (Camp, 1989). The rapid emergence of benchmarking clubs and a number of high profile research studies (Andersen Consulting, 1993, 1994; IBM Consulting & London Business School, 1993, 1994; Womack *et al*., 1990) have also heightened industrial interest. In essence, however, benchmarking studies, especially those which compare performance rather than practice, are effectively structured applications of business performance measurement. Data, which summarise the performance of different businesses, are gathered and compared. Performance gaps, performance shortfalls, even performance advantages are identified. Such studies are valuable precisely because they provide rich performance insights. Often these performance insights result in organisations realising that they need to achieve radical performance improvements merely to survive, let alone prosper. One method for achieving these is business process re-engineering (Hammer & Champy, 1993). Instead of seeking to optimise the efficiency of each operation within each function, business process re-engineering calls for the horizontal flows of information and materials to be considered holistically when seeking performance improvements. This relies on a clear understanding of how the outputs of one micro process impact upon the next micro process, which in turn requires data to be fed back from the receiving process to the supplying process (Slack, Chambers, Harland, Harrison, & Johnston, 1995). Few organisations have measurement systems which allow this to happen, and rarely be the traditional measures of business performance appropriate. Measures such as labour utilisation, for example, might provide some insight into how efficiently a process is running, but provide no indication of the impact the outputs of one process have on the next process in terms of quality and time. One of the first things organisations realise, when they begin to re-engineer their processes, is that once they have done so they will have to re-engineer their measurement systems.

IV. Changing organisational roles - The 1980s and 1990s have seen subtle changes in organisational roles. Many of the most vocal critics of traditional performance measurement systems have come from the academic accounting community. As the force of their arguments has gathered strength, the professional accounting associations have reacted. In the UK, both the Chartered Institute of Management Accountants (CIMA) and the Institute of Chartered Accountants of Scotland (ICAS) regularly organise conferences and workshops on non-financial performance measurement. Both of these bodies encourage their members to take a more active role in the development of balanced measurement systems, arguing that the role of the management accountant is to provide the management information necessary for running a business, rather than merely the financial information required for external reporting. Human resource managers and personnel managers are another group of business professionals who are now taking a more active role in business performance measurement. There appear to be three reasons for this. First, performance measures tend to be integral to performance management systems - goal setting, measurement, feedback and reward (IPM, 1992) and these generally fall within the remit of the human resource function. Second, there is considerable debate as to whether performance measures should be linked to reward - again an issue which concerns human resources. Finally, many organisations have been through substantial downsizing programs in recent years. One of the challenges these organisations face is motivating the people who remain once the downsizing program has been completed. There are several examples of firms using performance measures to achieve this on the grounds that performance measures help clarify performance expectations, which in turn allow more discretion to be given to individuals as the boundaries within which they have to work become more obvious.

V. Changing external demands - Organisations today are subject to a wide variety of external demands, each of which has implications for business performance measurement. Deregulation in the UK's power generation, telecommunications and water industries, for example, has resulted in the establishment of various regulators. These regulators demand that the firms which fall under their jurisdiction achieve certain performance standards and have the power to fine those which fail to do so. To enable the regulators to assess whether the required standards are being met, firms in each of these industries have to submit detailed performance statistics on a regular basis. Businesses are being judged on sustainability aspect of their performance; the triple bottom line – people, planet and profit. Some customers today not only expect high levels of service, but also expect firms to operate in specific ways. The extent to which a customer can influence the way in which their supplier works is a function of many factors, a key one being power. Ford, for example, used their power as a major purchaser of automotive components, to demand that their accredited suppliers introduce a scheme known as quality operating system (QOS). Basically, QOS is a performance measurement process. Suppliers to Ford are expected to identify six key business parameters, record the relevant data in a format approved by Ford and submit the information to Ford on a monthly basis. When they introduced the scheme, Ford declared that they expected all accredited suppliers to show improvement in the majority of these parameters on an annual basis if they wished to remain accredited. In many ways, QOS is simply an extension of the various supplier accreditation schemes that came into being through the 1980s and beyond. In the automotive industry, moves have been made to rationalise these schemes as suppliers were being forced to achieve accreditation to slightly different standards by each of their major customers. These accreditation schemes were introduced for two reasons. First, to enable cost in the customer-supplier relationship, especially that associated with multiple inspections, to be reduced. Second, to help customers decide with which suppliers they should concentrate their business, as they sought to rationalise their supply base. As more and more organisations moved down this route, more and more suppliers are being asked to submit themselves for audit, again a form of business performance measurement. So once again external demands, i.e. those external to the business, come into play, as organisations are forced to improve their performance data in preparation for these audits.

VI. Power of information technology - The final driver in the performance measurement revolution is undoubtedly the power of information technology (IT). Not only has this made the capture and analysis of data far easier, but it has also opened up new opportunities for data review and subsequent action. Indeed the considerable effort that is being exerted by supermarkets on data mining is a case in point. The electronic point-of-sale systems used in most supermarkets provide an opportunity to monitor individual buying patterns and tailor discount offers to them to encourage them to shop in particular stores. Of course IT plays a role not only in data capture, but also in data analysis and presentation. There has been a rapid growth in demand for management information systems and executive information systems in recent years.

2.8 Who Needs to Monitor Maintenance Performance and Why?

Performance measurement is integral to business improvement; it is also well-established in the literature on performance evaluation that the performance of an organization should be appraised simultaneously, both in terms of its efficiency in resource utilization process and effectiveness in realizing the pre-determined goals (Mouzas, 2006; Asmild, Paradi, Reese, & Tam, 2007). This is because the overall performance measure has been derived as the product of efficiency and effectiveness measures, thereby neglecting either of these, provides an incomplete picture of the true performance of an organization (Ho & Zhu, 2004; Ho, 2007).

Though, performance can be defined as an appropriate combination of efficiency and effectiveness, there seems to be some inconsistency in the use of these terms in the existing literature on the subject matter. For the managers, these terms might be synonymous but each of these has their own distinct meaning.

While commenting on effectiveness, Keh, Chu, and Xu, (2006) observed that a measure of effectiveness assesses the ability of an organization to attain its pre-determined goals and objectives. Simply, an organization is effective to the degree to which it achieves its goals (Asmild *et al.*, 2007). In summation, effectiveness is the extent to which the policy objectives of an organization are achieved. It is significant to note that though efficiency and effectiveness are two mutually exclusive components of overall performance measure yet they may influence each other. More specifically, effectiveness can be affected by efficiency or can influence efficiency as well as have an impact on the overall performance (Ozcan, 2008).

Revision to ISO 9004 came off the press in the last quarter of 2009. It is considerably different from its predecessor; ISO 9004 exhibits' the quality management principles relating to continual improvement. The technical experts made bold efforts to address market needs by producing a standard that would help organizations maintain and improve their quality management systems over time. "Performance improvements" is a great idea, but more potent question is "what is the value in improving performance?"

That answer is found in ISO 9004's new title; "Managing for the sustained success of an organization - A quality management approach." It's not good enough to achieve ISO 9001, proudly displaying the coveted certificate on the wall; to conform to the requirements of ISO 9001, it's important to maintain the quality management system that has been established. It's important to consistently fulfill requirements found in multiple sub-clauses relating to establishing objectives (5.4.1), monitoring and measuring product and processes (8.4), reviewing changes that could affect the quality management system (5.6.3), and striving for continual improvement (8.5.1). The new ISO 9004, particularly the annexes, is heavily inclined toward monitoring and periodically assessing so that organisations can respond to change (ISO, 2009).

What gets measured gets done (Drucker, 1994); management requires performance information to be able to control the maintenance process. Information should bear on the state of the maintenance process and developments in it and the environment the maintenance function operates in. It focuses on the effectiveness and efficiency of the maintenance process, meaning its activities, organization and cooperation with other organizational units. Here the authors discuss performance indicators for evaluation of the maintenance activities only. Evaluation involves systematic, obdurate and meticulous application of scientific methods to assess the strengths and weaknesses of programs. It is a resource-intensive process; frequently requiring resources, such as, evaluator expertise, labor, time and a sizeable budget (Rossi *et al.,* 2004). Performance measurement is needed on all of the three levels of control. In a practical situation this means that performance indicators are needed by the maintenance manager, supervisors, foremen, and engineers as well as planners. Performance indicators are a numeric value for an aspect of a sub-process that isn't influenced by related processes and is representative as a measure for the effectiveness and/or efficiency of that aspect of the sub-processes (Chemicals, 1991). The absolute value of such indicators compared to a norm, to be chosen beforehand, or a trend in this value can be used to glean performance levels.

2.8.1 Why Measure Maintenance Performance?

Maintenance is a supporting function in any organization, especially an industrial one. It is part of the production process that transforms raw materials into final products. Geraerds (1992) defines maintenances as the total of activities serving the purpose of retaining the production units in or restoring them to the state considered necessary for fulfillment of their production function. Traditionally, maintenance was mainly an action-oriented function, the firefighters that solved production problems. Its objective was to keep the process running, i.e. availability maximization. Little time was spent on planning maintenance activities. This was called BDM or failure-based maintenance (FBM), maintenance which will not be carried out until the event of failure (Geraerds, 1992). This strategy was feasible as long as customer demand exceeds supply and profit margins were large. However, today we face global competition, small profit margins, high safety awareness and strict environmental regulations. Maintenance management tries to adapt to these changes by putting more emphasis on developing maintenance concepts, i.e. the collection of rules that prescribe which maintenance activities have to be performed and by what event these operations are initialized. Clearly, maintenance management needs to analyze what maintenance operations need to be performed on each item of equipment and how the maintenance needs to be initialized. The changes in the organizational environment cause a need for maintenance managers to concentrate on efficiency, safety and environmental concerns. Performance indicators are needed to give maintenance management quantitative information on the extent to which these goals are reached and what actions to take to improve its operations. There are means to achieve maintenance control, so that maintenance costs can be reduced, productivity can increase, safety of the process can be achieved and environmental regulations can be fulfilled. These objectives of maintenance are omitted in the definition of maintenance from a functional viewpoint, given by Geraerds (1992). The definition used by an organization in the process industry includes most of these objectives explicitly (Chemicals, 1991). All servicing activities are needed to ensure the availability of capital equipment in an economical optimal way for the fulfillment of its designated function. Maintenance in the discrete units manufacturing industry is different from that in the process industry. These differences cause a need for the other specific performance indicators, beyond the scope of this study. However, in the capital intensive industries, production is generally on a continuous basis. Therefore, availability of production equipment is even more important. This makes the maintenance function an important part of such an organization, as well.

2.9 Description of the Maintenance Management Information System Required to Measure Performance

Three levels of control can be distinguished, depending on the time horizon. At each level certain decisions need to be made, for which performance indicators can be used. The levels are:

2.9.1 Strategic Planning

Strategic planning is the decision-making process leading to the formulation of the strategy of an organizational unit or the organization as such (Gits, 1991). In the strategy, the objectives to be reached and the means with which to reach those objectives are developed. For the maintenance function, the strategy is deduced from the company strategy and the preferences of the production function. The selection or statement from a maintenance point of view of the design requirements of production units to be developed or purchased is considered to be made on this level. The LCC theory, estimating all cost factors including maintenance during the life of the production unit, can be used to support the selection or design decision.

2.9.2 Tactical Control

Tactical control consists of all decisions contributing to the policy making concerning effective and efficient use of resources (Gits, 1991). This leads to categorization of maintenance based on its urgency (time within which maintenance has to be performed) and the influence that the production function has on scheduling of the maintenance actions. On this level the capacity load per category is restricted; the volume flexibility of the different capacities is limited as well as the work load of the maintenance function. The decisions made in developing maintenance concepts for production units are also considered on this level of control. These decisions include the efficiency of different potentially effective maintenance rules or the selection of inspection frequencies.

2.9.3 Operational Control

Operational control is the decision making process aimed at the effective and efficient execution of specific activities. It concerns the short term allocations of maintenance capacity to maintenance demand and results in work orders (Gits, 1991). Decisions concerning to maintain now or later, maintain or replace, use contractors or work overtime. This consideration concentrates on performance indicators that support decisions at this level of control in the maintenance control system. Since data for performance indicators originate from the maintenance management information system (MMIS) used by the maintenance organization, they need to describe what they want the MMIS to look like, if they want to glean useful performance information from it.

2.10 Maintenance Management Performance Evaluation

There are various key performance measuring tools being applied in the industry, depending on the strategies adopted, however, TPM's KPIs (Metrics) are described here, in brief. For the purpose of this study, OEE has been described in detail. TPM seeks to improve OEE, which is an important indicator, used to measure TPM. An overall 85-95% of OEE is considered as world class and a benchmark for others (Blanchard, 1997; McKone, Roger, & Kristy, 1999; Chand & Shirvani, 2000; Wireman, 2004).

2.10.1 Mean Time between Failures (MTBF)

The first metric for TPM is MTBF (Mean Time between Failures). This is measured by machine, and for this metric, the larger number the better it is. This means that breakdowns are less frequent, and that repair costs are lower. That can be measured as a direct cost savings when compared on an annual or quarterly basis. Indirectly, less downtime could mean more production output.

2.10.2 Mean Time to Repair (MTTR)

Mean Time to Repair (MTTR) is the second metric. For this metric, the smaller the number the better it is. As TPM progresses, repairs are less serious and are quicker. Tracking repair hours and showing an overall reduction is a direct cost savings. Another cost savings is in avoiding expedite charges and added downtime by creating a spare parts list and identify sources of critical components.

2.10.3 Percent Reactive Maintenance

The third metric is 'Percent Reactive Maintenance' (% Reactive). The smaller the number the better it is. World class is 20% or less reactive and 80% preventive, improvement, or scheduled maintenance. The best way to show direct cost savings for this metric is when repairs that were previously outsourced can be done in-house because of less reactive activity, and because of time spent improving maintenance technicians' skills. Indirect benefits include using the same maintenance hours to speed up machines or improve quality.

2.10.4 OEE and Maintenance Performance Evaluation

With the increasing awareness that maintenance not only ensures safety and track performance, but also creates additional value in the business process, the Swedish Rail Administration (Banverket, 2007) is treating maintenance as an integral part of the business process, i.e. applying a holistic view of the infrastructure maintenance process in order to fulfil customer requirements (Karlsson, 2005). Maintenance is an activity that has a significant contribution in operation costs; approximately 30% of operation costs, if the company is implementing an automated production system (Garg & Deshmukh, 2006). Therefore, measurement of maintenance performance has become an essential element of the strategic thinking of assets owners and managers. Without any formal measures of performance, it is difficult to plan, control, and improve the maintenance process (Liyanage & Kumar, 2000).

Every factory attempts to be an effective, low cost producer. This effort is required in today's challenging environment when customers demand quality product at the best value. Few factories attain and maintain high level productivity and low costs. Many of these use a disciplined approach to identify the best improvements to make. They use teams to eliminate the root problems that otherwise keep the factory from driving towards continuously higher levels of effectiveness. In short, they have found the power of OEE. World-Class manufacturing areas share two common characteristics. They are data driven, and are led by synergistic multi-function leadership teams. Accurately measuring and driving key success parameters that contribute to higher productivity for both the area and the planet; OEE can help you better understand how well a manufacturing area is performing, and identify what is limiting higher effectiveness.

Manufacturing systems are composed of equipment and machinery that combine to transform materials and sub-assemblies into products that are either part for the next step of manufacturing or finished goods. A significant amount of capital is often invested to design, build, and implement a system so that products can be made uniformly at a higher rate with minimal waste. Every business plan should include projections about effectiveness of the proposed system and how well it will contribute to the bottom line. The company should also be aware of the degree to which it is at risk if the expected effectiveness is not attained and sustained.

Nearly every industry has multiple manufacturers, each competing for its share of the market. Even a company with the best product may not stay in business if its expense for getting the product to the customer is excessive, fierce competition usually exists. Companies with the most effective factories will have the staying power to be the long-term survivors. In short, factories are at the core of any manufacturing organization. Staying in business requires building and maintaining effective factories.

At any given factory, a vast number of events occur simultaneously every workday. The task of producing goods and maintaining equipment usually hold the central focus. However, take a moment to think about all the activities which go on and how and when they impact the manufacturing process. Decisions made in purchasing today set in motion a timeline for each item ordered and used. How well a piece of equipment is repaired today will influence some future runtime. In the spare parts warehouse, if a bearing is accidently dropped on the floor today, and re-shelved for later use, the piece of equipment that eventually uses it may have a shortened life. Approval or rejections of various projects can affect overall operations for years to come. Hiring and training decisions by human resources set the stage for subsequent events. In short, all the pieces of a factory interlock; one event eventually affects all. Left on their own, all these elements can create a chaotic, reactive environment full of surprises.

What makes the difference between world class manufacturers and the rest of the pack? World-Class organizations have evolved from a factory of individuals to a factory of coordinated teams working together with a common purpose. All areas have win-win relationships with their interdependent areas, a relationship of interconnection. They make certain that decisions are made correctly the first time. They balance production and production compatibility appropriately. They are in control of the ‘big picture’; they have engaged every one’s support in working toward a high level of excellence and sustaining that position. The bottom line; they know where they are and where they are going.

Having an effective factory is not the only requirement of a successful business. Many other factors are also important. Which way is the economy going to move? Will the competition cut prices? Is the product in demand? Will the product evolve into another? What are the distribution channels for the product? Should the source of supply be in one place or several? World-Class companies continually address these and other questions as they shape and modify their business plans. World-Class companies are known for another attribute. They are built around the concept that an affective factory producing ‘good goods’ as needed to meet market demands is a valuable asset for any company to have. This attribute is maintained both, short and long term. One of the main metrics used to identify World-Class companies addresses how effectively factories run their processes when scheduled to run. OEE is designed to provide this number; yet most factories do not compute OEE or use it to set and maintain their priorities (Hansen, 2001).

OEE is an index frequently used in the manufacturing industry to calculate the overall equipment effectiveness of a production system or parts of it. The index itself was presented as an overall metric in the TPM concept (Nakajima, 1988). OEE is an aggregated productivity measure that takes into consideration the six big losses that affect the productivity of equipment in production systems (Venkatesh, 2006). Equipment failure, setup, and adjustments are related to the downtime and expressed in terms of availability. Idling and minor stoppages, together with reduced speed, are related to speed losses and expressed in terms of the performance rate. Finally, process defects and reduced yield are related to defects and expressed in terms of the quality rate. OEE itself multiplies the equipment's availability, performance rate, and quality rate. The three factors involved in this calculation are independent of each other; i.e. variations in one of the three factors will not affect the other two. Normally, OEE figures can be found from 30-95% (Ljungberg, 1998; Ahlmann, 1995).

The definition varies among applications by different industries, and therefore it is difficult to identify the ideal OEE figures as well as compare the OEE figures among different companies (Jonsson & Lesshammar, 1999). Generally, availability is defined as the ratio of the actual uptime and the intended uptime, the performance rate as the ratio of the actual production time and the intended production time, and finally the quality rate as the ratio of the good items produced and the total amount of produced items. The availability and performance rate normally refer to the loading and operating time (Nakajima, 1988) or the planned time and amount of production (De Groote, 1995). Various aspects of OEE can be found in the literature. The availability metric is targeted in these discussions. Some authors claim that the availability metric is influenced by factors beyond the equipment itself, such as operators, facilities, the availability of input materials, scheduling requirements and many more; i.e. the OEE metric reflects the integrated equipment system and not the equipment itself (De Ron & Rooda, 2005, 2006). Others argue that the OEE metric does not take into consideration all the factors that reduce the availability, such as the planned downtime and the lack of material and labor (Ljungberg, 1998; Sheu, 2006). It is likely that the figure might be overstated and the mill's OEE would be higher than it genuinely is. Operators could also be tempted to record 'target' figures. This means that if the operator is allowed to take 60 minutes to set-up the mill equipment he or she may always take 60 minutes, or record 60 minutes, even if it is less. It matters, if the mills do not find out the actual performance level of their equipment, they may not utilize their equipment to its full potential and miss the chance to improve OEE and performance of their investment.

2.11 Malaysian Palm Oil Industry: Scope, Importance & Challenges

2.11.1 Malaysian Palm Oil Industry and Palm Oil Mills

Oil Palm, a native of West and Central Africa, originally introduced to South East Asia more than a century ago, is a miracle crop. It is prolific, perennial, provides forest cover and requires only a marginal investment compared to other oilseed crops. It has an unlimited future and is the most sought after oil for food, cosmetics and industrial uses. The Malaysian Oil Palm industry has a long history of development and over the past 90 years from 1917 to 2007, it has achieved tremendous success and will continue to be one of the main pillars of the Malaysian economy when projected over the next 100 years to 2107 (Wahid, Chan, & Masri, 2009).

The total oil palm planted areas showed a modest increase of 4.3% to 4.48 million hectares in 2008. The national average FFB yield increased by 6% to 20.18 ton/ha/yr compared to 19.03 t/ha/yr achieved in 2007; which is a record since 1994. In addition, the expansion in matured area by 151534 hectare coupled with the improvements in the national average OER to 20.18% also contributed to the higher CPO production. The average oil yield/ha posted a 6.5% year-on-year increase to 3.7 t/ha, the highest since 1987. The production of CPKO also rose by 11.7% to 2.13 million tons (MPOC 2010).

Although palm oil area growth in Malaysia has been slowing, particularly in Peninsular Malaysia, further expansion in area in the Malaysian Sabah and Sarawak provinces on the island of Borneo are expected to increase. By contrast, the area planted with oil palm in Indonesia has been growing fast in the past few years and has the potential to continue expanding particularly in Kalimantan province in Borneo.

Translating oil palm areas into palm oil production volumes requires a forecast of future palm oil yields. For this forecast Carter *et al.* (2007) provide a picture of what can be expected in terms of palm oil production. As yields are much more volatile in Indonesia than in Malaysia, the clear trend in Malaysian yields were used to estimate the yield forecasts for both producers. Based on calculation, Malaysian palm oil yields have been increasing by almost 0.03 tons (i.e. almost 30 kg) per year. This trend for Malaysia was used and assumed that Indonesia will be able to increase yields from their current level at this rate. Thus, the forecast with a continuation of the past trends in the growth in yields, the global production of palm oil, with plantings responding to high prices, would be expected to increase by 20 million tons from the level in 2005 to almost 54 million tons by 2012, with the two main players continuing to account for 88% of the world output (Carter *et al.,* 2007).

2.11.2 CPO Biodiesel Prospects

With crude oil prices soaring, vegetable oils are the new sources of energy. Palm oil, compared to other vegetable oil (e.g. soybean, rapeseed) is a cheaper raw material for biodiesel and is the most abundantly produced vegetable oil in the world (Ramachandran, 2005). According to Basiron (2008a) biofuel and biodiesel demands are changing the dynamics of the palm oil industry. EU is now the major user of vegetable oils for fuels and is expected to remain so in the medium term due to its increased target for biofuel usage. Therefore, the higher demand for vegetable oil for biodiesel in Europe has contributed to increased supply pressure. Given the scenario in Europe and in the US, it would be difficult for their domestic vegetable oils to provide the raw materials needed. Therefore, the palm oil has to play the role in filling the supply gap for food and other applications. Expectedly, more palm oil will be going to biofuel production (Butler, 2008a). European governments are trying to promote the use of biofuel, notably biodiesel derived from vegetable oils and ethanol that can be produced from grains, sugar or biomass, to cut GHG emissions from fossil fuels (Ramachandran, 2005). As such, the EU became the second largest importer of palm oil in 2008 just behind China, almost exclusively on the basis of its use as a fuel. Industrial use of palm oil in the EU 2010 was estimated at 2.1 million tons, with about 1 million of that for fuel. This fuel was mostly used for generating electricity in power plants rather than in automobiles or trucks. This important development in the palm oil industry has prompted the dramatic increase in production of biofuel from palm oil as well as the development of new biofuel markets like the European Union (EU). As such, biofuel from palm oil are taking on significant global importance as many countries seek to substitute the soaring price of conventional oil and also cut GHG emissions. With high petroleum prices, palm oil as an alternative source of fuel puts the palm oil industry in big global business (Smith, 2006). For Malaysia, being the leading producer and exporter of palm oil, catering to the local and global demands for biofuel means increase in production and expansion to new markets. Many analysts believe that biodiesel usage has the potential to become the biggest component of growth in vegetable oils. This undoubtedly is a strong catalyst for the palm oil industry to improve productivity to meet the growing demand. Certainly, the growing palm oil industry has been an important source of foreign exchange and employment in countries like Malaysia and Indonesia.

The investors, for the bio-diesel projects, included those from Italy and Singapore. The German trains' operator, 'Prignitzer Eisenbahn Arriva AG' is working with MPOB on the use of oil palm biodiesel to run trains in Germany. According to reports, the trial run in September 2005 had been promising and Prignitzer had ordered 100 tons more palm biodiesel from Malaysia (POIC, 2009). In another development, Neste of Finland opened its biodiesel plant in Singapore in 2011. The plant with annual capacity of 800,000 tons of biodiesel would be the worlds largest and a potential market for

Malaysian CPO. The government has issued 60 biodiesel manufacturing licences as of February 2011. However, by the end of 2010, out of the 29 established plants with an installed annual capacity of 3.37 million tons, only 10 were operational. Malaysia produced only 170,000 tons of biodiesel in 2011 (MPOB, 2012).

Research results have shown that CPO can be used directly as a fuel for cars with suitably modified engines. Palm oil is also used for non-food products important applications such as diesel, engine lubricants, drilling mud, base for cosmetics, and many more (Butler, 2006). A more detailed study on the material flow chain of palm oil-based diesel production was conducted by Smith (2006). The material flow starts where palm oil is cultivated in oil palm plantations, the harvested fresh fruit bunches delivered to crude palm oil mill where CPO is extracted and finally delivered to a refinery where 'NExBTL-diesel' is produced through hydro-treatment process. The crude palm kernel oil (CPKO) is not used in 'NExBTL-production' (Neste Oil, 2008).

MPOB is the premier government agency entrusted to serve the country's palm oil industry. Its main role is to promote and develop national objectives, policies and priorities for the Malaysian palm oil industry. It was incorporated by an Act of Parliament (Act 582) and established on May 1st. 2000, taking over, through a merger, the functions of the Palm Oil Research Institute of Malaysia (PORIM) and the Palm Oil Registration and Licensing Authority (PORLA). Ever since, MPOB has played an active role in developing new technologies which have contributed to the advancement of the Malaysian palm oil industry (Basri, Chan, & Basiron, 2002).

2.11.3 GAP and EU-RED

GAP, a framework for good agricultural practices, is a means of incorporating Integrated Pest Management (IPM) and Integrated Crop Management (ICM) practices within the framework of commercial agricultural production. Adoption of IPM/ICM is regarded by EUREP members as essential for the long-term improvement and sustainability of agricultural production. EUREP supports the principles of and encourages the use of 'Hazard Analysis Critical Control Points' (HACCP). It is essential that all organizations involved in the food production chain accept their share of the tasks and responsibilities to ensure that GAP is fully implemented and supported. If consumer confidence in fresh produce is to be maintained, such standards of good agricultural practice must be adopted, and examples of poor practice must be eliminated from the industry. To achieve these objectives the directive established, for each member state, a mandatory national target for the overall share of energy from renewable sources in gross final consumption of energy. This target was set on the basis of the different starting points of the various countries. In order to ensure consistency in transport fuel specifications and availability, the 10% target for the transport sector was set at the same level for each member state. EU-RED Directive, exclusively for trade in biofuels mainly pertaining to the sustainable criteria feedstock meant for EU's energy and transportation sector, established a set of sustainability criteria for biofuels and bio-liquids. According to the directive, only biofuels and bio-liquids (including those imported and/or obtained from raw materials cultivated outside the territory of the EU Community) that fulfill these criteria can be taken into account for the following purposes: Measuring compliance with the requirements of this Directive concerning national targets; Measuring compliance with renewable energy obligations; and Eligibility for financial support for the consumption of biofuels and bio-liquids. The sustainability criteria established by the directive relate mainly to the following environmental aspects/issues: Biodiversity; Protection of rare, threatened or endangered species and ecosystems; and GHG emission savings (Ismail & Rossi, 2010). Considering sustainability, it is important to distinguish between RSPO membership and RSPO certification. RSPO certification is the approval given to palm oil produced on a plantation that has been certified through a verification of the production process by a certifying agency and the RSPO certified oil is traceable through the supply chain. RSPO membership does not constitute an assured RSPO certification. The RSPO certification process for palm oil mills has resulted in increased production costs with upward trend of labor, maintenance and consumables mainly due to the environmental compliance requirements; however, the palm oil so certified is in high demand and easily marketable. In order to facilitate this process it is essential for palm oil industry to adopt best practices in manufacturing and maintenance.

2.11.4 Palm Oil Production Process and Developments in Milling Technology

The following processes are merely described and do not discuss the different handling techniques, problems and its effects associated in each process; e.g. bruising of fruits during harvesting, contamination, rancidity and others.

I. **Harvesting** - As fruit ripen, FFBs are harvested using chisels or hooked knives attached to long poles. Each tree must be visited every 10-15 days as bunches ripen throughout the year. Harvesting involves the cutting of the bunch from the tree and allowing it to fall to the ground by gravity. These fruit bunches (each bunch weighing up to 25 kg) are then collected, put in containers and transported by trucks to the factories (Poku, 2002); FFBs arriving in the factory are weighed accordingly.

II. **Threshing** (removal of fruits from bunches) - The FFB consists of fruits embedded in spikelets growing on a main stem. Manual threshing is achieved by cutting the fruit-laden spikelets from the bunch stem with an axe or machete and then separating the fruits from the spikelets by hand. Children and the elderly in the village earn income as casual laborers performing this activity at the factory site. In a mechanised system, a rotating drum or fixed drum equipped with rotary beater bars, detach the fruit from bunches, leaving the spikelets on the stem (Poku, 2002).

III. **Sterilisation of bunches** - Sterilisation or cooking means the use of high temperature wet-heat treatment of loose fruits. Cooking normally uses hot water while sterilisation uses pressurised steam. Cooking typically destroys oil-splitting enzymes and arrests hydrolysis and auto-oxidation, weakens the fruit stem and makes it easy to remove the fruits from bunches, helps to solidify proteins in which the oil-bearing cells are microscopically dispersed, weakens the pulp structure, softening it and making it easier to detach the fibrous material and its contents during the digestion process and breaks down gums and resins.

IV. **Crushing process** - In this process, the palm fruit is passed through shredder and pressing machine to separate oil from fibre and seeds (kernel).

V. **Digestion of the fruit** - Digestion is the process of releasing the palm oil in the fruit through the rupture or breaking down of the oil-bearing cells. The digester commonly used consists of a steam-heated cylindrical vessel fitted with a central rotating shaft carrying a number of beater (stirring) arms. Through the action of the rotating beater arms the fruit is pounded. Pounding, or digesting the fruit at high temperature, helps to reduce the viscosity of the oil, destroys the fruits' outer covering (exocarp), and completes the disruption of the oil cells already begun in the sterilisation phase (Poku, 2002).

VI. **Extracting the palm oil** - There are two distinct methods of extracting oil from the digested material. One system uses mechanical presses and is called the "dry" method while the other called the "wet" method uses hot water to leach out the oil.

In the "dry" method, the objective of the extraction is to squeeze the oil out of a mixture of oil, moisture, fibre and nuts by applying mechanical pressure on the digested mash. There are a large number of different types of presses but the principle of operation is basically the same. The presses may be designed for batch (small amounts of material operated upon for a time period) or continuous operations (Poku, 2002). A unique feature of the oil palm is that it produces two types of oil, palm oil from the flesh of the fruit, and palm kernel oil from the seed or kernel. For every 10 tons of palm oil, about 1 ton of palm kernel oil is also obtained. Several processing operations are used to produce the finished palm oil that meets the users' requirements. The first step in processing is at the mill, where CPO is extracted from the fruit (Poku, 2002).

VII. **Kernel recovery** - The residue from the press consists of a mixture of fibres and palm nuts which are then sorted. The sorted fibres are covered and allowed to heat by own internal exothermic reactions for about two or three days. The fibres are then pressed in spindle press to recover second grade (technical) oil that is used normally in soap-making. The nuts are usually dried and sold to other operators who process them into palm kernel oil. Large-scale mills use the recovered fibres and nutshells to fire the steam boilers. The superheated steam is then used to drive turbines to generate electricity for the mill. For this reason it makes economic sense to recover the fibres and to shell the palm nuts. In the large-scale kernel recovery process, the nuts contained in the press cake are separated from the fibres in a depericarper. They are then dried and cracked in centrifugal crackers to release the kernels. The kernels are normally separated from the shells using a combination of winnowing and hydro-cycloning. The kernels are then dried in silos to a moisture content of about 7% before packing (FAO, 2002).

VIII. **Refining process** - After the process of extraction, CPO goes through a refining process to become refined oil. The refined oil will undergo a fat segregation process to get refined palm oil. Finally, the refined palm olein which is a part of fractionation process will be used in related industries (Poku, 2002).

IX. **Oil storage -** Palm oil is stored in large steel tanks at 31 to 40°C to keep it in liquid form during bulk transport. The tank headspace is often flushed with carbon dioxide to prevent oxidation. Higher temperatures are used during filling and draining tanks. Maximum storage time is about 6 months at 31°C (Poku, 2002).

Carter *et al.* (2007) forecast that the future palm oil supply depends on the ability to mechanise, the potential for improving yields and the scope for expanding the oil palm areas in Malaysia and Indonesia, since ultimately they will determine the palm oil supply for decades to come. Much of the technology used in a conventional palm oil mill can be attributed to the comprehensive research carried out in Congo in the 1950s as reported in the Mongana Report (1952-1955). The spectacular growth of the palm oil industry in Malaysia since the 1960s did not lead to any significant advances in the process used for extracting oil and kernels from fresh fruit bunches. There is increasing awareness of the need for the palm oil industry in Malaysia to upgrade in order to remain viable and competitive in the light of various new challenges including; more stringent environmental regulations, labor shortage and competition from other palm oil producing countries. Acute labor shortage has made the palm oil industry in Malaysia highly dependent on migrant workers (Sivasothy, Basiron, Anhar, Ramli, Tan, & Mohammad, 2006); automation in the milling and refining processes of palm oil could help solve the labor shortage problem.

Progress in palm oil milling would have been difficult without central intervention. With the help of Palm Oil Research Institute of Malaysia (PORIM), new concepts could be researched and experimented using central funds and the equipment manufacturers with new designs or concepts were able to approach PORIM for joint evaluation trials (Basiron & Chan, 2004). Developments of new technologies for oil extraction such as Steam less palm oil extraction, new system for continuous sterilization of oil palm fresh fruit bunches, Flottweg Drupalm Process, and new boiler technologies developed through joint ventures with ‘Vyncke NV’ and ‘Ansaldo Volund A/S’ are reflective of sound PORIM’s technical support to the industry (Schuchardt, Darnoko, Herawan, Erwinsyah & Gurintno, 2001). However, milling operations of Palm Oil Industry need to automate and, in addition, the palm oil industry needs to exploit the potential benefits of maintenance function in order to enhance productivity.

Recent development in the palm oil milling sector involves new process for ‘continuous sterilization’ in palm oil mills. Laboratory-scale pilot studies on a new process for continuous sterilization demonstrated its technical and economic viability. A commercial-scale system was subsequently built in the MPOB Palm Oil Mill Technology Centre (POMTEC) in Labu, Negeri Sembilan. In the new process, the closed-knit arrangement of the spikelets in bunches is first disrupted using a double-roll crusher. The FFB are then heated using live steam at low pressure to facilitate continuous processing. Continuous sterilization process provides the impetus for new paradigms in the design and operation of palm oil mills. The use of technology that is simple and uncomplicated ensures that the system is competitively priced. It eliminates the use of sterilizer cages, rail tracks, overhead cranes, tippers, transfer carriages and tractors and thereby facilitates the design and construction of mills having significantly smaller footprints than conventional mills. It will lead to an overall improvements in the design of mills, reduce the number of process operators, lower the operating and maintenance costs, and simplify mill operation. Mills using the process can be more easily supervised and automated. By avoiding the use of pressure vessels for sterilization and cages and cranes for the handling of bunches, palm oil mills are made safer for operators. The use of conveyors in place of cages also minimizes spillage of fruits and oil, making mills cleaner (MPOC 2010).

A significant advantage of continuous sterilization over batch sterilization is that it renders the palm oil milling process a continuous operation from start to finish, making it cost-effective to automate the bunch handling operations. A plant-wide control system can now be used to facilitate overall monitoring and control of the mill from a control room. Mills should automate for the following three reasons: compelling issues such as labor shortages, more stringent regulations, increasing environmental concerns and escalating production costs; significant advances in automation technology in recent years, spurred on by hardware and software developments in information and communication technology (ICT); and continuous sterilization which makes palm oil mill automation cost-effective. In order to improve efficiency of palm oil mills PORIM introduced the milling certificate of competency (MCC), the scheme was started in 1984 by the Chemistry and Technology Division, of PORIM. The number of mills certified to date, is 200.

As palm oil is a late comer to the oils and fats scene, the persistent efforts in promoting its hygiene, technical and nutritional attributes have been successful in convincing many new users that palm oil production is hygienic, its products versatile and consumption wholesome, thereby opening up many new markets.

2.11.5 Sustainability and the Roundtable on Sustainable Palm Oil

The increasing global attention and concerns about the various environmental and social impacts of palm oil production has raised the issue of sustainability. This is highlighted by the recent criticisms and accusations to the industry over health, environmental and social issues associated with palm oil production in developing countries particularly in Malaysia and Indonesia (Oh, 2004). These include allegations that oil palm cultivation had led to deforestation, pollution and social conflicts among other things. Industry players have often characterised these issues as anti-palm oil smear campaigns but it is clear that they cannot afford to ignore the fact that others are watching closely the practices of the industry (Oh, 2004). However, with the growing palm oil demand and consumption worldwide, large-scale palm oil production is now saddled with the very fundamental question of "compatibility with sustainable development". Oh (2004) pointed clearly about the concerns that further expansion and larger scale of production cannot go on for long if oil palm is grown purely to fatten the economic bottom line without taking into account the long term needs of society and environment; the key word is sustainability.

Malaysia has been an active member of RSPO with government agencies and private companies like MPOA, FELDA, Golden Hope Plantation Bhd. and United Plantation Bhd. taking important roles and positions in the organisation. In fact, MPOA and Golden Hope were among the founding members of RSPO in 2004 while MPOA and FELDA are current Executive Board members of RSPO. By November 2011, RSPO comprised of 722 member companies from close to 50 countries around the world. RSPO has three categories of membership. Ordinary Membership (OM) consists of the main players in the palm oil supply chain, namely; the oil palm growers, processors and traders, manufacturers of consumer goods, retailers, banks and investors, environmental NGOs and social or developmental NGOs. The global production of CSPO reached 5 million tons in 2011, 10% of global palm oil production (RSPO, 2012).

With huge support from those in palm oil industries, this RSPO’s initiative on principles and criteria is hopefully a progressive step towards sustainable palm oil production (Tan, 2007). They have been described as the world's toughest standards for sustainable agriculture production and have been variously adapted for other crops. No public claims relating to sustainable palm oil production, to the RSPO P & C, can be made without RSPO approved third party inspection.

As traditionally practiced in Southeast Asia, oil palm cultivation is responsible for widespread deforestation (forest loss) particularly in leading palm oil producing countries as Malaysia and Indonesia (Oh, 2004; Butler, 2007a). When the industry saw a surge in planted area from the 1990s, the government in Malaysia has started to intensify laws on the preservation of the environment, and such laws included the Protection of Wildlife Act 1972 (Basiron, 2007). In the recent past, by subscribing to RSPO, some producers have started to adopt the guidelines for environmentally sustainable palm oil production. Another concrete example is the government’s ban on the establishment of palm oil plantations in natural forests areas and peat lands (Butler, 2007b). To date, Malaysian oil palm cultivation takes place only over previously logged land, and mainly on land converted from rubber, cocoa and coconut cultivation. Additionally, the government has stopped the opening of new forest land for agriculture since the 1990s (MPOC, 2007a). Other initiatives recently forwarded by the Malaysian government, producers and owners include among others; comprehensive review of environmental impacts of oil palm plantations, creation of riparian reserves along rivers and oxbow lakes, establishment of wildlife corridors, and promotion of biological pest control measures (Basiron, 2007).

Pride (2006) wrote that FELDA has been very active in providing support for the socio-economic development of the many rural Malaysians whose livelihood depends on palm oil. Various infrastructure facilities such as housing, roads, rural clinics, rural schools, educational loan funds, transport systems among others, have been built and upgraded through the years. Well-organised and well-managed over a long period of time, plantations are the established centres of economic and social life of entire communities in the rural heartlands of Malaysia today. The question of how effective the implementation of those policies and regulations is another point of discussion. However, there is a strong legislative framework that many companies in the industry must abide by the "polluter pays principle" was adopted in Malaysia to assess the amount of fee to operate the palm oil mill premises. The amount of effluent-related fee payable to the Government was linked to the biochemical oxygen demand (BOD) load of the effluent discharged either onto land, watercourse or both (Idris, 2003). Likewise, all oil palm planters, including smallholders pay a windfall tax that took effect on 1st July 2008 (Business Times, 2008).

2.11.6 Waste and Pollution from Palm Oil Production and Management

The two main wastes resulting from palm oil production in a mill are the solid and liquid wastes. Solid wastes typically consist of PKS, mesocarp fruit fibres (MFF) and EFBs. The liquid waste generated from the extraction of palm oil of wet process comes mainly from oil room after separator or decanter. This liquid waste combined with the wastes from steriliser condensate and cooling water is called POME (ADB, 2006). Air emission from the oil palm mills are from the boilers and incinerators and are mainly gases with particulates such as tar and soot droplets of 20-100 microns and a dust load of about 3000 to 4000 mg/nm. Incomplete combustion of the boiler and incinerator produce dark smoke resulting from burning a mixture of solid waste fuels such as shells, fibres and sometimes EFBs. These boiler fly ashes are also wastes and pose problems of disposal.

From the palm oil mills, according to the Asian Development Bank (ADB) study, the impacts of palm oil processing activities to the environment are in the following (ADB, 2006): Biogas generated from the anaerobic digestion escapes into the atmosphere and such biogas contains about 65% methane, which is one of the most potent GHG; the incineration of EFBs emits particulates into the surrounding atmosphere; and indiscriminate dumping of EFBs causes additional methane emission into the atmosphere.

In terms of water pollution, illegal disposal of POME into waterways creates some problems related to killing of life-forms in the water (Shirkie & Ji, 1983; Ahmad, Ismail, & Bhatia, 2003). However, because of the strict current regulation and stringent standard on effluent discharge imposed by the Malaysian Department of Environment, nowadays, it is difficult to find a case of direct POME disposal into water bodies in Malaysia. Even if such illegal practice exists, it is in terms of waste management, the demand is generally driven by the government first and then by the private sector. The government is typically responsible for policies and regulations that establish standards for enforcement of waste management practices. The private sector is responsible for productive use of technologies (ADB, 2006). The Malaysian experience in effluent control in the palm oil industry demonstrates that a set of well designed environmental policies can be very effective in controlling industrial pollution. The Malaysian government's efforts to reduce the effluent from palm oil industry have been implemented through a licensing system, which mainly consists of effluent standards and effluent charges. Progressively, stringent effluent standards were stated in the government's environmental quality regulations (Igwe & Onyegbado, 2007). Solid wastes, mainly PKS and MF are used for in-house energy generation. PKS are used as a source of fuel for the boilers. The fibres recovered from the nut/fibre separation stage are good combustible materials and can be used as fuel to the boiler. The fibres constitute the bulk of materials used to fire large boilers for generating superheated steam to drive turbines for electrical power generation. Unfortunately, the shells contain silicates that form scales in the boilers. Also, when too many shells are fed into the furnace, it limits the amount of shells that can be utilised in the boilers. Residual shell is disposed of as gravel for plantation roads maintenance. The application of shells for road hardening has no impact to environment.

EFBs are partly dried in the sun and later used as fuel, if not incinerated or applied to the fields. Some mills are further processing EFBs to recover the residual 2% oil and fibre for sale as boiler fuel. Another economic use of EFBs is to return them to the plantation as a mulch to enhance moisture retention and organic matter in the soil. On the other hand, the ash recovered from the incinerated EFBs can also be sold or used as fertiliser in the palm plantations (ADB, 2006). Boiler ash is recycled as fertiliser and factory floor cleaning agent. The potash in the ashes reacts with the oil to form a weak potash soap that is washed away with water. In the bid to achieve a zero discharge of the palm oil mill, boiler fly ash has been used to reduce the BOD, TSS, and other contaminants from

POME before discharge. Boiler fly ash has also been used in the removal of heavy metals from other industrial effluents (Igwe & Onyegbado, 2007).

Liquid waste treatment involves anaerobic fermentation followed by aerobic fermentation in large ponds until the effluent quality is suitable for discharge. As observed in some mills, the treated effluent can be used in the farm as manure and source of water for irrigation. The sludge accumulating in the fermentation ponds is periodically removed and transferred to the land. Some of the viable waste recovery methods are listed as follows.

I. **Use of palm oil waste for the production of thermal energy -** EFBs and PKS are wastes generated by the palm oil milling process at the rate of 23% and 7% respectively from processed FFBs. PKS generated during the palm oil mill are commonly used as a boiler fuel while EFBs are left to decay naturally in the plantation. Since the ban imposed by the Malaysian government in 2000 on open-air burning particularly in the palm oil industry, mills are facing the challenge to dispose large amounts of waste. Nowadays, a common practice consists of stock piling waste in the mill premises and eventually transport these waste to the plantation sites to decay. EFBs biomass residues are abundant and are combustible in the boiler. However, the fuel characteristics of EFB are poor (low calorific value, high moisture, formation of clinkers), co-combustion of PKS or other biomass might be required to improve the combustion process. EFB is characterised by a low homogeneity and high moisture content that entails technical sophistication in a project. The production of energy from EFBs requires specific technological development which is not well developed yet in

Malaysia. However, according to Finpro (2001) at least one Malaysian company Szetech Engineering Sdn. Bhd. manufactures equipment for pre-treatment of EFBs prior to conventional boiler combustion. The major problems are linked to the poor fuel characteristics of this biomass residue causing unstable combustion. On the other hand, PKS is another waste generated by the palm oil industry that is also used as a boiler fuel at the mills. The challenge that PKS poses is on identification of some efficiency measures to the current system and from that identify possible technological options that could improve the processing of PKS. For example, considering the high calorific value of the PKS the use of the excess shells as fuel for generating power or electricity in gasification plants for villagers or palm oil mills could possibly be an option for an optimum and efficient waste utilisation.

II. **Methane recovery with energy production -** POME is characterised by a very high organic matter contents derived from the organic fractions of the palm oil production process with an average BOD and COD level of 25,000 and 55,000 mg/L, respectively. POME is ranked among the strongest industrial wastewater in terms of organic matter contents in the world, and the most significant because of its large volume generated from the palm oil industry.

Typically, POME is treated in open lagoons before discharge. The anaerobic decay of organic matter inside the lagoons is accompanied by the production of biogas containing methane, usually released in the atmosphere in an uncontrolled manner. The challenge for improvement in this respect is to improve the collection efficiency, treatment and utilisation of methane for energy.

III. **Co-composting of POME and EFBs -** Green waste composting facility is the treatment component of an agricultural management system for the biological stabilisation of organic waste material from palm oil mills (i.e. EFBs, boiler ash, POME, and decanter sludge). The main objective is to reduce the pollution potential of organic agricultural waste to surface and ground water. The challenge in this area is to find efficient technological options for better and more efficient composting facilities and biogas collection and utilisation technologies (e.g. for combustion, grid energy).

2.11.7 Clean Development Mechanism (CDM) projects

Palm oil mills are large generators of organic wastes that are often improperly managed or under-valorised. For every ton of FFBs processed, about 20% of CPO is produced leaving major waste streams. For an average mill capacity of approximately 200,000 tons per year, there is 160,000 tons of bio-waste generated; proper management of waste is a key factor towards sustainability of the milling operations.

MF and PKS are often burned on-site in inefficient boilers for the production of process steam and electricity; the other waste streams end up being dumped in the plantation while POME is treated in anaerobic lagoons. Both activities result in the uncontrolled released of large quantities of methane into the atmosphere. Details of the potential areas for improvement are mentioned in the Kyoto accord: however, typical projects that are potentially eligible as CDM project include; waste to thermal energy, methane recovery, and co-composting (Kyoto Energy, 2008).

There are many opportunities that prevail in palm oil milling sector for a successful implementation of a CDM project in a manner that is fully sustainable and with sound financial returns (Krishnamurthy, 2008). According to Leong (2007) CDM projects have been touted as good initiatives to boost sustainable development for Malaysia's palm oil industry. Besides combating global warming, palm oil mills can also gain competitive advantages with CDM implementations by increasing the efficiency of their waste management, benefitting from the transfer of technology, reducing cost and gaining additional revenue stream from sales of Certified Emission Reduction (CERs). An effective maintenance management, while contributing to reliable milling operations, can undoubtedly contribute positively to achieve this goal. In Malaysia, several CDM projects on palm oil sector are successfully implemented. Notably, the Biomass Energy Plant at Lumut, Perak, was the first Malaysian project registered at the UNFCCC as a CDM project (Rao, 2006).

2.11.8 Capitalizing on Palm Oil Sector Synergies

In today's operating environment, both management and the operation of the oil palm estates and crude palm oil mills need effective team work, fruitful synergy effect on each other, cross-functional responsibility and accountability, inter personnel co-operation and relationship, reduced bureaucracy and resources utilization to achieve higher productivity and better quality product. Production costs have increased with upward trend of labor, maintenance and consumables. Handling the situation of increasing production costs and possibly lower commodity prices would be a challenge for the palm oil industry.

Maintenance offers a scope of cost savings with; prolonged life cycle, tried and tested technology, and design for reliability. There are savings derived from operating a conventional and new CPO mill, identifying and reducing the high costs areas are necessary. It has been generally agreed that there has been no significant change in the overall processing technology and techniques for crude palm oil in the last 40 years. Changes that have taken place so far are evolutionary rather than revolutionary (Basiron, 2000). When one looks objectively at the palm oil processing business today, it becomes very obvious that all efforts for the future can be summed up in this phrase: “Lower cost of production, higher productivity and better quality”. This is the key for the success or failure of the industry (MPOB 2009).

Ismail *et al.* (2009) conducted a case study on “Implementation of preventive maintenance program at a Malaysia Palm Oil Mill”; they elaborated on the effects of Preventive Maintenance Program (PMP) implementation at a palm oil mill in Malaysia but did not provide in depth analysis of the evaluation aspect of maintenance management performance at the palm oil mill.

2.12 Underpinning Theory and Theoretical Framework

In the quest to improve manufacturing performance, with maintenance function at its core, a number of broad-based operations management philosophies, e.g. TQM, JIT, TPM, lean manufacturing (LM), theory of constraints (TOC), and more recently, six sigma (SS) and supply chain management (SCM) have been proposed in the literature and are being implemented in practice. It is widely held view that the successful implementation of these philosophies requires systems thinking, functional integration, and flatter organizational structures. From the operations perspective these practices require managers to work on cross-functional implementation teams and participate in cross-functional decision-making processes. To do so, managers need a common language, the language of theory (Handfield & Melnyk, 1998). Areas, such as marketing, finance, strategy, and organizational behaviour are well grounded in theory-development methods but the need for theory-building, testing, and modification in operations management (OM) has been widely recognized (Meredith, Raturi, Amoako-Gyampaeh, & Kaplan, 1989; Flynn, Sakakibara, Schroeder, Bates, & Flynn, 1990; Swamidass, 1991; McCutcheon & Meredith, 1993).

A number of attempts have been made to develop and propose theories and theory-like principles of operations management. These attempts include trade-off theory (Skinner, 1969), the process-product matrix (Skinner, 1969), the customer-contact model (Chase & Tansik, 1983), the TOC (Goldratt & Cox, 1984; Boyd & Gupta, 2004), the cumulative theory (Ferdows & DeMeyer, 1990), the theory of production competence (Cleveland, Schroeder, & Anderson, 1989; Vickery, 1991), priority management theory (Westbrook, 1994), the theory of TQM (Flynn *et al*., 1994; Handfield & Melnyk, 1998) the theory of swift and even flow, and the theory of performance frontiers (Schmenner & Swink, 1998). This list is not exhaustive but rather an attempt to highlight major initiatives undertaken in the academic OM literature. Schmenner and Swink (1998) further suggested that these theories in operations management should be carefully examined, refined and, if warranted, abandoned.

Maintenance management performance is a wide-ranging field in operations; its evaluation is equally complex. Alkin (1990) eloquently states that "evaluation is a large, but not unified theoretical area. No single theory specific to evaluation is available to describe, explain and predict all types of evaluation activities". Potter (2006) contends that "evaluation is an eclectic and diverse field". He argues that this diversity is reflected in the body of literature around evaluation, as the literature, "draws on a number of disciplines, which include management and organisational theory, policy analysis, education, sociology, social anthropology, and social change". There are several theories, embedded in the aforesaid disciplines that seem to contribute to the maintenance management performance. However, given the present day global pressures on businesses, and in line with the theme of this study (maintenance management that prides itself on continuous improvement, is efficient &effective, and is sustainable); the scientific management theory (SMT) contributes profoundly to the organisational performance, including operational performance, for competitiveness, and sustainability. SMT is described in the following section.

2.12.1 Scientific Management Theory (SMT)

Fredrick W. Taylor first introduced SMT in 1911. The reliability centered process is grounded in the work of Fredrick W. Taylor, scientific management theorist. Taylor believed that minimizing unnecessary steps could result in efficient productivity. According to Wren (2004), Taylor utilized time motion study to analyze and minimize the number of redundant steps, thus increasing productivity and efficiency.

Management theory consists of applying quantitative management techniques to resolve management and organizational challenges (Bowditch & Buono, 2005). This may require that organizations evaluate their strategic perspectives, combined with planning and forecasting to reach the organizational goals. Today, management science has expanded to include management practices, JIT, Six Sigma, TQM, TPM, RCM, and Continuous Improvement (CI) programs (Bowditch & Buono, 2005). TPM is a means to improve the performance and condition of projects or manufacturing plants with the assistance of repetitive maintenance activities (Sharma *et al.*, 2005).

I. **Overview and context -** The core ideas of scientific management were developed by Taylor in the 1880s and 1890s, and were first published in his monographs '*Shop Management (1903)'* (Taylor 1903), and the '*Principles of Scientific management (1911)'* (Taylor 1911). While working as a lathe operator and foreman at Midvale Steel, Taylor noticed the natural differences in productivity between workers, which were driven by various causes, including differences in talent, intelligence, or motivations. He was one of the first people to try to apply science to this application, that is, understanding why and how these differences existed and how best practices could be analyzed and synthesized, then propagated to the other workers via standardization of process steps. He believed that decisions based upon tradition and rules of thumb should be replaced by precise procedures developed after careful study of an individual at work, including via time and motion studies, which would tend to discover or synthesize the "one best way" to do any given task. Scientific management's application was contingent on a high level of managerial control over employee work practices. Scientific management is often called Taylorism, the terms are often considered synonymous. A discerning view considers Taylorism as the *first form* of scientific management, which was followed by new iterations. Thus in today's management theory Taylorism is sometimes called (or considered a subset of) the classical perspective **(**Gershon, 2001). Taylor's own early names for his approach included "shop management" and "process management". When Louis Brandeis popularized the term "scientific management" in 1910 (Drury, 1915), Taylor recognized it as another good name for the concept, and he used it himself in his 1911 monograph.

Scientific management is a variation on the theme of economic efficiency. It is a late 19th and early 20th century instance of the larger recurring theme in human life of increasing efficiency, decreasing waste, and using empirical methods to decide what matters, rather than uncritically accepting pre-existing ideas of what matters. Though there isn't one single theory that encompasses all the aspects of maintenance management, this author has opted in favour of SMT as it is a chapter in a larger narrative that includes many ideas and fields, from the folk wisdom of thrift to a profusion of applied-science successors, including time and motion study, the efficiency movement, operations management, operations research, industrial engineering, manufacturing engineering (maintenance was a part of manufacturing back then), logistics, business process management, business process reengineering, lean manufacturing, and six sigma. There is a fluid continuum linking scientific management by that name with the later fields, and there is often no mutual exclusiveness when discussing the details of any one of these topics.

II. **Scientific Management's Legacy -** Although the typical application of scientific management was manufacturing, Taylor himself advocated scientific management for all sorts of work, including the management of universities and governments. Most of its themes are still important part of industrial engineering and management today. These include analysis, synthesis, logic, rationality, empiricism, work ethics, efficiency and elimination of waste, standardization of best practices, the transformation of craft production into mass production, and knowledge transfer between workers and from workers into tools, processes, and documentation. Scientific management was one of the first attempts to systematically treat management and process improvement as a scientific problem. It was probably the first to do so in a "bottom-up" way, which is a concept that remains useful even today, in concert with other concepts. Two corollaries of this primacy are; one - that scientific management became famous, and second - that it was merely the first iteration of a long-developing way of thinking and much iteration that have come since. Nevertheless, common elements unite them. With the advancement of statistical methods, quality assurance and quality control could begin in the 1920s and 1930s. During the 1940s and 1950s, the body of knowledge for doing scientific management evolved into operations management, operations research, and management cybernetics. In the 1980s total quality management became widely popular, and in the 1990s "re-engineering" went from a simple word to a mystique. Taylor's impact has been so great because he developed a concept of work design, work measurement, production control and other functions, that completely changed the nature of industry. Before scientific management, such departments as work study, personnel, maintenance and quality control did not exist. What was more his methods proved to be very successful. Today's Six Sigma and Lean Manufacturing could be seen as new kinds of scientific management, although their evolutionary distance from the original is so great that the comparison might be misleading. In particular, Shigeo Shingo, one of the originators of the Toyota Production System, believed that this system and Japanese management culture in general, should be seen as a kind of scientific management; TPM is the off shoot of Toyota Production Systems.

III. **Other Contributors to the Scientific Management Theory:**

Frank and Lillian Gilbreth (1868-1924, 1878-1972) – were associates of Taylor. From their various studies the Gilbreths' developed the laws of human motion from which evolved the principles of motion economy. It was they who coined the term "motion study" to cover their field of research and as a way of distinguishing it from those involved in the "time study"; it is a technique that they believed should always precede method study. This still holds true today.

Henry Laurence Gantt (1861 – 1919) – another well known pioneer in the early days of scientific management was Henry Gantt. Gantt worked for Taylor in the USA and is to be remembered for his humanising influence on management, emphasising the conditions that have favourable psychological effects in the worker. The Gantt chart for which he will also be remembered is a visual display chart used for scheduling which is based on time, rather than quantity, volume, or weight. From the Doctrines of Taylor and the Gilbreths', there followed rapid development in machinery and technology and with the improvement of material, came the moving assembly line.

George Elton Mayo (1880-1949) – an Australian psychologist, sociologist, and organisation theorist. Mayo is known as the founder of the Human Relations Movement, and is known for his research including the Hawthorne Studies and his book "*The Human Problems of an Industrialized Civilization"* (Mayo, 1933). Mayo and his Harvard colleagues examined fatigue in their research for a rational explanation to differences in performance at a Philadelphia textile mill. These studies showed that motivation was outside the boundaries of the systematic, logical and rational model of Taylor. What was found and has been substantiated many times since is that people have multiple needs, feelings, and personal goals that are not always consistent with the good job design, exact standards, and performance measures obtained from traditional techniques and approach.

Charles Eugène Bedaux (1887 – 1944) – another pioneering contributor to the field of scientific management was Charles Bedaux. Although not embarking on his career until after Taylor's death, he was to have widespread influence, firstly in the USA and later Europe. Bedaux introduced the concept of rating assessment in timing work. Although crude and poorly received at first, his system has been of great consequence to the subsequent development of work study. He is also known for extending the range of techniques employed in work study which included value analysis.

Peter Ferdinand Drucker (1909 – 2005) – Drucker saw Frederick Taylor as the creator of knowledge management, because the aim of scientific management was to produce knowledge about how to improve work processes. He was a writer, management consultant, and self-described "social ecologist" (Drucker, 1992). His books and scholarly and popular articles explored how humans are organized across the business, government and the non-profit sectors of society.

He is one of the best-known and most widely influential thinkers and writers on the subject of management theory and practice. His writings have predicted many of the major developments of the late twentieth century, including privatization and decentralization, the rise of Japan to economic world power, the decisive importance of marketing, and the emergence of the information society with its necessity of lifelong learning (Byrne, 2005). In 1959, Drucker coined the term "knowledge worker" and later in his life considered knowledge work productivity to be the next frontier of management (Davenport, 2007).

Several ideas run through most of Drucker's writings:

i. Decentralization and simplification - Drucker discounted the command and control model and asserted that companies work best when they are decentralized. According to Drucker, corporations tend to produce too many products, hire employees they don't need; when a better solution would be outsourcing and expand into economic sectors that they tend to avoid.

ii. Respect of the worker - Drucker believed that employees are assets and not liabilities. He taught that knowledgeable workers are the essential ingredients of the modern economy. Central to this philosophy is the view that people are an organization's most valuable resource and that a manager's job is to prepare and free people to perform (Drucker, Collins, Kotler, Kouzes, Rodin, & Rangan, 2008).

iii. The need for “planned abandonment”: Businesses and governments have a natural human tendency to cling to "yesterday's successes" rather than seeing when they are no longer useful.

iv. A belief that taking action without thinking is the cause of every failure.

v. The need to manage business by balancing a variety of needs and goals, rather than subordinating an institution to a single value (Drucker, 1954 &1992); this concept of management by objectives forms the keynote of his 1954 landmark “*The Practice of Management”* (Drucker, 1954).

vi. A company's primary responsibility is to serve its customers; profit is not the primary goal, but rather an essential condition for the company's continued existence (Drucker, 1954).

vii. An organization should have a proper way of executing all its business processes.

viii. A belief in the notion that great companies could stand among humankind's noblest inventions (Drucker, 2008).

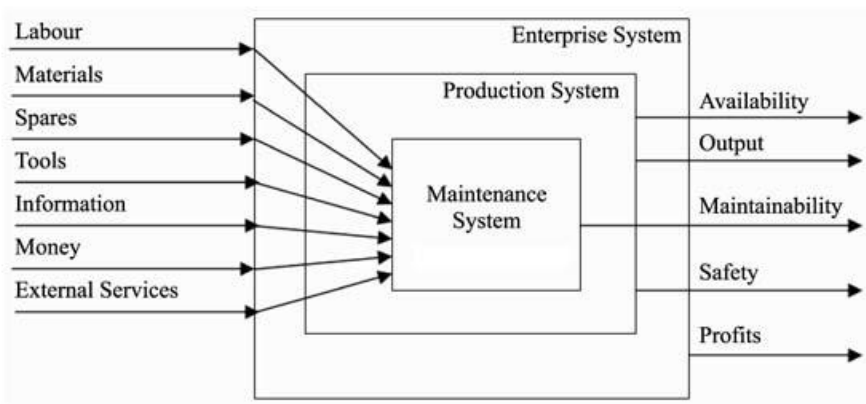
IV. Scientific Management Theory’s Criticism - Frederick Winslow Taylor is a controversial figure in management history. His innovations in industrial engineering, particularly in time and motion studies, paid off in dramatic improvements in productivity. At the same time, he has been credited with destroying the soul of work, of dehumanizing factories, making men into automatons. Perhaps the key idea of scientific management and the one which has drawn the most criticism was the concept of task allocation. Task allocation is the concept that breaking task into smaller and smaller tasks allows the determination of the optimum solution to the task. "The man in the planning room, whose specialty is planning ahead, invariably finds that the work can be done more economically by subdivision of the labor; each act of each mechanic, for example, should be preceded by various preparatory acts done by other men." The main argument against Taylor is this reductionist approach to work dehumanizes the worker. The allocation of work, "specifying not only what is to be done but how it is to be done and the exact time allowed for doing it" is seen as leaving no scope for the individual worker to excel or think. This argument is mainly due to later writing rather than Taylor's work. As Taylor stated "The task is always so regulated that the man who is well suited to his job will thrive while working at this rate during a long term of years and grow happier and more prosperous, instead of being overworked". Taylor's concept of motivation left something to be desired when compared to later ideas. His methods of motivation started and finished at monetary incentives. While critical of the then prevailing distinction of "us "and "them" between the workforce and employers he tried to find a common ground between the working and managing classes (Taylor, 1911). Applications of scientific management sometimes fail to account for two inherent difficulties. Individuals are different from each other, the most efficient way of working for one person may be inefficient for another and the economic interests of workers and management are rarely identical. So both the measurement processes and the retraining required by Taylor's methods are frequently resented and sometimes sabotaged by the workforce. Taylor was so immersed in the vast work immediately in front of him (getting the world to understand and to implement scientific management's earliest phases) that he failed to strategize about the next steps (sustainability of the system after the early phases). Many other thinkers soon stepped forward to offer better ideas on the roles that humans would play in mature industrial systems. James Hartness, a fellow ASME member, published "*The Human Factor in Works Management*" in 1912 (Hartness, 1912). Frank Gilbreth and Lillan Moller Gilbreth offered alternatives to Taylorism. The human relations school of management evolved in the 1930s. Some scholars, such as Harry Braverman (Braverman, 1998), insisted that human relation did not replace Taylorism but rather that both approaches were complementary. With Taylorism determining the actual organisation of the work process and human relations helping to adapt the workers to the new procedures. Today's efficiency-seeking methods, such as lean manufacturing, include respect for workers and fulfillment of their needs as inherent parts of the theory; it is only in flawed implementations that these methods make jobs unpleasant.

Scientific management caused the strengthening of labor unions by giving workers more to complain about than bad or greedy managers already gave them. It also led to other pressures tending toward worker unhappiness, the erosion of employment in developed economies via both off-shoring and automation. Successors such as 'corporate reengineering' or 'business process reengineering' brought into sight the distant goal of the eventual elimination of industry's need for unskilled, and later, perhaps even most skilled human workers in any form, all stemming from the roots laid by Taylorism recipe for deconstructing a process. As the resultant commodification of work advances, no skilled profession, even medicine, has proven to be immune from the efforts of Taylorism successors, the 'reengineers', whose mandate often comes from skewed motives among people referred to as ‘bean counters’; a term used for incompetent managers.

Implementations of scientific management, often if not always, worked within the implicit context of a particular technological moment and thus did not account for the possibility of putting the "continuous" in “continuous improvement process”. The notion of a "one best way" failed to add the coda, "[… within the context of our current environment]"; it treated the context as constant, which it effectively was in a short-term sense, rather than as variable, which it always is in a long-term sense. Later methods such as lean manufacturing corrected this oversight by including ongoing innovation as part of their process and by recognizing the iterative nature of development.

V. Scientific Management in 21st Century - It is not difficult to find examples of Scientific Management in the 21st Century; the car and computer manufacturing plants, the work environments we go to everyday, the hospitals we are treated in and even some of the restaurants we might eat in. Almost all of them function more efficiently due to the application of Scientific Management. In fact, these methods of working seem so commonplace and so logical to a citizen of the modern world that it is almost impossible to accept that they were revolutionary only 100 years ago. Although Scientific Management does play an important role in the 21st century, it is necessary to note that this method of management contains weaknesses that limit its influence in current work environments, and consequently not all of its tenants are applicable to modern organizations. Scientific Management is perhaps best seen as an evolutionary stage in management ever developing history. Scientific Management was developed in the first quarter of the 20th Century against the backdrop of Bethlehem Steel plant. The backbone of this activity was his ‘Time And Motion Study’ (Dale, 1973). George Ritzer in his book “The McDonaldnization of Society” notes a similar philosophy in a McDonald’s staff manual, it told operators precise cooking times for all products and temperature settings for all equipment. It specified that French fries be cut at nine-thirty-seconds thick, grill men were instructed to put hamburgers down on the grill moving left to right, creating six rows of six patties each (Ritzer, 2000). The antithesis of scientific management is the human relations movement established by Elton Mayo. The model is based on the research undertaken by Mayo at the Hawthorne electrical components factory between 1927 and 1932. Mayo followed Taylor’s methods and was attempting to measure the impact on productivity of improving the lighting conditions within the factory. He followed Taylor’s scientific principles by testing the changes against a control, a section of the factory with unchanged lighting (Kelly, 1982). Scientific Management, however, is an incomplete system. What is seen in both the Bethlehem Steel plant under Taylor’s management in 1911, and in every McDonald’s restaurant in the World now is a deskilling of labour. As jobs are broken down into their constituent elements, and workers tasks are made easier, humans become little more than machines in the chain. Their cognitive input is not required and their motions do little to develop themselves. It is here that we touch upon the first problem Scientific Management faces in the 21st Century. Higher levels of access to technology and information as well as increased competition present another difficulty to theory of Scientific Management being applied to organizations in the 21st Century. Modern organizations process huge amounts of input and employees no longer work in isolated units cut off from the organization at large, but are quite literally connected to it. Satellite link-ups and the Internet provide organizations with billions of bytes of information every day, enabling companies to work on a global scale and within ever shortening time frames. Delivery times, information gathering, data processing and manufacturing techniques are constantly becoming more technologically advanced and efficient. Alongside this rapid technological growth organizations are finding it increasingly important to react quickly to developments that may affect their welfare. Managers recognize they are unable to control all aspects of employee's functions, as the sheer layers of information factored into everyday decisions are so high that it is imperative employees use their own initiative. High competition between organizations also means that companies must react fast to maintain market positions. All of these forces modern companies to maintain high levels of flexibility. Another weakness in Scientific Management theory is that it can lead to workers becoming too highly specialized therefore hindering their adaptability to new situations. In the 21st Century employers not only want workers to be efficient they must also exhibit flexibility. However, it can be reasoned that scientific management is still a relevant concept for understanding contemporary work organizations. Scientific management has proved it has a place in a post-industrial economy and within work organizations, albeit in a hybrid form with the human relations model. This is because scientific management allows a company to control its workforce through a series of measures that guarantees them the desired levels of productivity and efficiency. In spite of this guarantee, the model, as Taylor prescribed it, also manages to alienate the workforce and cause dissatisfaction due to the authoritarian structure of the role of management. The human relations model adds a new dimension to scientific management as it allows management to work on the same principles as Taylor approved, such as time and motion studies, while also serving to fulfill employees' social needs at the same time. In conclusion, it can be seen that Scientific Management is still very much a part of any organization in the 21st Century. Its strengths in creating a divide between management functions and work functions have been employed widely at all levels and in all industries. In addition its strengths in making organizations efficient through replacement of 'rules of thumb' with scientific fact has both insured its widespread application and ironically bred the conditions that make it less applicable to modern organizations. Now that all modern organizations work on a factual basis and all of them have managerial and employee structures competition is controlled by other factors outside the realms of Scientific Management. Modern organizations rank humanistic factors such as employee initiative, loyalty and adaptability alongside efficiency. It is perhaps then better to accept that as a complete theory Scientific Management is not visible in modern organizations, however, elements of it are so relevant that they have become deeply ingrained in all modern organizations and are the very reasons why management has taken on new dimension in the 21st Century.

2.12.2 Theoretical Framework - Based on SMT and inspired by Tsang's (2002) input-output model, author of this study has developed a "theoretical framework" (Figure 2.9). According to Tsang (2002), the outputs of the production system, availability, volume, quality and cost of production and safety, determine the profit of a firm. These outputs are, in their turn, influenced by the maintenance function (Figure 2.8).



Source: Tsang (2002)

Figure 2.8
Tsang Input Output Model (Tsang, 2002)

In the, developed, 'Maintenance Management Performance Model' (MMPM) the maintenance management system in the framework is influenced by maintenance strategies adopted (BDM, PM, TPM, RCM, CBM).

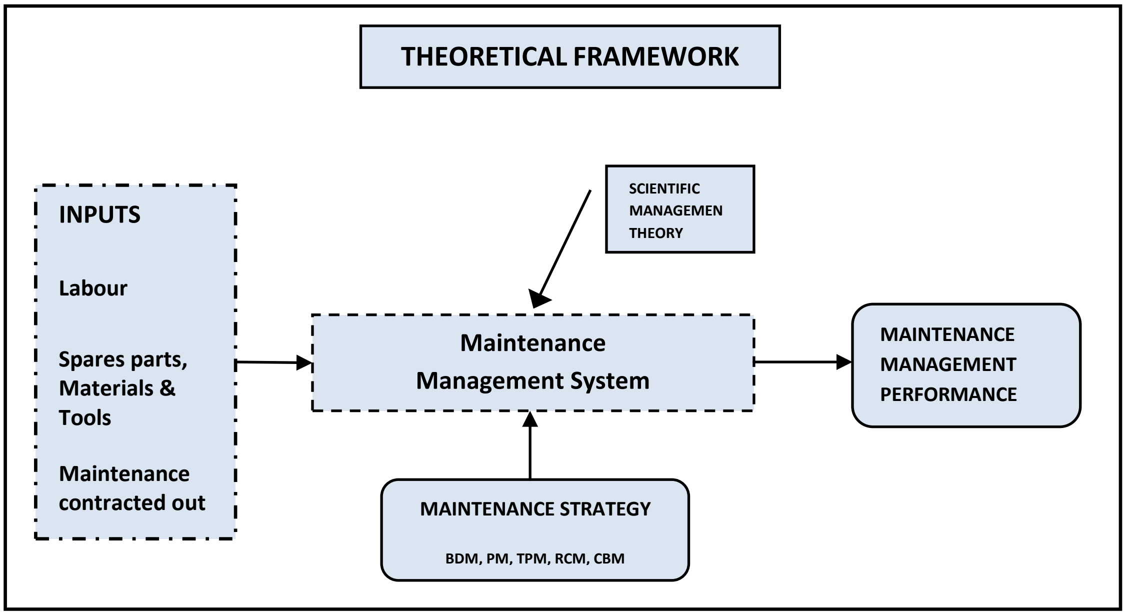


Figure 2.9
Theoretical Framework

2.13 Chapter Summary

Maintenance is considered as a process that monitors a technical system's capability to deliver services, records problems for analysis, takes corrective/adaptive/perfective or preventive actions, and confirms restored capability. The manufacturing industry has experienced an unprecedented degree of change in the last three decades, involving drastic changes in management approaches, product and process technologies, customer expectations, supplier attitudes as well as competitive behaviour. With the trend to JIT production, lean, flexible and agile manufacturing, it is vital that maintenance becomes integrated with corporate strategy to ensure equipment availability, quality products, on-time deliveries and competitive pricing.

There are several theories that seem to contribute to the maintenance management performance; however, given its multidimensional traits, SMT contributes profoundly to the organizational performance. Taylor has been regarded as the creator of knowledge management, because the aim of scientific managements was to produce knowledge about how to improve work processes. Scientific Management is still a part of most of organizations; it was one of earliest attempts to systematically treat management and process improvement as a scientific problem. Today, task-oriented maximization of work is pervasive in industry. Six Sigma and lean manufacturing are considered as new kinds of scientific management; TPS and the Japanese management culture in general is envisaged as a kind of scientific management, as well. Theoretical underpinnings, models, and frameworks should be more practitioner friendly; only then one can appreciate their relevance and employ them to produce results. The developed theoretical framework draws on the 'input-output' concept put forward by Tsang (2002). The maintenance system management in the theoretical framework is influenced by SMT and maintenance strategies adopted.

Theory and practice knowledge gap is evinced in this research as the literature supports the advantages that can be derived from efficient and effective use of maintenance inputs (IV) namely: Labor; Spare-parts, material & tools; and maintenance contracted out. Adopting appropriate maintenance strategy (MV), such as TPM, ensures better performance of maintenance system evident in higher OEE figure. The practice side has been analyzed in chapter four (4.5) to identify theory practice gaps. Maintenance system management evaluation through measuring OEE is the core element of developed research model. The process is facilitated by the research methodology using triangulation for data validation and reliability.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

Maintenance management is an integral part of production and operations. Operations management literature advocates performance measurement as integral to business improvement (Neely *et al.,* 2001; Slack & Lewis, 2008). For nearly 30 years, the performance measurement literature has focused on developing relevant, integrated, balanced, strategic and improvement-oriented performance measurement systems (Bititci *et al*., 2005). A plethora of frameworks has been developed that aim to provide a balanced view of a business (Bititci, Carrie, & McDevitt, 1997; Cross & Lynch, 1988/1989; Fitzgerald, Johnston, Brignall, Silvestro, & Voss, 1991; Kaplan & Norton, 1992; Keegan *et al.,* 1989; Neely *et al.,* 2002). This body of literature has made practical and theoretical contributions to performance measurement in private sector organisations. Still, consensus has not been reached as to the metrics or frameworks that can or should be used to evaluate private sector performance. Scholars advocate the continual evolution of measurement metrics and some remain sceptical about the longevity of any performance measurement system (Bititci, Turner, & Begemann, 2000; Kennerley & Neely, 2002). The challenge of "designing" the ideal model to drive maintenance activities has become a research topic and a fundamental question to reach the effectiveness and efficiency of maintenance management and to fulfill enterprise objectives. In the historical development of maintenance, diverse authors have proposed what they consider the best practices, steps, sequences of activities or models to manage this function. This chapter discusses the MMP Model and framework applied in this research study, elaborates on its variables (IVs, MV & DV) and explains the methodology applied.

3.2 Maintenance Optimisation Models

In this author's view theoretical underpinnings, models, and frameworks should be more practitioner friendly. Only then one can appreciate their relevance and utilize them to produce results that meet the TBL of organisations, namely: People; Planet; and Profit. This study bridges this gap by applying practitioner's perspective to the evaluation of maintenance management performance through the MMPM model and theoretical framework developed by the author.

Maintenance optimization models can be both qualitative and quantitative. The former includes techniques like TPM, RCM, etc. while the later incorporates various deterministic / stochastic models like Markov Decision Process, and Bayesian models. There has been a long journey of maintenance techniques evolution from CM in 1940 to various OR models for maintenance as on today. A number of latest techniques have been analyzed under this broad area. However, the first maintenance management information system (MMIS) appeared in the 1980s due to the full recognition of maintenance as an important business function. The same has now become an essential component of any maintenance organization and thus merits investigation also under a separate area. Similarly, various maintenance policies can also be classified as; age replacement policy, periodic repair policy, failure limit policy, block repair policy and many more. Each has different characteristics, advantages and disadvantages, and requires extensive research.

The quantitative approach to maintenance optimization is covered in detail in the literature with numerous papers in past two decades, starting in early ninety's. Since the 1980s widespread mechanization and automation has reduced the number of production personnel while capital employed in production equipment has increased manifold (Dekker & Scarf, 1998). In general, maintenance optimization models cover four aspects:

i. a description of a technical system, its function and importance
ii. a modeling of the deterioration of the system in time and possible consequences for this system
iii. a description of the available information about the system and actions open to management and
iv. an objective function and an optimization technique which helps in finding the best balance

Dekker and Scarf (1998) also present another classification of these models as; age and block replacement models, Markov decision models, and time delay models.

3.3 Constraints in Applying Optimisation Models

I. **Gap between Theory and Practice -** Maintenance optimization models are difficult to understand and interpret. Many maintenance models have a stochastic nature, which is not only difficult to grasp by technicians and managers, but also difficult to interpret (the frequentist interpretation of probability is often hampered by many interfering circumstances). For example, a Markov decision model is far more difficult to understand and to interpret than a routing problem. Education of engineers traditionally focuses on deterministic approaches, which hampers effective use of reliability concepts. As maintenance is being underrated compared to other disciplines, academic support is limited.

II. **Companies are not interested in publications -** Although many good ideas have been developed in industry, only a small amount has appeared in scientific literature. To have academics study industry problems, they have to be exposed to them and to be rewarded if they solve them. Although academic freedom is a great thing, it does not expose academics to tackle industrial problems. So, companies should stimulate researchers by offering them problems and allowing them to publish their results.

III. **Many papers have been written for math purpose only -** Mathematical analysis and techniques, rather than solutions to real problems, have been central in many papers on maintenance optimization models. Mathematical results on the existence and structure of optimal policies (e.g. control limit policies), however, are not appealing to practitioners. The structure of policies is generally determined by the problem setting. It is astonishing how little attention is paid either to make results worthwhile or understandable to practitioners, or to justify models on real problems or to consider real problems. Operational Research and Optimising Models have flourished only as a mathematical discipline with in OR. The applications of the same have been very limited so far due to lack of studies that have been published. It can be said that its impact on decision making within a maintenance organization has so far been limited.

IV. **Data Problem -** Decision support systems are needed to optimise maintenance; almost no maintenance optimisation model yields results which only require simple calculations. To determine the optimal maintenance policy one either has to use numerical integration or to solve sets of equations; except for some specific cases for which graphical methods have been developed or analytical solutions exist. An essential part of a maintenance optimization model is the modelling of the deterioration and the occurrences of failures of a system in time such a way that it is clear how both are influenced by the maintenance regime. Maintenance actions will only be effective if they specifically address the most relevant deterioration and failure mechanisms. Global statistics, like an average failure rate, will therefore be inappropriate for most maintenance actions, and apply only to complete replacements, which tend to be costly. Analysing data without knowing the underlying failure mechanisms can lead to totally wrong results (consider failures caused by wear out and by operator errors). Hence data has to be collected under strict rules, defining failure and individual maintenance actions precisely, using a well-defined system-component structuring and indicating what events have happened on purpose. This is, however, not the case, except perhaps in the airline industry. Maintenance information systems thus mainly store accounting information on events and there is a wide concern about the value and integrity of their data for engineering decision making. As collecting data requires a lot of effort, one should concentrate on the most relevant areas, which is a problem on its own. Data should be, current, relevant, accurate and credible. Exceptions are the condition-monitoring programs, for which dedicated manpower is usually available. An alternative is to make use of the knowledge contained in the maintenance technicians. This, however, requires a reformulation of most maintenance optimisation models since it is very difficult to illicit probability distributions from people (Van, Dekker, Cook, & Mazucchi, 2002). Another aspect one should realize is that under good maintenance practices there are little failure data. If the failure occurs repeatedly, one may either change the system design or its operation to prevent failure, with the result that data collection has to start all over again. Apart from problem with data on deterioration, one also has problems with cost data, especially with respect to the indirect costs. It is easy to quantify direct maintenance costs, but very difficult and sometimes subjective to quantify the benefits of maintenance. In the case of maintenance for production equipment one has to value the increase in reliability, availability, and efficiency.

V. **Information Technology** - It seems that a number of papers have been published in this area since the year 2000. This sudden rise is due to the fact that IT (both soft and hardware) is now becoming available at low cost and is rapidly developing. However, limited work is directed towards developing an operational decision support system.

VI. **Problem Owner** - More application will be seen if models are developed in conjunction with the problem owner. Limited application is also attributed to inadequate definition of a problem by its owners and lack of training in education of engineers, which presently focuses on the design of systems and not on maintenance. Engineers need to be taught economics of maintenance and principles of optimization.

VII. **Reliability Measures and Optimum Maintenance Policies -** Presently, many researchers are pursuing the development of various mathematical maintenance models to estimate the reliability measures and determine the optimum maintenance policies. However, these models may be useful to maintenance engineers if they are capable of incorporating information about the repair and maintenance strategy, the engineering management policies, the methods of failure detection, and failure mechanisms. Justifying reasonableness of assumptions, and the applicability of model in a given system environment that can give greater confidence in estimates based on small numbers of production data. No attempts have been made to integrate these quantitative approaches with qualitative ones, like RCM, and TPM.

VIII. **Maintenance comprises of multitude of different aspects -** Maintenance is a generic term referring to a variety of actions on all kinds of diverse technical systems, deteriorating in various ways. Hence, it is not surprising that there is no general model covering all possible cases. Despite the multitude of models, there is little knowledge on which models are suited for which practical problems or which types of data are really driving problems. Instead of publishing new models one would be better of unifying existing models and critically reviewing them on applicability and utility.

IX. **Optimization is not always necessary -** Maintenance models indicate in principle the best decision given a certain problem and available information.

The value of such a procedure (i.e. the savings because of a better decision making process) has to be balanced against the effort to apply the procedure and to get the required data. In some problem instances the potential savings are just too low to justify such sophisticated decision making. Furthermore, optimisation often results in a lowering of the indirect costs, from which other parts of the organisation, like operations, benefit, but not maintenance itself. Since this type of savings is less tangible, it is also less convincing to higher management.

X. **Optimisation models often focus on the wrong type of maintenance -** Finally, an often heard complaint is that optimisation models focus too much on the wrong type of maintenance i.e. that is planned revisions and overhauls. Although this type of maintenance was advocated in the 1950s and 1960s to prevent failures, it did not always prove to be effective. Efforts from manufacturers (e.g. design failures) have further decreased the need for this type of maintenance. Furthermore, condition based maintenance has replaced another part. Note that this complaint refers to the type of maintenance and not to the optimisation models. It is true, however, that a large part of optimisation models focus on planned maintenance, though not always on revisions, but also on replacements and inspections; the reason is that in planning optimisation methods have a well established role. Condition based maintenance depends upon a measurable quantity which gives information about the actual state of systems. If there is such a quantity, it will very likely provide better information than time or run-hours can offer as prognostic variable and hence it will form a better basis for maintenance. Yet, such a condition quantity may be expensive to measure and may relate to some future modes only. Furthermore, many of the condition indicators available so far (like vibration level), have a short-term prediction capacity only, which does not leave much room to save on costs by planning maintenance on appropriate moments.

XI. **Future Prospects -**Despite all the constraints mentioned above, there is scope for maintenance optimization, because of two main reasons; the technological push and the economic necessity. Firstly, computers are becoming affordable by the day, not only in terms of computing power, but also with respect to clever registration devices. Integration of information systems implies that data on deterioration may be obtained from process monitoring systems. Furthermore, new developments in software technology enable better software development, with more intelligence embedded devices, in a shorter time span. Optimisation models are so far the only way in which scientifically justified statements on maintenance can be made. Secondly, it is widely accepted that the amount of capital invested in technical systems will keep growing. Due to increased demands on performance of these systems (quality, reliability, and safety) spending on maintenance is likely to grow as well, a trend which is visible in many companies. Contracting out maintenance also increases the need for higher quality of decision making. Maintenance optimization models, embedded in decision support systems provide an objective and quantitative way of decision making, especially since it allows us to evaluate the economic consequences of decisions. As maintenance optimisation models are the only approach which combines reliability with economics in a quantitative way, they are in fact nothing more than the extensions of basic economic methods to justify maintenance. It is their role in structuring of the decision process (pointing at which information is essential), the possibility to reduce uncertainty by investigating 'what if' scenarios and the better insight into the effects of decisions across maintenance and production areas, which yields most benefits (Dekker, 1996).

3.4 Model and Framework applied in this study

In order to remain competitive in today's highly challenging and rapidly changing business environment, a keen understanding of the intricate dynamics of the production facility is required to be able to manage the organizational resources effectively to meet the organization's sustainability efforts. The success in highly challenging contemporary manufacturing scenario depends on the implementation of multiple complimentary and proven strategies. The author has developed a maintenance management performance evaluation model (MMPM) that draws on the 'input-output' concept put forward by Tsang (2002) and uses OEE, TPM's KPI, for maintenance evaluation (Figure 3. 9).

3.4.1 Spread of TPM

In today's global economy, the survival of companies depends on their ability to rapidly innovate and improve. As a result, an increasing search is on for methods and processes that drive improvements in quality, costs and productivity. In today's fast changing marketplace, slow, steady improvements in manufacturing operations will not guarantee profitability or survival. Companies must improve at a faster rate than their competition if they are to become or remain leaders in their industry.

Western products, practices and methods were long considered the best in the world. This perception is constantly changing as a result of new competition and economic pressures. Arrogance or self assurance has devastated specific sectors of western manufacturing base. For example, the Japanese now own the consumer electronics industry. Changes in the automotive industry are well documented, and for the first time Western dominated industry such as computers and aviation are facing serious challenges by foreign competitors. Other companies and cultures have proven they can compete successfully in the world marketplace with western manufacturing. To confront this challenge, enlightened company leaders are benchmarking their organizations' performance and improvement processes against domestic and international competitors. TPM is a complex, long term process which must be sold to the workforce as a legitimate improvement methodology. For TPM to succeed in any industry, both management and the workforce must address issues strategically while operating in an environment of trust and organization. The improvement process must be recognized as benefiting both the company and the workers. The ultimate responsibility for success or failure of the TPM process rests more with management than the plant floor employees.

Performance target must always be dynamic, not static. If a company sets goals and measures to reach performance levels of their best in class competitor in two years, they will lag behind, since their competition will have improved over that same period of time. To be the best in class, a company must leap-frog its competition by setting goals beyond where their competition is projected to be. Likewise, in TPM, employee involvement is a necessary part of the TPM process; the goal is to tap into the expertise and creative capabilities of the entire plant or facility through the use of small group activities. The total involvement of plant personnel generates pride and job satisfaction as well as financial gains for the organization. TPM requires employees to take a more active role in decision making and to accept responsibility for the plant and its physical condition. They have a heightened role in defining their job content, along with work systems and procedures. The intent of TPM is that each employee takes pride in their equipment and all efforts must be directed towards the plant's objectives. For example, JIPM recommends that management adopt the theme of "My Plant" to increase the level of autonomous maintenance.

TPM improvement methods and activities are also being adopted in product development and sales department. This trend underlines the increasing tendency to consider production processes and equipment at the product development stage in an effort to simplify production, improve quality assurance and enhance and reduce the start-up period for new production. These issues are of particular concern most especially in the process industries today as product diversification continuous and product life cycle shortens. Interest in TPM outside Japan has also expanded throughout the recent years. Many companies in the United States, Europe, Asia and South America are planning to or are now actively pursuing TPM.

3.4.2 Why TPM is so popular?

There are three main reasons why TPM has spread so rapidly throughout Japanese industry and why companies outside Japan are becoming interested; it guarantees dramatic results, visibly transforms the work place, and raises the level of knowledge and skill in production and maintenance workers.

Companies practicing TPM invariably achieve astounding results, particularly in reducing equipment break downs, minimizing idling and minor stoppages (‘chokotei’ in Japanese), and lessening quality defects and claims boost in productivity, trimming labor costs, shrinking inventory, cutting accidents and promoting employees morale as shown by the increase in improvement suggestions. Through TPM, a filthy, rusty plant covered with oil, mist and grease, leaking fluids and silt powders can be reborn as a pleasant, safe working environment. Customers and other visitors are impressed by these changes and their confidence in their products increases. As TPM activities begin to yield concrete results which is improving the working environment, minimizing breakdowns, improving quality, reducing set-up and change over times and so on; workers become motivated, involvement increases and improvement suggestions proliferate. People begin to think TPM as part of their day to day jobs making TPM a way of life for all people. TPM helps operators understand their equipment and widens the range of maintenance and other tasks they can handle. It enables them to make new discoveries, acquire fresh knowledge and enjoy new experiences. It strengthens motivation, engenders interest in their work and concern for equipment and fosters the desire to maintain equipment in top peak condition. McKone *et al.* (2001) show that there is a significant and positive indirect relationship between TPM and manufacturing performance through JIT practices. Ireland and Dale (2001) discuss study of TPM in three companies. These companies had followed Nakajima's seven steps of autonomous maintenance. Das (2001) presents a case study where TPM is implemented in a step-by-step manner and also develops some parameters for measuring the effectiveness of TPM. Gupta *et al.* (2001a, b) address basics of TPM and its key issue, OEE. Finlow-Bates, *et al.* (2002) show that in order to implement TPM successfully, three strong tools i.e. " seven simple tools of TQM", four thinking models of "Kepner-Tregoe" and "Root cause analysis" are to be navigated as all three are complementary to each other. Hansson, Backlund and Lycke (2003) put forward the importance of top management leadership to focus on strategic planning, training and education, monitoring and evaluation, empowerment, and information and communication in increasing the successful implementation of not only TPM but TQM and RCM as well. Shamsuddin, Hassan and Zahari (2005) argue that TPM can go beyond maintenance and may encompass a host of business functions within an organization.

3.4.3 TPM and OEE

In today's competitive economy, the survival of companies depends on their ability to briskly innovate and improve. As a result, an increasing search is on for methods and processes that drive improvements in quality, costs and productivity. They are adopting and adapting best in class manufacturing practices and improvement processes. As part of these benchmarking efforts TPM has been identified as a best in class manufacturing improvement process (Robinson & Ginder, 1995). From generic perspective, TPM can be defined in terms of OEE which in turn can be considered a combination of the operation maintenance, equipment management and available resources (Chan, Lau, Ip, Chan & Kong, 2005). The term "Total Productive Maintenance" was first used in the late 1960's by Nippondenso, a supplier of electrical parts to Toyota (Robinson & Ginder, 1995). TPM has also been defined as a plant improvement methodology which enables continuous and rapid improvement of the manufacturing process through the use of employee involvement, employee empowerment and closed looped measurements of results (Robinson & Ginder, 1995).

In an industry, ideally, equipment should operate 100% of the time at maximum capacity giving an output of 100% good quality product. However, this seldom happens because there are losses which occur in a real life situation that differentiate between the actual and the ideal performance. OEE needs to be measured in every organization that is committed to eliminate equipment or process related wastes through implementing TPM along other initiatives such as LM, Operational Excellence, and WCM.

OEE is a formula used in the manufacturing industry to calculate the overall equipment effectiveness of a branch or complete production system; formula was presented as an overall metric in the TPM concept (Nakajima, 1988). OEE is a crucial measure in TPM that reports on how well equipment is running. It factors three elements; the time the machine is actually running, the quantity of products the machine is turning out, and the quantity of good output - into a single combined score. It directly addresses those, the operators, who are best positioned to track and improve the effectiveness of the equipment. OEE helps define basic concepts and provides a systematic explanation to the operators as to how OEE should be applied to maximize a piece of equipment's productivity and recognize the signs when its efficiency is being compromised.

It is essential to realise the importance of optimising OEE. That is equipment availability, actual output compared to standard, and the quality level of the output; and how to improve equipment OEE through reducing breakdowns and minor stoppages, restoring efficiency, and eliminating quality defects. Equipped with the knowledge and training, the operators should be able to identify opportunities for TPM in their company, and apply a range of tools & techniques for improving OEE. This will also help them to develop a pro-active strategy for optimising the effectiveness of production equipment.

3.4.4 Data Collecting Issues and Challenges

Collecting the data from operators on the performance factor is not always a reliable measure. If the mill decides to settle on manual data collection there is a hereditary problem in that; manual forms are often filled in at the end of shift and may not reflect the truth of what is happening. This is not because there is an inherent dishonesty in machine operators. The problem is that 'remembering' what happened in terms of set up time, run time and downtime including the reasons is subject to the 'witness effect'. This means that you may get several witnesses to a crime but it is unlikely that they will all describe the suspect precisely and the same!

The longer the time between the event and the recording, the greater the inaccuracy you will get. Some companies may insist that the data is recorded at the end of the job or at the end of the shift, some even at the end of the week. This method will entirely compromise the factor that contributes to the OEE figure. It is likely that the figure will be overstated and the mill's OEE will be higher than it genuinely is. There will also be a danger that the figures recorded will also be the 'target' figures. This means that if the operator is allowed to take 20 minutes to set-up a machine he or she may always take 20 minutes, or record 20 minutes, even if it is less. It matters, of course, if the mills are not finding out the truth they may not be revealing the hidden capacity that may be utilized to improve the performance (and the OEE) of their investment. In some palm oil mills, for example OEE can appear improved by actions such as purchasing oversize equipment, providing redundant supporting systems, and increasing the frequency of overhauls. Investment in higher installed mill capacity and purchase of redundant standby critical equipment, such as spare ‘boilers’, ‘presses’, ‘decanters’, and turbines are some of the examples that compensate for their operational inefficiencies.

Some may suggest that collecting data manually as the events happen may be the answer, but the reality is that any manual method would actually also impair the OEE figure simply through the act of collecting it. The solution is that the recording of all the factors needs to be automatic or as unobtrusive as possible. Proper sensors installed strategically can provide the data required. This can be addressed by installing a simple ‘heartbeat’ sensor to monitor if the machine is running or not and at what speed. In the event of the machine stopping, the operator simply has to record the reason for the stop through a scan of a barcode. This ease of use will provide the mill with ‘machine truth’. This is the starting point to not only implementing OEE measurement but gaining the power to improve it.

Maintenance daily service log, similar to the one designed by this author’ template shown in Figure 5.20, recordings can also be used to cross check the down times.

Self contained more sophisticated sensing devices are available, that can report what is happening at the machine in near real-time. It gives instant insight to the machine performance at a job, shift and machine level. A critical element of the sensing devices is a light emitting diodes (LED) text display that is located near the machine to provide feedback on performance to the operator. The nature of the feedback relating to current production rate, if the machine is running or idle, the current OEE and other vital signs gives them the information required to help them run the machine in a more efficient manner. Most operators welcome the objective measurement and feedback from the LED, and that motivates them to achieve greater efficiencies. Importantly, the user interface for the person managing the plant is very intuitive and reveals through meaningful representation of the data what can be improved. Data thus collected can be triangulated; individual machine or a production line downtime recorded in maintenance daily logs should enumerate with the downtime recorded in the production operational availability logs. Any discrepancies observed would direct to non-maintenance related losses such as operator errors encountered due to incompetent machine operators.

Collection of data for calculating OEE for individual machines or equipment can also be done through daily production logs; it can be computed to obtain operational history of critical machines and equipment on daily, weekly, monthly, or annual basis for comparison and improvement. There is a variety of maintenance and production management software available that can be utilized to maintain downtime and repair history of the machines & equipment as well as complete production lines through organized maintenance daily service log and work order management system support. A Malaysian developed computer maintenance management system (CMMS) software "CWORKS" is adequate for most manufacturing operations including palm oil mill applications; there is also a free version of 'CWORKS' available. Work Order (WO) management system is an integral part of CMMS and helps to build up operational history of the critical machines and equipment; it helps to track various costs pertaining to specific assets such as cost of labor, and parts.

3.4.5 OEE Calculation, explained

OEE is an accumulated production measure that takes into deliberation, as stated earlier, the six big losses affecting the productivity of equipment in production systems. Equipment failure, setup, and adjustments are related to the downtime and expressed in terms of availability. Idling and minor stoppages, together with reduced speed, are related to speed losses and expressed in terms of the performance rate. Finally, process defects and reduced yield are related to defects and expressed in terms of the quality rate. Three main factors that make up the OEE calculation; Availability, Performance, and Quality are expressed as a percentage and are multiplied together to give a single OEE figure, also expressed as a percentage. OEE template designed by the author (Figure 5.19) depicts a generic daily production log & OEE for an individual mill. Three factors involved in this calculation are independent of each other; i.e. variations in one of the three factors will not affect the other two. Normally, OEE figures can be found from 30-95 per cent (Ljungberg, 1998; Ahlmann, 1995; Wireman, 2004).

The point of the final calculation is that it gives a single figure to measure, and then compares OEE. Therefore factory may, on a single machine perhaps, compare the OEE between jobs. This will allow business to see which jobs run well and which ones do not. One can then take corrective action, may compare shifts and gain an insight to whether one shift performs better than another or investigate the underlying reasons and take action to improve the OEE.

Businesses may compare machines within, or across several plants and may even compare different manufacturing plants where they make similar product and understand underlying reasons why one may have a better OEE than another, and then take corrective action. Ultimately, if the data is available, businesses may compare their OEE to that of their competitors or industry's best and put plans in place to reach the best in-class. Like best practice initiatives businesses may look at industries that have similar characteristics to their own and then try to emulate practices that improve their OEE to the levels they can sustain.

Though data for this is readily available through production logs and financial statements that most palm oil mills maintain through some sort of manual or computerized generic spreadsheets, dummy figures have been used here to illustrate OEE calculations. Let's take a look at each factor in turn.

I. **Availability -** The calculation for availability is simply the actual production time, including set up, out of the planned production time. Time that is lost due to downtime through machine failure, lack of input materials, lack of operator(s), as a series of examples; will be set against the calculation. Therefore the actual consumed time divided by the available time will give a figure, expressed as a percentage that is a factor that contributes to the overall OEE calculation. The availability rate is the time the equipment is really running, versus the time it could have been running (Figure 5.19).

$$Availability\ Rate = (Operating\ Time - Downtime) \div Operating\ Tim\ (column\ 15)$$

II. **Performance -** the next factor, performance, is in theory very simple. It is the actual achieved run rate against the ideal run rate for the machine. Often the machine ideal or optimum run rate may be the figure published by the machine manufacturer. However, it is well known that the ideal run rate may be affected by the situation of machine, heat, cold product running through and so on. Purists would still refer to the published run rate while others may suggest that expected performance may necessarily be degraded by the nature of the product going through it. In a situation where the same product, with no expected variability, passing through the machine, such as a line in a bottling plant or CPO production line, one would expect the ideal run rate to remain constant and therefore variances may easily be identified. However, if looked at another example, such as a machine used in packaging carton manufacture, then the machine performance can be degraded by the size of the input product or the number of slots and folds or the quality of the material. In this situation one may wish to measure the performance against the degraded expected run time rather than, or maybe as well as, the ideal run rate. Performance rate is the quantity produced during the running time, versus the potential quantity, given the designed speed of the equipment (Figure 5.19).

$$Performance\ Rate = Total\ Output \div Potential\ Output\ at\ Rated\ Speed\ (column\ 16)$$

Majority of palm oil mills that belong to first and second generation mills (mills established in 1960s' and 1980s' respectively) do not run their equipment on variable speeds. The whole manufacturing line runs at one speed; it is either running or not running, there is no slow or fast run mode in the process line. However, provision has been made for the ones who do run on variable speed and it is reflected in the 'performance rate' calculations.

III. **Quality -** this is simply a measure of good product divided by the total product; for the job, shift, day, or week. (Figure 5.19).

$$Quality\ Rate = Good\ Output \div Total\ Output \ldots (column\ 17)$$

The quality rate is percentage of good parts out of total produced sometimes called “yield”. In case of palm oil mills it is the CPO produced; within spec and out of spec.

3.4.6 OEE - To arrive at OEE; simply multiply the figures together; dummy figures, in the following calculation, have been taken for illustration only (Figure 5.19).

$$OEE = Availability\ Rate \times Performance\ Rate \times Quality\ Rate \ldots\ (column\ 18)$$

For ease of use and interpretation at the shop level, all the information is negotiated, using simple calculations, through linked spreadsheet cells containing readily available data. OEE figure thus obtained can be improved upon. In terms of Availability mills can look at activities that reduce unplanned downtime; this may be putting engineers on call, making sure mills have critical spares, input products (raw materials) do not run out, and that the operator is ‘available’. Performance may be addressed, dependent perhaps on the machine and industry, by good maintenance routines to maintain speed, or in a degraded environment, redesign of product if necessary to achieve the planned or ideal run speed. Quality of course can be addressed, perhaps, by improved maintenance routines or improved quality of raw materials, amongst others. There will be debate within organizations about what should actually be within the overall factors and there are flexible interpretations of this. One may think that agreeing about an OEE initiative and the measures is a complex task and depending on one’s organization it may well be; however, it is the smaller of the challenges one will face.

3.4.7 Maintenance Management Performance Model (MMPM) Explained

Figure 3.10 depicts the maintenance model that has been derived from the theoretical framework discussed earlier (2.12.2). Inputs are being fed into the maintenance management system; these inputs are the independent variable. Independent variable comprises of three sub-IVs: Labor; Spares-parts, Materials, & Tools; and Maintenance Contracted out. These inputs vary in size and quality, depending on the corporate policy being followed and the resources available to the organization.

Maintenance management, the core function of production and operations, is influenced by the “moderator variable”, the maintenance strategy. Organizations may have one or more of the following strategies implemented; BDM, PM, TPM, CBM and RCM. An appropriate and effective maintenance strategy will ensure reliable production equipment- reflective of the effective performance of the maintenance management system. This in turn will provide the quality product that the ‘Enterprise’ will sell in order to obtain profit. The goal of the organizations is to operate the business that is profitable and sustainable. Maintenance Management Performance is the dependent variable; it will be measured using TPM’s key performance indicator, OEE.

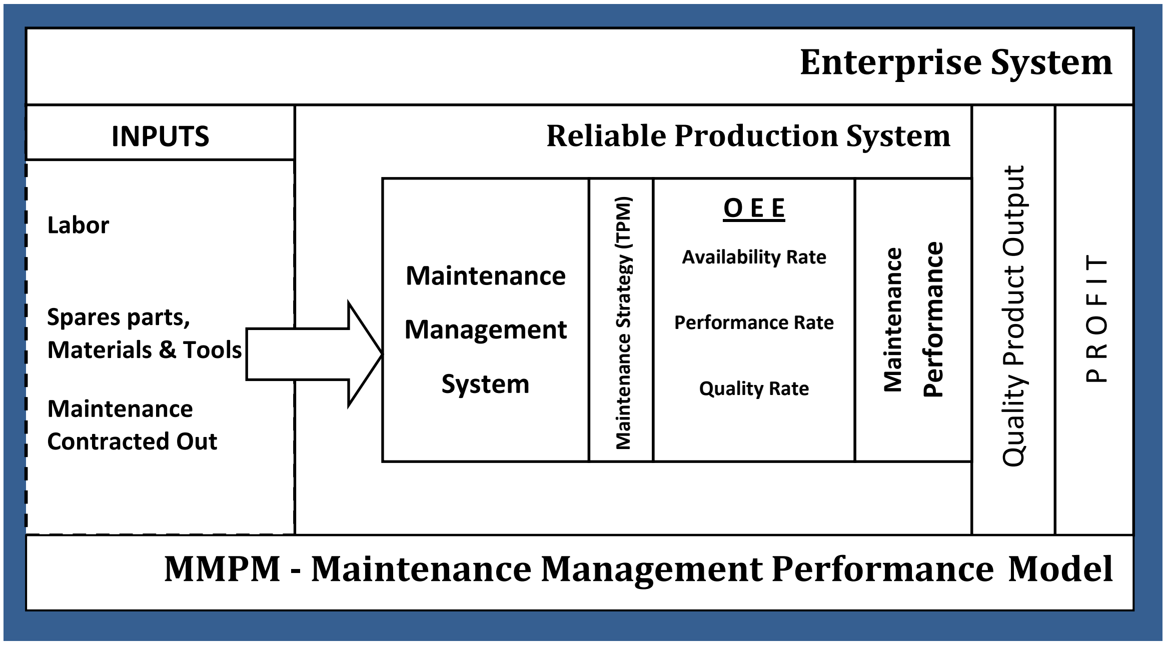


Figure 3.10
Maintenance Management Performance Model

3.5 Variables in this research study

3.5.1 Independent Variable (IV): In this study, inputs to the maintenance system is the independent variable (IV); the independent variable is typically the variable that is being manipulated or changed, and would have an effect on the dependent variable. IV in this study is subdivided into three sub IVs: Labor; Spares parts, Materials & Tools; and Maintenance Contracted out. Sub-IVs are further explained here (Figure 3.11).

I. Labor (maintenance workforce) - Competitiveness depends on many things. One vital determinant, ultimately perhaps the most important single determinant, is the level and improvement of labor skills at all levels. In a general sense, this is so widely accepted that there is no need to argue the case at length. Emerging new technologies often call for entirely new types of skills, both for direct production and services and for the organisation of production and for managing knowledge networks. The recognition that skills or human capital are important to comparative advantage is of long standing; however, there is a new burst on interest in its role in economic growth and competitiveness. The new technological paradigm calls for more skills, for higher levels of skill and for different kinds of skill. The reasons for these trends are obvious. The pace and ubiquity of technical progress means that all activities have to improve their technologies, and so the skills needed to operate them, if they are to compete. With the liberalization of trade and investment, even non-traded activities are increasingly exposed to international competition, and have to improve their competitive base to survive and grow. The need for increased skills rises with the level of development.

Labor specialization - Trade specialization is a characteristic of traditional maintenance organizations, the drawbacks of which have been highlighted earlier. Where the work requires special skills and where the workload can be made relatively smooth, it is appropriate to adopt trade specialization. However, it is more usual to find maintenance work that requires a range of skills, although one skill is usually predominant. In such cases, inter-trade flexibility is of paramount importance. This can be achieved by developing a multi-skilled workforce. However, making the transition from a highly specialized structure to a flexible one is often a lengthy and expensive process because of the investment in training and the installation of the new structure. Apart from introducing inter-trade flexibility within the maintenance workforce, there is another emerging trend in maintenance management; amalgamating the roles of plant operator and first-line maintainer. The operator-maintainer is trained both to operate the plant and do first-line maintenance across all the traditional trades. An advanced form of this approach is autonomous maintenance, a key element of TPM (Nakajima, 1988). Autonomous maintenance fosters a sense of plant ownership by developing the operator-maintainer to be involved in continuous improvement. Campbell (1995) classifies the commonly used measures of maintenance performance measures of cost performance; e.g. operations and maintenance labor and material costs. Labor comprises of the workforce, how well trained and equipped they are for the job.

Training and Development - Empowerment will degenerate into abandonment if employees fail to get the right tools, training on their use and support in their implementation. Educational resources, which can include technical consultation as well as training, must be available and accessible to employees with identified needs. For instance, the specialists of maintenance department are called upon to upgrade operators to operator-maintainers in TPM, or external consultants are hired to train members of the contract-negotiation team and the contract-management team for outsourcing of maintenance work. However, the training should not be limited to transfer of technical skills and knowledge needed for optimal task performance. It should also cover generic matters like the business imperatives peculiar to the organization (what determines the value of its product and services to customers), problem-solving techniques, team dynamics and facilitation skills. The additional training for managers' addresses issues such as the new roles (leader, communicator, coach, resource providers) they perform in the change programs, and the new management behaviours that will align efforts and foment commitment towards organizational goals.

II. Spares parts, Materials & Tools include: Spare parts, how well is spare parts inventories stocked to meet maintenance demand. Materials include consumables such as welding rods, chemicals for the water treatment, or steel for fabrication, and many more. Tools include hand tools, power tools, specific equipment such as weld sets, portable lathes, band saws, grinders, pipe benders, electric diagnostic meters, and many more. In most cases, these measures are tracked because the organization has always used them, other organizations are using them or the required data are easy to collect. These are diagnostic measures (Simons, 1995) that determine whether the maintenance function remains in control or compares favourably with its counterparts elsewhere within or outside the organization. Thus, they are selected largely to support operational control and benchmarking of performance. They are furthermore characterised as being backward looking and introspective, with a strong bias on financial and process-related measures. This type of unbalanced measures would encourage dysfunctional behaviours such as cutting back investment in operator training and equipment design modifications to achieve cost reduction in the short term. However, the potential recurring savings that can be realized from reliability and maintenance improvement are missed and committing to longer than necessary turnaround time for major overhauls to produce good results in schedule compliance. Obviously, these commonly used performance measures are often inappropriate for determining the contribution of maintenance to the business success of the organization. To achieve that purpose, the performance measures must be linked to the adopted strategy of the maintenance function. In some cases, data on labor cost includes the cost of tools and equipment provided to the maintenance personnel to do their job. The widely used performance measures were developed on the premises of the scientific management movement pioneered by Frederick Taylor about a century ago, a period when demand far exceeded supply, the operating environment was very stable, and labor intensive operations were the norm. The conventional wisdom of management which evolved from such a background is characterised by a preoccupation with maximizing the utilization of resources. Thus, in assessing maintenance performance, various efficiency indicators (such as equipment availability and labor utilization) and financial measures (such as repair and preventive maintenance costs) are routinely tracked.

III. Maintenance contracted out: Prior to starting the outsourcing program the company should objectively evaluate its actual situation with respect to some critical issues. Maintenance staff should adequately review internal structure, processes and management procedures, personnel capabilities and their responsiveness to changes and innovations. A definite picture of the overall ability to manage the outsourcing program could be drawn and company's readiness to outsource maintenance activities could be somehow quantified. The choice of the activities to be externalised represents another important decision to be faced at the very early stages of the outsourcing program. Generally, “non-core” competencies are all good candidates for outsourcing, being standard, well defined and repetitive activities (such as, repair of generic and common equipments, electrical and electronic parts and plant overhauls). Besides, many of them are adequately performed by a growing number of specialized suppliers available in the marketplace, with interesting costs and quality rates. In this case, the risk of losing expertise and know-how is minimal while, on the other hand, in-house maintenance personnel can concentrate on critical and valuable technical topics (Dunn, 2009). To maximise the potential advantages and to minimise the risks deriving from the adoption of outsourcing policies, an extremely important role is covered by the selection of the right supplier. It is, therefore, necessary to develop the selection criteria and the benchmarking activities to evaluate and analyse their capabilities including geographical position (i.e. local presence), the perceived quality of goods and services, contractor flexibility, technical excellence, plant-specific know-how and experience, and competitive low price. These are some good examples of performance factors that may be used to this end (Choi & Hartley, 1996). It is crucial to obtain a sustained spirit of co-operation and mutual understanding that benefits both parties. The most successful outsourcing arrangements are those in which the supplier brings a "partnership philosophy" to the alliance (Judenberg, 1994). Of particular importance will be the explicit consideration of risk at various key points in the contracting process, and the identification of appropriate strategies for managing those risks. The specification of requirement during the tendering process will need to be carefully considered. In particular, for those contracts involving large-scale outsourcing of most maintenance functions, there will be a demand to ensure that the requirements specification is outcome-based, rather than input-based. In other words, the specification will need to detail what is to be achieved from the contract, not how it is to be achieved, or what inputs will be required for its achievement.

3.5.2 Moderating Variable (MV) - In this study, “maintenance strategy” is the moderating variable; moderating variable is the one that affects the direction and/or strength of the relation between an independent or predictor variable and a dependent or criterion variable. Several maintenance strategies are being applied in the industry, namely; BDM, PM, TPM, RCM, and CBM.

3.5.3 Dependent Variable (DV) - Dependent variable is a variable in a logical or mathematical expression whose value depends on the independent variable; "if $f(x) = y$, y is the dependent variable". In this study “maintenance management performance” is the dependent variable; dependent variable is the observed result of the independent variable (Figure 3.11).

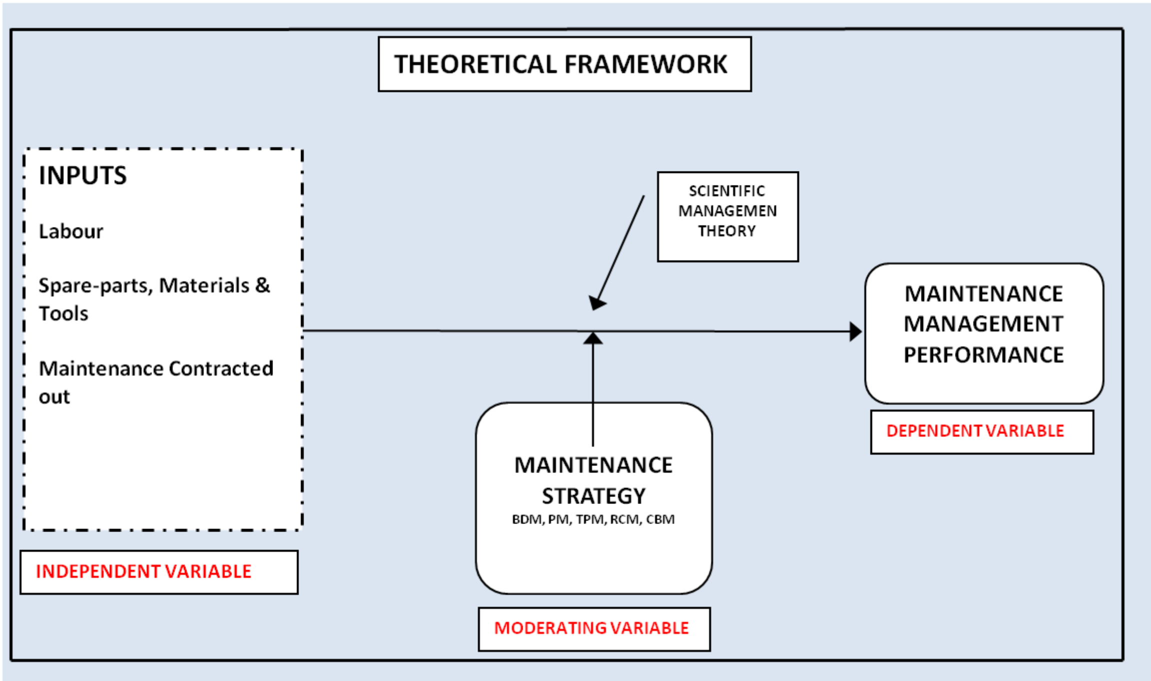


Figure 3.11
Variables Depicted in the Framework

3.6 Research Methodology

A methodology is instantiated and materialized by a set of methods, techniques and tools; whereas, a tool is an instrument or apparatus that is necessary to the performance of some task. A methodology does specify several processes that need to be followed; these processes constitute a generic framework. They may be broken down in sub-processes, they may be combined, or their sequence may change. However any task exercise must carry out these processes in one form or another (Katsicas, 2009).

The research design and methodology for this study constitutes the road map for the collection, measurement and analysis of data. It is the plan and structure of investigation so conceived as to obtain answer to research questions; a guide line for the researcher.

This study utilizes descriptive statistics, discussed in the following paragraphs, since the purpose of this research is to measure the maintenance management performance of palm oil mills; the target population of this study. Measurement serves the researcher as a numerical report of observations. In some respects, measurement can be considered a special “language” for reporting observations numerically. Measurement bridges the gap between what a researcher reports as an observation of a variable in the real world and what has been defined as a variable in a statistical model. A graphic depiction of the methodology is given in Figure 3.12.

3.6.1 Indexes of Population and Sample Design

Indexes of populations: it is rarely feasible to observe and measure an entire population. What is done, instead, is to measure some portion (sample) that is taken as the representative of a population. However, anticipating a lower response rate due lack of CSR culture prevalent in Malaysian industries (MIM, 2009), survey questionnaire was mailed to entire palm oil mills population, all 373 of them supposed to be in operation out of the total 434 registered according to MPOB, 2010, list.

Descriptive statistics, applied in this study, provides a basis for calculating such indexes as the mean, median, mode, and standard deviation; given these indexes, the researcher then applied statistics to generalise these indexes as to how they apply to the entire population.

The researcher compiled a complete list of the entire palm oil mills population; official master list on compact disc was obtained from the MPOB and verified against the listed companies in MPOC data base.

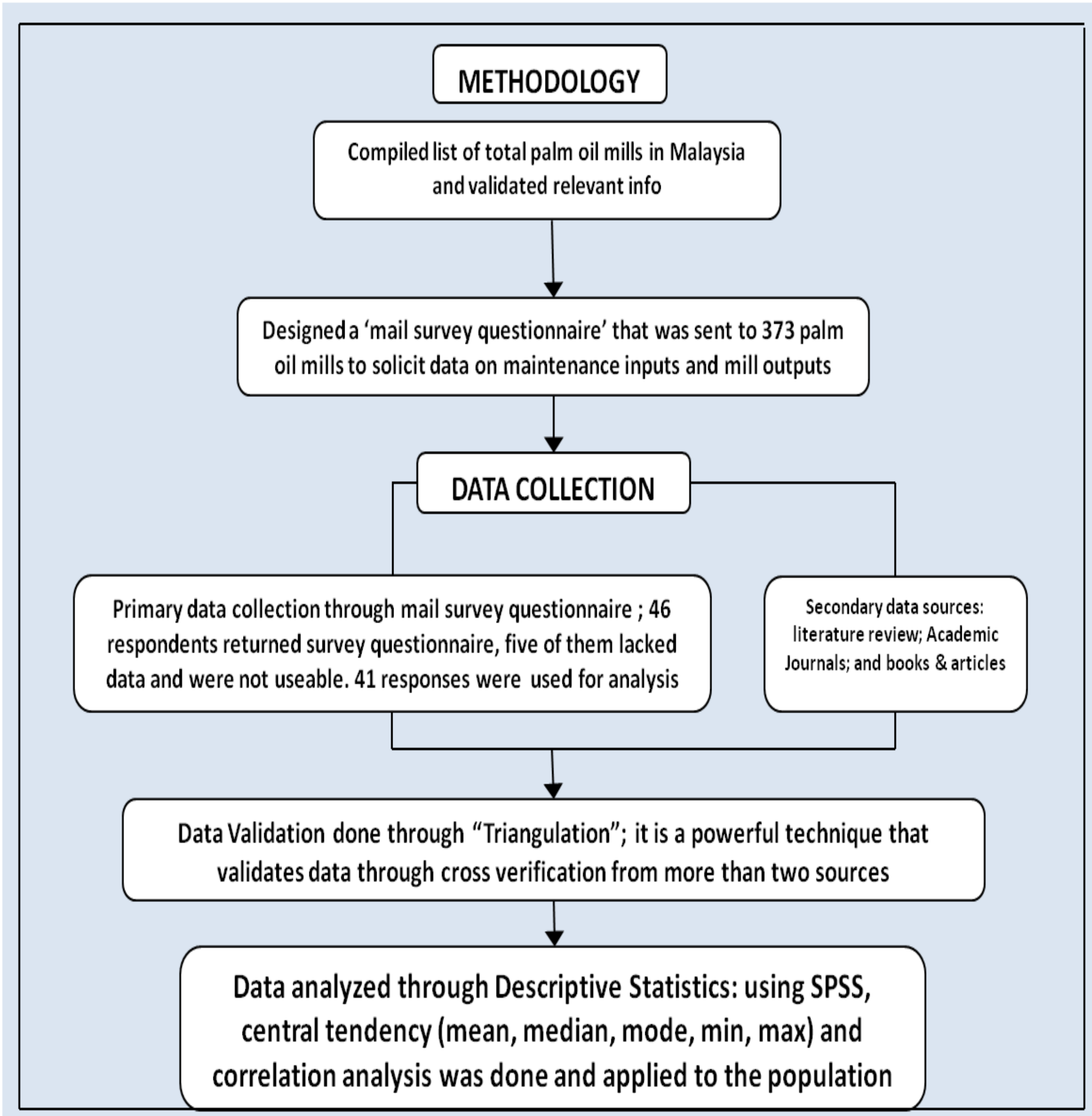


Figure 3.12
Graphic depiction of Methodology

3.6.2 Measuring Instrument – Design, Testing, and Validation

An Instrument – in statistics, is a tool used to collect measures of the research variables. Variable is an observable characteristic of an object or event that can be described according to some well-defined classification or measurement scheme that is likely to change or vary, subject to variation; changeable.

There are three main variables that constitute the design of this study. Independent variable is a variable whose values are independent of changes in the values of other variables; “Inputs” to the maintenance function is the independent variable (IV), further classified into three sub-IVs. Moderating variable is characterized statistically that affects the direction and/or strength of the relation between dependent and independent variables; “maintenance strategy” is the moderator variable (MV). Dependent variable is an observed variable in an experiment or study whose changes are determined by the presence or degree of one or more independent variables; "maintenance management performance” is the dependent variable (DV).

3.6.3 Measuring Instrument: Survey Questionnaire

A questionnaire is a research instrument consisting of a series of questions and other prompts for the purpose of gathering information from respondents. An effective questionnaire should include “Questions” that are reliable when they elicit the same response at different times, or with different respondents, when the levels of functioning and related circumstances are the same. Data collection instruments should always be tested, a small investment in resources on testing can save a large amount of resources if errors are detected. Systematic errors, if undetected, can make the data collection activity unfit for the purposes it was meant to serve. Thorough testing minimises non-sampling errors. Additionally, testing provides management information useful for planning the conduct of any data collection undertaking. A complete testing strategy involves the following two components: Pre-testing, the investigation of possible data quality concerns and the identification of ways to minimise identified sources of non-sampling error; Field testing (or pilot testing) - systematic testing on a set of respondents to isolate potential bias and sampling errors.

The questionnaires for this research study strike a balance between simplicity and sufficient detail to enable reasonably well informed managers to systematically assess the strategic contribution of their own operations, overall and in detail. Two types of questionnaire were designed for the data collection. One was meant for the private mills operating in individual capacity (Appendix-A) and the other catered to head offices of the multi-mill operations (Appendix-B). Some of the problems with the questionnaire were anticipated such as the design of the questionnaire could be criticized, terminology could be seen problematic for some respondents leading to ambiguous responses, and there may be some respondents who do not fully understand the questionnaire. However, as middle managers and management students who had been exposed to, widely in use, maintenance strategies – such as PM and TPM, they ought to have a good understanding of the terminology used. There may be some respondents who do not have an adequate level of knowledge of operations to be able to answer appropriately. However, the author provided easy to understand questions to respondents in order for them to answer the questionnaire as explicitly as possible. Calls for more empirical research in operations management have led to an upsurge in the use of questionnaire-based survey methodologies over the last decade (Filippini, 1997; Scudder & Hill, 1998; Malhotra & Grover, 1998) and this is now the most commonly used methodology in empirical operations management research. Considerable care was taken to make the questionnaire, simple and suitable, for the Malaysian audience. The questionnaire was reviewed, modified and approved on three separate occasions by mill managers and mill maintenance engineers. This was done in exclusive visit to three palm oil mills during the pilot study; list of the mill participants is given in Appendix-E. Particular attention was given to the facts that questionnaire is not too long and questions are not cumbersome to answer. Mill will impart with voluntarily the information solicited, without risk of compromising their commercial confidentiality; and solicited information is relevant to the research goals. The cover letter that was sent to mills (Appendix-C) and the head offices (Appendix-D) contained a non-disclosure agreement to ensure confidentiality of the data collected.

Questionnaire cover page contains information about the research title, researcher, supervisors, and the non-disclosure agreement. The questionnaire is divided in the following two parts. Part one solicits background information of the responding organisation and respondent, and its maintenance department. Part two comprises of 11 strategically selected questions that solicit data on Maintenance Inputs, CPO Production, mill hours worked & hours of downtime and POME Generated & Treated. This data was collected for the 'Financial Year 2010' and utilized to calculate overall OEE for CPO overall extraction process, for complete palm oil mill sector and assessment of POME disposal practices under sustainability regulations.

During validation of the list of palm oil mills it was established that only 15% of the total palm oil mills had valid email address. Considering this, a direct mail survey was selected to collect data from the palm oil mills, mail survey was deemed as the most appropriate method for data collection (Salant & Dillman, 1994; Mangione, 1995).

The questionnaire was mailed to palm oil mills in a two-week period using the Malaysian Postal Service starting 7^{th}. July 2011. The participants were asked to answer all questions objectively and to reply by regular mail through the addressed and postage paid envelop provided. Most of the replies were received by the end of August 2011; however, the last reply was received at the end of January of 2012. After receiving each reply, it was immediately entered into a computer database along with the returned letters.

3.6.4 Primary Data Collection and Validation

Primary Data collected through the survey questionnaire was entered in an excel spreadsheet (Appendix-G) under four subheads of: Mill's general information 2010; Mill's maintenance inputs 2010; Mill's outputs 2010; and Mill's downtime 2010. Validation of the primary data was done through triangulation (4.2.1). Triangulation is a powerful technique that facilitates validation of data through cross verification from more than two sources. In particular, it refers to the application and combination of several research methodologies in the study of the same phenomenon (Bogdan & Biklen, 2006). It can be employed in both quantitative (validation) and qualitative (inquiry) studies and it becomes an alternative to traditional criteria like reliability and validity. Altrichter *et al.* (2008) contend that triangulation "gives a more detailed and balanced picture of the situation." While, according to O'Donoghue and Punch (2003) triangulation is a "method of cross-checking data from multiple sources to search for regularities in the research data.

Denzin (2006) identified four basic types of triangulation: *Data triangulation* - involves time, space, and persons; *Investigator triangulation* - involves multiple researchers in an investigation; *Theory triangulation* - involves using more than one theoretical scheme in the interpretation of the phenomenon; and *Methodological triangulation* - involves using more than one method to gather data, such as interviews, observations, emails, phone calls, questionnaires, and documents.

The purpose of triangulation in research is to increase the credibility and validity of the results. This is the most widely practiced validation tool in the industry, worldwide. Operations management is provided with data from several sources that sometimes have competing interests such as maintenance, production, quality assurance, and sales. Each department, to some extent, has a tendency to skew the data to their eminence.

3.7 Chapter Summary

Primary Data was collected through the survey questionnaire and, for reliability and validation, triangulation was applied. The purpose of triangulation is to increase the credibility and validity of the results. This is the most widely practiced validation tool in the industry, worldwide. The chapter also discusses variables. ‘Inputs’ to the maintenance system is the independent variable (IV) which is divided into three sub IVs: Labor; Spares parts, Materials & Tools; and Maintenance Contracted out. Maintenance strategy is the moderating variable (MV) and maintenance performance is the DV. Descriptive statistics, applied in this study, provides a basis for calculating such indexes as the mean, median, mode, and standard deviation; these indexes, have been used to generalise as to how they apply to the entire population. Correlation tests were carried out using SPSS and added to the analysis.

Maintenance comprises of multitude of divergent prospective, and given the constraints, optimization is not always necessary. The developed maintenance management evaluation model draws on the ‘input-output’ concept put forward by Tsang (2002) and uses OEE, TPM’s KPI, for maintenance evaluation. OEE is a formula used in the manufacturing industry to calculate the overall equipment effectiveness of a branch or complete production system; formula was presented as an overall metric in the TPM concept. OEE is a crucial measure in TPM that reports on how well equipment is running. Collection of data for calculating OEE for individual machines or equipment can also be done through daily production logs; it can be computed to obtain operational history of critical machines and equipment on daily, weekly, monthly, or annual basis for comparison and improvement. For ease of use and interpretation at the shop level, all the information is negotiated, using simple calculations, through linked spreadsheet cells containing readily available data. OEE figure thus obtained could be improved upon. TPM and its KPI ‘OEE’ has been determined as a best in class manufacturing improvement tools and the proposed ‘MMPM’ model offers a pragmatic elucidation for performance measurement and improvement.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Introduction

Data analysis is a process of inspecting, cleaning, transforming, and modeling data with the goal of highlighting usefulness of research results, suggesting conclusions, and supporting decision making. Data analysis has multiple facets and approaches, encompassing diverse techniques under a variety of names, in different business, technology, physical science, and social science domains. Data integration is a precursor to data analysis, and data analysis is closely linked to data visualization and data dissemination. Data integration involves combining data residing in different sources and providing users with a unified view of these data (Lenzerini, 2002). According to Lane (2006) this process becomes significant in a variety of situations and appears with increasing frequency as the volume and the need to share existing data explodes, it has become the focus of extensive theoretical work and in management circles, people frequently refer to data integration as Enterprise Information Integration (EII).

Data visualization is the study of the visual representation of data, meaning; information which has been abstracted in some schematic form, including attributes or variables for the units of information (Friendly, 2008). The main goal of data visualization is to communicate information clearly and effectively through graphical means. It doesn't mean that data visualization needs to look boring to be functional or extremely sophisticated to look beautiful. To convey ideas effectively, both aesthetic form and functionality need to go hand in hand, providing insights into a rather sparse and complex data set by communicating its key-aspects in a more intuitive way. Yet designers often fail to achieve a balance between design and function, creating gorgeous data visualizations which fail to serve their main purpose; to communicate information (Friedman, 2008). Data visualization is closely related to Information graphics, Information Visualization, Scientific Visualization, and Statistical Graphics. In the new millennium data visualization has become active area of research, teaching and development. It has united the field of scientific and information visualization (Post *et al.,* 2002). Applying aforesaid analyzing tools, this chapter validates data and calculates the central tendency of IV and DV. It also quantifies the inefficiency cost of the milling sector by analyzing OEE, OER, and yield. The chapter also discusses the role of moderator, maintenance strategy (TPM), and POME generation and treatment in the palm oil milling sector.

4.2 Data Collection and Enumeration

Given the fact that only 15% of the total palm oil mills had valid email address, and considering other options and constrains (i.e. mail survey, phone survey, face-to-face survey and internet survey), a direct mail survey was sent to all the palm oil mills. The mailing list consisted of contact information of 373 operating companies out of the 434 listed with MPOB, spread throughout Malaysia. 41 usable responses were received, 38 by mail and three by email. None of the 20 head offices contacted for survey responded. The questionnaires sent to 15 companies were returned to the sender due to wrong mailing addresses, listed. Three companies called in that they were not willing to participate in the survey, and five companies returned the survey unfilled. This led to response rate of 11% as expected for a direct mail survey (Erdos & Morgan, 1983). 41 respondents are adequate as 30 is the minimum number of respondents required to do just basic quantitative statistical analysis (O'Leary, 2004). It is worth noting that a CSR survey was sent out to 2000 companies by the MIM in 2009; of the 2000 to whom the survey was sent, only 110 responded. The low response rate of 5.5% is reflective of Malaysian Companies' lack of interest and respect for CSR activities. Primary data information received through the respondent surveys was entered in the Excel spreadsheet under four subheads with the following information under each subhead:

i. Mill's general information: name of the mill; year started production; approved FFB processing capacity tons/h; maintenance personnel employed; maintenance strategy adopted by the mill; and equipment contracted out for maintenance
ii. Mill's maintenance inputs, cost in Ringgits, 2010: Labor (maintenance workforce); spares, materials, & tools; and maintenance work contracted out
iii. Mill's production outputs, in tons, in 2010: FFB processed; CPO produced (in spec); out of spec CPO and slush oil produced; and mill effluent (POME) produced and treated
iv. Mill's uptime 2010: total mill hours worked; and mill's total downtime

For privacy of the mills, their names have been omitted from all the tables provided in this thesis. Prior to the start of data analysis process, the preliminary data was checked for normality, information was triangulated; compared to the data collected through pilot study on three mills. 87.8% of the respondents belong to SMEs; classified according to FFB processing capacity, under 60 tons/h fall under SMEs (MPOB, 2010). Data for these subheads was tabulated from the primary information recorded in Excel spreadsheet, through simple calculations entered in linked cells (Appendix-G).

4.2.1 Data Validity and Reliability

Mills' Data collected through survey questionnaire was validated by triangulation:

i. Data reported by mills in the survey regarding hours worked, FFB processed, and CPO produced, in the financial year 2010, comes from the financial statements that mill submit to their head offices for profit and loss calculations; the records are factual, valid, and reliable.

ii. Mean OER calculated using respondents' data comes to 0.2044 (20.44%). This figure concedes with the of average OER industry figure reported by MPOB (2010) further validating the primary data provided by the mills.

iii. Data of hours worked by the mills conforms to CPO produced at the calculated OER and affirms its reliability.

4.2.2 Data adaptations: presumptions conceived from the survey (appendix-E&G)

i. An hour daily added for set-up & adjustment; boiler start-up and other adjustments, 1/2 hour per shift added for minor stops – availability.
ii. Mills worked two, 8-hour shifts, 6 days a week, 50 weeks per year.
iii. First hour CPO production treated below spec and accounted towards quality rate.
iv. Unfilled information was supplied with average figures to keep continuity in calculations.
v. For per ton cost of Sub-IVs for a ton of CPO good quality CPO was taken into account.
vi. FFB processing capacity adjusted where the actual running capacity was dissimilar.
vii. Below spec CPO for the year include 300 hours of production plus reported slush oil recovered.
viii. POME figures were reversed where POME treated figures were more than POME produced.
ix. Missing data was calculated at the average cost per ton of CPO produced.

Information for analysis and interpretation through SPSS regarding three sub-IVs, MV, and DV, was further processed. In this Excel spreadsheet informative data was computed to arrive at per ton cost of CPO for three sub-IVs: Labor (maintenance workforce); spares, materials & tools; and maintenance work contracted out. Data was also computed to calculate OEE (DV) through simple calculations applied in linked cells

(Figure 4.12). For SPSS analysis, data was entered in 26 variables that were created and labeled according to the primary information obtained through the survey questionnaire. Information computed in the Excel spreadsheet (Appendix-H) was entered in SPSS for descriptive analysis. Descriptive Statistics applied in this study comprise of Central Tendency and Relationship.

4.2.3 Central Tendency - Several indexes tell us about central tendency of the scores in a distribution; in simpler terms, these indexes refer to how scores tend to cluster in a particular distribution. Apart from Min & Max, four such indexes are the: *mean* (the sum of the scores in a distribution divided by the number of scores); *median* (the midpoint or mid score in a distribution); *mode* (the most frequent score in a distribution); and standard deviation (shows how much variation or "dispersion" exists from the mean). Central tendency was calculated using SPSS for: IVs; OER; OEE Factors; and OEE (Figure 4.13).

Central Tendency: IVs, OER, OEE and OEE Inputs		**Labour RM) per ton of CPO**	**Spares (RM) per ton of CPO**	**Maint. Contracted (RM) per ton of CPO**	**OER**	**Availability**	**Performance**	**Quality**	**OEE**
N	Valid	41	41	41	41	41	41	41	41
	Missing	0	0	0	0	0	0	0	0
Mean		7	42	19	**.2044**	.86	.77	.91	**.62**
Median		5	36	17	.2059	.87	.81	.92	.63
Mode**		1(a)	50	19	.1874	.86	.54	.94	.41
Std. Deviation		5	46	14	.0098	.04	.12	.05	.11
Minimum		1	3	0	.1874	.74	.54	.63	.41
Maximum		25	272	60	.2281	.91	.92	.96	.80

**** Multiple modes exist. The smallest value is shown**

Figure 4.13

Central Tendencies

4.3 OEE – the Dependent Variable (DV)

The foremost research objective of this study was to evaluate performance of maintenance management system at the Malaysian palm oil mills, by measuring OEE. In today's highly competitive environment maintenance, quality, and productivity are essentially related components and are integral operational elements for a modern, sustainable, and profitable production system. Suitable maintenance policy and strategy leads towards improving equipment reliability and maintainability, and maximizes OEE (i.e. zero breakdowns, zero accident, and zero defects); it raises productivity and contributes to better quality output as detailed in section 1.2.5. Continuous manufacturing systems used within the palm oil milling industry involve different machines, equipment, and processes that are arranged in a sequence of operations in order to manufacture the product - CPO. The palm oil industry is generally categorized as capital-intensive industry and, because of high capital investment, the utilization of equipment as effectively as possible is of high priority. As evidenced by literature, the idea of linking maintenance quality and productivity together and finding analytical and/or mathematical relationship among them is perhaps at its early stage, at present (Ben-Daya & Duffuaa, 1995; Jambekar, 2000; Alsyouf, 2007); however, there is literature support to demonstrate that a one to one relationship between the two components has been viewed in a number of sources (Ben-Daya & Duffuaa, 1995; Jambekar, 2000; Alsyouf, 2007; Lee, Beruvides, & Chiu, 2007; Helms, 1996). Ben-Daya and Duffuaa (1995) highlighted and proposed conceptual approaches for linking and modeling the relationship between maintenance and quality and Alsyouf (2007) proposed a conceptual model that links maintenance, productivity and profitability. Hansen (2001) describes OEE as a powerful production and maintenance tool for increasing profit while Bamber, Castka, Sharp, and Motara (2003) have discussed OEE as a total measure of performance. This research seeks to illustrate that OEE can be used for the precise calculation of equipment effectiveness for full process cycle. The average OEE figure of 62% (Figure 4.14) is below the, lower end, bench mark of 85% (Wireman, 2004); however, this figure could have been subjacent as the data constituting three parts seems to have been compromised (3.4.4). OEE can appear improved by purchase of redundant standby critical equipment such as spare boilers, presses, decanters, turbines and many more; 81% of respondents reported having an array of redundant equipment compensating for their operational inefficiencies. Here is a critical re-run of the concerning activities.

Availability: Typical Unplanned Downtime items include; waiting for operator, failure or breakdowns, setups & changeover, tooling or part Changes, and start-up & adjustment. Also includes material flow; Input (no FFBs) and Output (storage tanks full or not able to receive CPO). All the aforesaid have not been appropriately reported in the production sheets. Adjustments have been made in the data to afford reporting discrepancies revealed through data triangulation. Average of one hour for set up & adjustment every day, common in all the respondents, was accounted; and at a very conservative rate, accumulative, one hour for minor stoppages spread over two shifts was also considered. That amounted to 30 minutes per shift.

Performance: typical items include minor stops and reduced speed or cycle time. Calculations regarding CPO produced vs. CPO could have been produced are conciliated, idle time not reported and, generally, locally made, oil recovery equipment, such as presses and vibrating screens, is not efficient as oil recovery rate is poor, averaging under 20%, compared to 30% of mills with best practices (MPOB, 2010). More over 2 – 4% CPO ends up in EFB and POME. Reduced speed or cycle time was not being recorded by any of the responding mills. The one speed mill line ran continuously, with or without FFB supply.

Quality: CPO produced in the first hour of mill process is usually out of spec due to excessive moisture and other contaminations while the line is adjusted. However, mills have the tendency to pour the low quality CPO in the main storage tanks where it gets mixed with the rest of the day's production. Only 10% of the respondents reported on this account, separately. However, Low grade oil, slush oil, recovered from POME ponds, was reported by 41% of the respondents; the remainder might be incited to release it with the POME into dug channels, leading to adjacent open lands. Mills were not ready to disclose the sales figures. The author had no access to the sales figures of the mills, hence, there was no way to find out if the CPO sold by mills earned them the best market price for in-spec CPO, as low quality is bound to bring them low price. However, to satisfy share holders and pacify regulators, mills can get away with it by blaming it on the market fluctuations; nevertheless, data is compromised.

4.3.1 Data Collecting Issues and Challenges - Theory and Practice Gap

Collecting the data from operators on the performance factor is not always a reliable measure, explained at length in section 3.4.4. Pilot study and main data triangulation revealed that most of the mills settle on manual data collection. There is a hereditary problem in that. Manual forms are often filled in at the end of shift that may not reflect the truth of what actually happened. The longer the time between the event and the recording the greater is the chance of inaccuracy in data collected. Some companies recorded the downtime data at the end of the job, some at the end of the shift, and some even at the end of the week. The aforesaid methods could potentially compromise the figures that contribute to OEE. Pilot study and data triangulation revealed that most mills do not record or report minor stoppages of equipment (none of the respondents' recorded minor stoppages). That distorts the down time figure and skew OEE figure towards better efficiency.

To resolve the problems of data collection the recording of all the factors needs to be automated or achieved as unobtrusively as possible. Proper sensors installed strategically can provide the data required. This can be addressed by installing a simple 'heartbeat' sensor to monitor if the machine is running or not and at what speed. In the event of the machine stopping, the operator simply has to record the reason for the stop through a scan of a barcode. This ease of use will provide the mill with 'machine truth'.

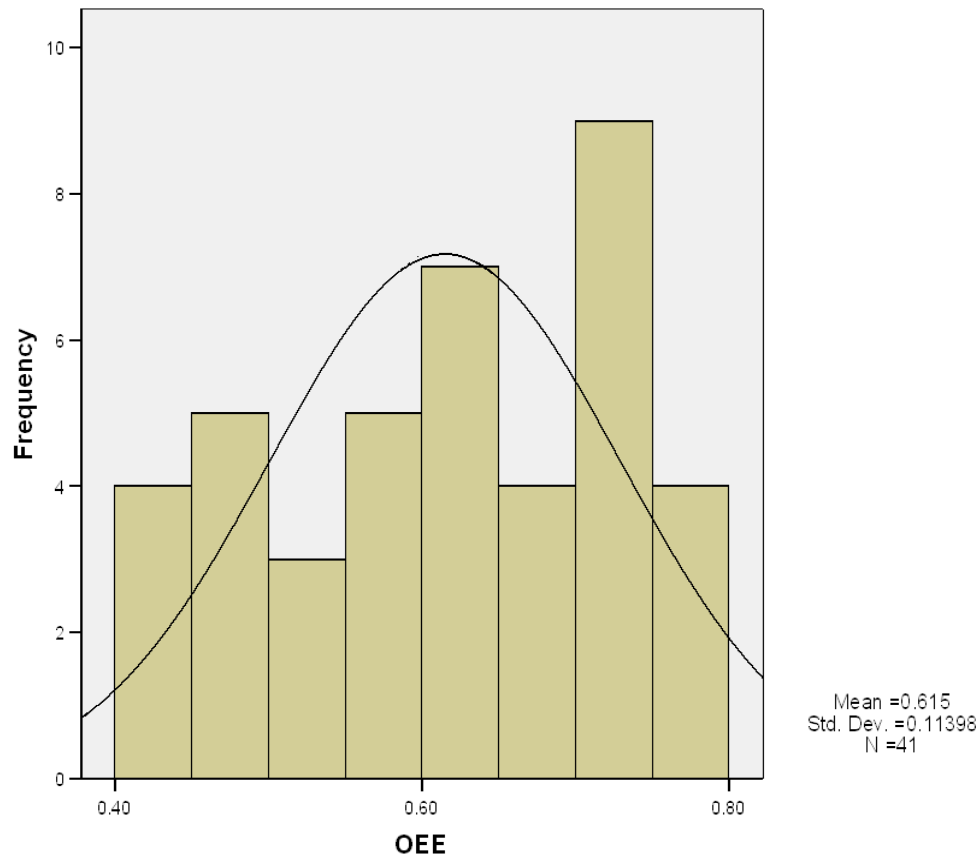


Figure 4.14
OEE: mean and standard deviations

Mills should adopt best practices including a participative and social process is in place. There is a widespread understanding of the maintenance role in OEE, maintenance strategy is widely communicated, momentum of change must be maintained, and the support infrastructure must be in line with the adopted strategy. This is the starting point to not only implementing OEE measurement but gaining the power to improve it. Maintenance daily service log (Figure 5.20) recordings can be used to cross check the down times. Some organizations may be instigated to misconstrue their OEE figures by using any of the following channels; log the breakdowns as planned maintenance, use an easy performance standard, measure the best machine or line and quote that figure, or set arbitrary targets and achieve them through the above.

4.3.2 OEE: Cautions for using and Issues to be considered

Based on the wide spread and diverse understanding and use of OEE, there are several cautions to be considered regarding its use:

i. Calculated OEE is not valid for comparing or benchmarking different assets, equipment, or processes. OEE is a relative indicator of a specific single asset or process effectiveness compared to itself over a period of time. However, OEE can be used to compare alike equipment in similar situations producing matching products or output.

ii. A calculated OEE percentage assumes that all equipment-related losses are equally important and that any improvement in OEE is a positive improvement for the business. This generally may not be the case. For example, the calculated OEE percentage does not consider that a one percent improvement in quality may have a bigger impact on the business than does a one percent improvement in availability. Also, in the OEE calculation, three different units of measure are erroneously considered as the same; chronological time, units per time, and counts of units produced and are converted to percentages for comparison. OEE percentages can actually improve while actual quality losses increase significantly. OEE percentages can actually decline while output improves; efficiency and quality losses are reduced and the same planned output is generated in less time thereby lowering the “availability” percentage, three shifts of output in two shifts.

iii. The only reason to measure and analyse anything is to improve it. If one is not going to use the whole improvement cycle there is no point in measuring OEE. It tells management nothing which they do not already know. At a gross level all OEE tells the organisation as to how much a product it made compared to how much could have been made. Averaging OEE's over whole plants, sometimes, hides issues. OEE is more effective improvement tool for use in specific improvement projects. The biggest misuse of OEE is to use it to compare different processes, plants or machines. It is an improvement measure for organisations who want to improve their equipment performance.

iv. Given the lack of agreement on OEE definition between recognized OEE experts and years of use and misuse, acceptance of a single OEE definition within business and industry is unlikely.

v. Comparable or similar metrics: The metrics of Asset Utilization (AU); Overall Plant Effectiveness (OPE) for petro-chemical process industries; and Total Equipment Effectiveness Performance (TEEP) are derivations of the original OEE metric

vi. Lack of agreement on the definition of "Availability" as 24 hours, seven days, scheduled time, or actual running time (utilization).

vii. The "Overall" nature of OEE is not all encompassing. Provided reliable data is available, other related metrics that should be considered include; operating and maintenance costs, RONA, MTBF, MTTR, and utilization.

4.4 Palm Oil Milling Sector 'Inefficiency Cost' Quantified

4.4.1 OEE

The computed average figure of 62% was measured against the world class industry benchmark of 85% (Wireman, 2004) for further analysis to compute annual industry losses and cost of this milling process inefficiency to the palm oil sector. There is a gap of 23% (85-62%). Malaysian CPO production is 18.9 million tons/year at an OEE of 62% this translates into 304,839 tons of CPO for 1% of OEE. For the gap of 23% the figure is, staggering, 7,011,290 tons CPO per year worth RM 22.44 billion, at prevailing rate of CPO per ton of MR 3200 (Figure 4.15).

4.4.2 Yield

Bridging the yield gap between national average of 4 tons/ha, and 8 tons/ha of mills with best practices, has the potential to produce an additional 18.9 million tons of CPO worth over RM 60.48 billion (Figure 4.14). It would be equivalent to RM 83.4 billion in export earnings.

4.4.3 OER

Mean figure afforded by the survey data for oil recovery is low, averaging 20%; whereas OER of mills with best practices is 30% (MPOB, 2010). If the palm oil mills can bridge this gap and improve their OER by 10%, they would be able to earn an additional RM 30.24 billion per year (Figure 4.15). Total recoverable potential cost due to the inefficiencies of Malaysian palm oil milling sector amounts to RM 114.556 billion per year. That is 12% of the Malaysian GDP of US$ 305.83 billion for the year 2011 (DFAT, 2011) and is a strong impetus for the Palm Oil Mills to adopt best practices that create conditions conducive to successful application of OEE.

Palm Oil Milling Sector 'Inefficiency Cost' Quantified							
Item & Reference	**Present Average**	**Potential**	**Gap**	**CPO/year production**	**one% of CPO equivalent t/y**	**CPO tons potential/y**	**Amount @ 3200 RM per ton of CPO**
OEE %	62	85	23	18,900,000	304,839	7,011,290	22,436,129,032
OER %	20	30	10	18,900,000	945,000	9,450,000	30,240,000,000
Yield ave 4 t/ha (50% of 8 t/ha - 100%)	50	100	50	18,900,000	378,000	18,900,000	60,480,000,000
Maint. Overspend	n/a	15%	15%	18,900,000			1,399,500,000
Total RM/year							**114,555,629,032**
Inefficiency cost' quantified in US$ (billions)	36.37	Malaysian GDP in $US - 1 US$ = 3.15		305.83	Palm Oil Milling Sector 'Inefficiency Cost' share of GDP		**12%**

Figure 4.15
Palm Oil Milling Sector 'Inefficiency Cost' Quantified

4.5 Maintenance Inputs (IV), OEE inputs, and OEE Correlation

Correlation looks at the relationship between two variables in a linear fashion. Applying SPSS for this study, simple bivariate correlation has been calculated. Simple bivariate correlation, also referred to as zero-order correlation, pertains to the correlation between two continuous variables and is the most common measure of linear relationship. Bivariate correlation evaluates the degree of relationship between two quantitative variables. Pearson Correlation (r), the most commonly used bivariate correlation technique, measures the association between two quantitative variables without distinction between the independent and dependent variables, e.g., maintenance inputs cost per ton of CPO to OEE. The coefficient has a range of possible values from -1 to +1. The value indicates the strength of the relationship, while the sign (+ or -) indicates the direction; simply put, it is an indication of general trend. There is a positive correlation between maintenance inputs and OEE (Figure 4.16). Likewise, OEE inputs:

availability and performance; have a significant positive correlation with OEE - KPI for measuring DV (Figure 4.17).

Correlations		Maintenance Inputs	OEE
Maintenance Inputs	Pearson Correlation	1	.055
	Sig. (2-tailed)		.734
	N	41	41
OEE	Pearson Correlation	.055	1
	Sig. (2-tailed)	.734	
	N	41	41

Figure 4.16
Maintenance Inputs and OEE Correlations

Correlations		Availability	Performance	Quality	OEE
Availability	Pearson Correlation	1	.194	.222	.506(**)
	Sig. (2-tailed)		.225	.162	.001
	N	41	41	41	41
Performance	Pearson Correlation	.194	1	.240	.941(**)
	Sig. (2-tailed)	.225		.131	.000
	N	41	41	41	41
Quality	Pearson Correlation	.222	.240	1	.295
	Sig. (2-tailed)	.162	.131		.061
	N	41	41	41	41
OEE	Pearson Correlation	.506(**)	.941(**)	.295	1
	Sig. (2-tailed)	.001	.000	.061	
	N	41	41	41	41

**** Correlation is significant at the 0.01 level (2-tailed).**
Figure 4.17
OEE Inputs and OEE Correlations

4.5.1 Labor in Theory and Practice: an analytical discourse

Labor is the next frontier in overall manufacturing performance; Labor represents the human factor in producing the goods and services of an economy, detailed in section 3.5.1 (I). Manufacturers know the problem well that the next critical manufacturing element to optimize in today's demand-driven world is Overall Labor Efficiency (OLE). During the past decade, manufacturers poured attention and resources into supply chain improvements as a way to increase competitiveness and profitability. It was a successful strategy, but now it's hitting the law of diminishing returns, manufacturing is now in the quest to move to the next level of performance. For many manufacturing executives, dealing with a changing workforce, competing with offshore manufacturing, and maintaining profitability are factors of corporate survival. These goals will be achieved only if they can optimize their workforce performance. Optimizing workforce performance requires new insight. Companies ought to establish methods of quantifying, diagnosing, and ultimately predicting the performance of their workforce; one of the most important and highly variable elements of manufacturing. That insight can be provided by OLE. Simply put, OLE is the analysis of the cumulative effect three workforce factors have on productive output; Availability, Performance, and Quality. OLE is the key to understanding the effect the workforce has on manufacturing performance and, most important, it provides a platform that helps diagnose and predict that performance.

Skilled labor specialization: Skill is a measure of a worker's expertise, specialization, wages, and supervisory capacity. Skilled workers are generally more trained, higher paid, and have more responsibilities than unskilled workers. Education and training are important factors in increasing skill levels. The shift from unskilled to skilled labour can be attributed to increasing the efficiency of humans through investment in knowledge, technology, and trade; the effects of globalization also play a role in affecting the relative demand of skilled labor. TPM’s autonomous maintenance emphasizes the role of operators as first line maintainers. Operators can make or break maintenance effectiveness. Without interrupting their production work, operators can easily prevent breakdowns, predict failures and prolong equipment life if they become more intimately familiar with the machinery they run every day. But to do this, they must become highly equipment-conscious, and that can require some intense training. They must know what to do to keep machines in normal operating condition. They must be taught how, when and what to lubricate, as well as the best methods for monitoring vital signs and recording abnormalities. Involving operators in routine care and maintenance of critical plant assets offers three major benefits: firstly it reduces maintenance labor cost, the proximity of the operator to the asset greatly reduces or eliminates travel time and waiting; secondly it increases the availability of the highly skilled maintenance workforce for those maintenance activities requiring specialized talent, rebuilds and overhauls; and thirdly it banishes the "we-they" syndrome so prevalent in many plants. Maintenance and production must function as an integrated team. The eventual reason for autonomous maintenance is simply to save money and improve profitability. Operators are typically under used and have the time to perform these lower-skilled tasks. Transferring these tasks to operating teams improves the payback on the burdened, sunk cost of the production workforce, and permits more effective use of the maintenance crafts (Mobley, 2011).

Deming, the quality guru behind the ‘theory of profound knowledge’, believed that every worker has nearly unlimited potential if placed in an environment that adequately supports, educates, and nurtures senses of pride and responsibility. Deming's ideas of hard work, sincerity, decency, and personal responsibility, forever changed the world of management. In the resulting company, workers better understand their jobs, the specific tasks and techniques as well as their higher value. Thus stimulated and empowered, they perform better (Haller, 1993).

Drucker, a business thinker, and an enormous contributor to the SMT, professed ‘respect of the worker’: he believed that employees are assets and not liabilities and that knowledgeable worker are the essential ingredients of the modern economy. Central to this philosophy is the view that people are an organization's most valuable resource and that management's job is to prepare and free people to perform (Drucker *et al.*, 2008).

I. **Equitable Compensation and Rewards** – To be able to attract competent skilled labor force, companies have to adequately and equitably compensate them. Compensation includes topics in regard to wage and/or salary program structures and benefits, and is payment to employees in return for their contribution to the organization, that is, for doing their job. The most common forms of compensation are wages, salaries, and benefits. Poverty is one of the social concerns in Malaysia. One of the factors that cause poverty is employment with very low wages. The Malaysian government has not set the minimum wage, yet, which keeps wages in low skill sectors very low. According to a World Bank report, about 34% of Malaysians earn wages below RM700 per month, which is below the Malaysian poverty line benchmark of RM720, majority of the palm plantation and mill workers fall under this category. Nevertheless, Ministry of Human Resources has organized Minimum Wage Laboratory Exercise with the collaboration of World Bank on 8 to 14 February 2011, and prior to that National Minimum Wage Workshop on 4 August 2010. In addition, the government has established a National Wage Consultation Council, which will determine the rate and mechanism of minimum wage. With the commitment from the government, the deliberation now will be on the mechanism and quantum of minimum wage. However, nothing has materialized yet. Programs aimed at the employees of the enterprises are widespread, and often come in the form of education and training in HES. Provisions of education grants are common among the larger companies. Bursa Malaysia found in a survey that measures aimed at employees is the CSR aspect with the highest priority among listed companies. This can in particular be attributed to HES-related measures (White-Paper 2010).

Money isn't everything, but there's no question that compensation is tied to job satisfaction. At a minimum, compensation has to be equitable, both within your organization and as compared to the industry as a whole. As a starting point, businesses should benchmark their salary and wage rates to make sure that they are at or above industry averages. Health benefits, time off policies and other compensation packages should be reviewed periodically in order to ensure they stack up to the competition. Businesses should conduct 360 degree surveys and ask employees if they believe that their pay plans, bonuses and other financial incentives were fairly managed. Labor productivity is correlated with the better performance as measured by OEE. Satisfied labor force learns fast, is more creative, optimistic and better motivated; bolstered with team spirit they fix problems instead of complaining about them. Per ton CPO cost of labor was correlated and it showed a positive correlation with OEE. The positive correlation simply indicates that higher labor cost per ton of CPO produced is a contributing factor to higher OEE. However, there is no, industry wide, set benchmark of labor cost per ton CPO produced available to which these data figures can be compared for efficiency. Mills, nevertheless, can set up their own bench marks to follow for improvement.

Compensation is usually provided as base pay and/or variable pay. Base pay is based on the role in the organization and the market for the expertise required conducting that role. Variable pay is based on the performance of the person, and may include incentive or bonus plans of pay. Major function of human resources and talent management is getting the best employees. Regardless of the nature of the organization, it must identify the most important roles in the organization and then recruit, orient, train and organize people to effectively perform those roles. It should then concentrate on their compensation, benefits, training and development, and a safe and equitable work environment. Assessment of the prevailing labor market reveals that a lot needs to be desired. Skilled labor is not compensated as its counterparts in the west, wages are low comparatively and the working environment is less than ideal in many cases.

However, the author, during the pilot survey for this study visited several private, palm oil mills in Malaysian peninsula and observed that CSR is not a priority for the mills. It was observed that there is a noticeable gap between the theoretical working conditions of the skilled labor and the shop floor reality. Mills were generally, dark, smoky, slippery - muddy floors, ill equipped, and the mill's manufacturing equipment was half buried in palm fruit bunch debris. In certain cases, they resembled 19^{th} century industrial organizations. General working environment of the mills operations revealed immensely under paid maintenance skilled labor working, without safety protective gear, in incongruous dingy workshops. Lack of respect for the workers was noticeable all around; the atmosphere seemed to impinge on 'master-slave' consociation. Culture of safety, environmental consciousness and labor welfare was not evident. Most of the mills visited, were far from the best management practices, so vigorously proclaimed by the MPOB. During one of the interviews with the mill engineer, the author was taken aback to know that there were illiterate skilled workers working in the mills as well. Workforce and management seemed world apart; 'we-they' syndrome was evident all over the place. Mills had the same 'we-they' attitude towards MPOB and MPOC; they commented that both these entities are not in touch with the mills and that the mills did not see them as partners, one could almost sense resentment. In fact, some of them commented that all that MPOB and MPOC were interested in is collecting the 'levy' palm oil cess money to help them keep their cushy jobs. They added that mills have not benefited from these organizations to the extent of the annual cess paid (RM 200 million). Nothing meaningful has come back to the mills, in the form of milling innovation, or equipment improvement. So, bottom line, they did not want to cooperate for any surveys etc., and they did not seem to care. It did not come as a surprise to this author that in a CSR survey conducted by MIM, out of the 2000 only 110 companies responded.

II. **Addressing the Social Impact of the Crisis -** The crisis-induced changes in employment, income, and prices not only directly affect households' current standards of living but they also have a major impact on household investment in human development. While it is not difficult to observe the direct and often immediate adverse social impact of the crisis, little is known about their indirect and long-term impact on the country's human development and social capital potential which are increasingly acknowledged in developing economies as a critical factor for sustainable development. As a result of the economic meltdown, Malaysia's unemployment resulted in 500,000 unemployed persons in 2009. The rise in unemployment and lower incomes are the main channels through which the social impact of the crisis has been transmitted. Against the above backdrop, it is expected then that the incidence of poverty levels rose (MIER, 2009).

Malaysian Institute of Economic Research (MIER) has highlighted skilled labor shortage as one of the main factors behind Malaysia's slower economic growth forecast for 2011-2012 on account of ongoing structural weaknesses in Malaysia. One of the most crucial structural weakness is the labor market, specifically, skilled labor market; this impedes FDI flow to Malaysia. Growth forecast for

2011 was downgraded from 6.8% to 5.2%; Malaysia should focus on attracting FDI through operations that requires skilled labor.

Government Interventions may influence the skilled labor market through such actions as paying unemployment insurance benefits, setting the minimum wage, raising or lowering business and income taxes, and establishing rules under which labor unions operate. It also can undertake special programs to create jobs temporarily when unemployment is unusually high.

However, employers in Malaysia are often frustrated by issues relating to Malaysia's skilled labor pool and government's unpredictable labor and immigration policies. The country has long been plagued with an acute shortage of skilled, local labor, as the labor force only numbers 11.63 million, supplemented with a foreign labor pool of 2 million legal workers and an estimated 800,000 illegal immigrants. Aggregate numbers on the legal work force in Malaysia are slightly worrying, as their productivity growth is low (3.3%) compared to that of China's (8.7%), which is the highest globally and has risen steadily. Nevertheless, Malaysia has advantage over China, its low turnover (5%) and wage inflation (5.5%).

Enterprises in Malaysia can expect to retain their employees longer and motivate them with more stable and equitable wage increases and comprehensive compensation packages. Prevailing compensation packages paid to Malaysian skilled workers are considerably subjacent compared to other countries, e.g. Singapore or Canada. In addition to this sustained labor shortage, it's the state's fluctuating policies on immigration and labor that have led many companies, local and foreign alike, to relocate their businesses outside of Malaysia. The government has at various times cracked down severely on illegal workers. In 2006, Malaysia saw periodic raids from government task forces attempting to flush out illegal immigrants. One factory alone was found to be employing around 1,500 illegal immigrants. Government reportedly performs approximately 16,000 canings per year, many of which are on illegal migrants working in Malaysia's manufacturing, agricultural and services sectors. The law also stipulates caning as the maximum punishment for an employer who hires illegal workers, though an offending employer has yet to receive the brutal lashing.

III. **Corporate Social Responsibility Framework** - In accordance with international trends, the focus on CSR in Malaysia has increased in recent years. Though several companies have CSR programs that go back many years, in some cases decades, it has in recent years been possible to identify an increased awareness of the issue. Malaysian government's increasing focus on CSR has resulted in the development of new frameworks for implementation of CSR initiatives for the country's businesses. However, inadequate reporting of implementation is a problem as stated CSR policies are not necessarily followed in practice. Global Reporting Initiative (GRI) reports that very few companies report their activity according to the organization's policies and that these reports often are deficient (White-Paper, 2010). Reports on environmental breaches, workers human rights infringements, and ethical abominations are often compromised.

IV. **Working and Human Rights** - Malaysia has ratified five of the International Labour Organization's (ILO) core conventions. The following three conventions are not ratified: Freedom of Association and the Right to Organize; Abolition of Forced Labour; and Abolition of Discrimination on the Basis of Occupation. There are many restrictions in connection with the right to organize, both in legislation and in practice. In principle, workers have the right to strike, but also in this area there are restrictions. Discrimination of women in employment is prohibited by law, but women are inadequately represented in jobs with decision-making authority. Child labor is not widespread, but occurs among small family firms. Forced labor is prohibited by law, but does occur, often in connection with illegal employment and trafficking. Malaysia has ratified the UN Human Rights Conventions no. 8 and 11, which deal with the 'Elimination of Discrimination against Women', and Children's Rights, respectively. The country has, however, opposed ratifying conventions such as: Abolition of all Forms of Racial Discrimination; Clause on Economic, Social and Cultural Rights; Clause on Civil and Political Rights; and Combating Torture and Other Forms of Inhuman Punishment. The authorities' commitment to safeguarding human rights in some areas may be questioned (White-Paper, 2010).

Disconsolate employees are definitely not good for business. They tend to deliver poor service and poor results, and are unlikely to feel committed to company objectives or motivated to go the extra mile. They also create missed opportunities, which can undermine the success of an organization. Companies have several options that can result in increasing employee satisfaction. Every business, large or small, has a great deal to gain from investing in employee satisfaction. Even more important, a satisfied staff will be much more motivated to put in the extra effort required to make the company more productive and profitable. Content employees can dramatically reduce attrition rates and lower the associated hiring and training costs. While businesses can invest in a wide variety of formal (and often inexpensive) initiatives to boost job satisfaction, the most powerful tool is one that costs nothing at all, good management. Management team should view every employee as a valuable individual worthy of respect for his or her time, talent and opinions and strive to understand each individual's unique needs and motivational triggers. To have satisfied employees, companies have to hire people who fit not just the job, but the company and its culture.

V. **Training and Development -** the opportunity to learn new skills is a highly sought-after benefit, particularly among engineers, scientists and other knowledge workers. Providing formal training and informal shared learning experiences creates an environment that keeps the most talented people excited about their careers. Personnel budgets should include item for training, and just as importantly, ensure that the budget gets spent. At the same time, businesses should ensure that expectations are consistent and equitable; discrimination in dispensing these benefits fosters discontent. It is beneficial to provide sincere, timely praise for accomplishments that merit recognition; often, praise is either never given out or given for every little task so that it becomes a cliché.

VI. **Skilled Labor and Future Developments in Manufacturing**: In October 2009, Wichita, Kansas (USA) based Spirit Aero Systems Inc., the world's largest independent supplier of commercial airplane assemblies and components, opened its 242,000 sq ft aerospace manufacturing and design facility adjacent to Kuala Lumpur's Sultan Abdul Aziz Shah Airport in Subang, adding lift to Malaysia's aerospace industry. Spirit Aero Systems Malaysia will occupy a central role in the development of the Malaysian aerospace industry as a whole, and is strategically located at the centre of the Malaysia International Aerospace Centre (MIAC). UPECA Technologies is a Tier 1 Boeing and Airbus parts supplier to Spirit Aero Systems; and there will be several others requiring a stable and available work force, a long-term strategy for successful operations. Manufacturing organizations, such as Spirit Aero Systems, usually, have in-house facility to train their skilled labor for maintenance reliability and operations. However, they rely on the local labor market, local technical institutes in particular, to provide them with, educated and semi-trained, technical graduates, that they can further train according to their specific needs of operation and equipment maintenance. They run their own apprenticeship programs for training workers as there is a gap between what schools turn out and what industry demands. The Malaysian aerospace industry has recorded 11% growth each year from 2004 to 2008, expanding by as much as 14% in 2009, despite the global economic slowdown. However, the industry faces a shortage of skilled personnel, especially licensed aircraft-maintenance engineers. Malaysia would need another 16,000 such skilled personnel by 2015; industry now employs about 51,000 people nationwide. The Economic Planning Unit in the Prime Minister's department is coordinating with the various aviation companies and government agencies to help address the problem. Spirit's entry into the Malaysia aerospace market may be behind the government's realization that far more workers will soon be required by the sector, especially if more suppliers, like Spirit and UPECA, see the opportunity to succeed in Malaysia. That prompted the establishment of the Universiti Kuala Lumpur Malaysian Institute of Aviation Technology program in Dengkil, Selangor (MIDA, 2011).

Migration of Skilled Labor – Professionals "Brain Drain": In addition to shortages in skilled & low skilled labor, Malaysia's labor force also suffers from a sustained "brain drain," as talented and highly-skilled professionals have been lured overseas by seemingly better job opportunities. The number of Malaysian migrants rose by more than 100-fold in a 45 year period (1965-2010); from 9,576 Malaysian in 1960 to 1,489,168 in 2005 according to the World Bank. From March 2008 to August 2009 alone, an exodus of 304,358 Malaysians did little to help the growth of the nation's economy, as the majority of those who left were professionals. An important trait of the labor market is the mobility of the workers that it constitutes. In theory, people in Malaysia can move anywhere to find or train for a new job. This mobility is important when employers match skills to job openings. In practice, however, people may be unwilling to move where the jobs are located, unwilling or unable to get training for a new career, or governments' predisposed policies may inhibit their mobility or employability. In these cases, the mobility in the labor market and the output of the economy slows down as people remain unemployed and jobs go unfilled. Intrusive government policies may also provide impetus to the skilled labor force to migrate, eliciting a "brain drain".

The newly established 'Talent Corporation Malaysia' (TalentCorp) under the Prime Minister's office will create programs and incentives to encourage the country's nationals engaged in key sectors and professions to return home. The International migration of skilled persons has assumed increased importance in recent years reflecting the impact of globalization, revival of growth in the world economy and the explosive growth in information and communications technology. The international mobility of highly skilled workers is likely to increase in the future. Adding to it is; better wages and employment conditions, faster and cheaper transportation, faster and cheaper information, expansion of global labor markets, shortage of highly educated workers in the information-age economies, the ageing of the workforce in developed economies, and just-in-time demand from industries eager to get on the front of technology curves. Globalization is linking together labor markets creating labor flows spanning global cities that are rooted in hierarchies of labor demand. A number of developed countries have recently liberalized their policies to some extent for the admission of highly skilled workers. This demand is largely met by developing countries, triggering an exodus of their skilled personnel. While some amount of mobility is obviously necessary if developing countries are to integrate into the global economy, a large outflow of skilled persons poses the threat of a "brain drain" and can adversely impact local growth and development (ILO paper, 2010).

More recently, during the global economic recession in 2009, the government enacted a complete ban on new hires of foreign employees in the manufacturing and services sectors, which was subsequently lifted. Investors are currently waiting on legislation proposed in June of 2011 to offer amnesty to the existing illegal workers in Malaysia, thereby increasing the legal labor pool. For the state, the dramatic move will raise much-needed tax revenues, improve national security, reduce human trafficking, and most importantly, attract more foreign investment. Naturally, this proposal has faced staunch opposition from Malay nationalists, whose interests lay with the rights of local workers. Nonetheless, until a decision is made official, employers should be cautious in knowingly hiring illegal migrants. Malaysia's ardent goal to become a high-income nation by 2020 portends very well for foreign investors in the region. Despite losing competitiveness, particularly in low-wage manufacturing, to neighboring countries, the government's New Economic Transformation Plan indicates a much more inviting investment climate in Malaysia than one might have found in the past. As is the case with China, Malaysia's state-led push into high tech industries and emerging manufacturing sectors offer investors a wide range of incentives that are sure to improve the profitability, inducement, and ease of doing business in Malaysia. However, corruption in Malaysia, in general, is an encumbrance on its socio-economic policies and impedes FDI in Malaysia. Fighting corruption is a responsibility that should be shared amongst all parties and not directed according to a particular race, religion, culture, age or economic group. The fight against corruption should not be based on 'who' the person is, and must be pursued regardless of the stature of the individual; failure can bring about severe and dire consequences to the future generations (MACC, 2011).

4.5.2 Spare-parts, Material, and Tools – Sub IV

Spare parts refer to the parts requirements for keeping owned equipment in healthy operating condition by meeting repair and replacement needs imposed by breakdown, preventive and predictive maintenance. The spare part management function is critical from an operational perspective especially in asset intensive industries such as refineries, chemical plants, paper mills, and oil mills as well as organisations owning and operating costly assets such as airlines, and logistic companies. Spare parts, in manufacturing, also include consumables such as; lubricating oils, touch up paints, cleansing agents, grinding & cutting discs, chemicals & neutralizers, industrial gases and many more. Maintenance Tools & Equipment are often lumped with spare parts. Apart from hand and power tools, they also include specific equipment such as, bearing installation kits, portable weld sets, portable magnetic base lathes, portable band saws, portable surface grinders, hydraulic pipe & conduit benders, diagnostic multi meters, safety test meters, safety gear and many more. Maintenance, Repair & Overhaul (MRO) spare parts are different from production parts whose demand is production dependent and is predictable, easier to forecast because of more predictable movement patterns and are typically input or output of a production process (such as water softening chemicals for boiler water supply or weld tips in weld assembly robots).

The exigency of spare parts management in manufacturing and service operations cannot be underrated. Given the determinants like demand, unpredictability, part substitution, and tight control on spare parts inventory coupled with high service level expectations. It is imperative to accurately forecast spare part requirement and to optimize on inventory; it warrants significant decision support. Historically, the standard philosophy regarding MRO in many Maintenance organizations was that high inventory levels and large numbers of SKUs must be maintained on site in order to ensure that equipment could be serviced and repaired on a moment's notice. The actual cost to support this environment is very high but rarely is the total costs associated directly to this decision are considered exclusively and reviewed. Traditionally the perceived cost is deemed acceptable due to the concerns voiced by Maintenance and Operations for the need to have the necessary MRO materials and assets on hand at all times (Timme & Christine, 2003). Proper planning and control of spare parts inventory is a critical component of an effective asset management program. If the right parts are not on hand when needed for routine maintenance or repairs, downtime is prolonged. If too many parts are on hand, the enterprise absorbs excessive costs and the overhead of carrying the inventory.

I. **Spare Parts Management & Equipment Reliability** - Spare Parts Management dispensing an organized maintenance storeroom is one of the key processes which support effective maintenance planning and scheduling, and equipment reliability improvement. Improved materials and spare parts management will free up time for maintenance planners, maintenance supervisors, and hourly maintenance personnel. It is not unusual to see an average of 20-30% of maintenance crafts peoples' time to be used for finding parts and material (Evans, 2008). The reliability and availability of industrial plants represents a critical aspect in many modern manufacturing and service organisations. Increased efficiency of production plants requires the minimisation of machines downtime. Spare parts availability and its prompt accessibility is among the major factors leading to a reduction of the protraction of downtime when a breakdown occurs. Thus, a logical approach to solving the issue of spare parts availability lies in preserving requisite sizes of inventories of spare parts for immediate disposition whenever needed. On the other hand, stocking is limited by space and cost. For these reasons, designing the reserve of spare parts in an optimal way represents a critical and important task for every parts inventory manager.

There are many aspects that must be considered when reviewing any MRO materials and asset management program. In those organizations where Purchasing and Materials management are not directly involved or empowered to impact the management and direction of these programs, significant opportunities exist for cost reductions and process improvements. Many times the responsibility for selecting items to be stocked, replenished, maintained and disposed off, is the responsibility of departments other than Material Planning or Management. The question that is commonly raised regarding the management of assets and MRO by Maintenance and Operations is, "why shouldn't those departments that use and require these materials also order, stock, repair, and maintain these materials?" The fact is that many companies effectively "carve out” several of the fiscal duties and responsibilities from the Materials and Purchasing Management function, and make it the direct responsibility of Maintenance and Operations. The issue is not whether the required repairs and services are performed, but rather how can this process be managed and performed at the same or higher service level at a lower cost. The other major problem is increasing the awareness of why the change is necessary and implementing the change inside the organization is critical, once opportunities have been identified (Timme & Christine, 2003).

Apart from new generation turbines and decanters whose maintenance is usually outsourced, most of the critical equipment in palm oil mills is low-tech. It does not warrant a finer spare parts management system that might be essential for, say, an automotive plant, as most of the mills still operate equipment that was designed in 1950’s and 1960’s (Sivasothy *et al.,* 2006). Given this level of sophistication, the classical ABC model is adequate to manage spare parts inventory in palm oil mills. The use of classification schemes as a spare parts management tool represents a popular approach in industrial world. ABC classification according to the Pareto's principle is the most well known and used classification scheme to manage the spare parts inventory management problems. A criticality classification of spare parts is generally based on administrative efficiency considerations, such as inventory costs, and usage rates derived from historical data of the company. The modern production planning software packages, such as ERP, are able to obtain similar analyses easily and with a reduced time consuming operation. Based on these analyses, oversized inventories, obsolescence aspects or stock-out problems for the different items are recognised.

Besides being the central hub for maintenance, the storeroom also provides functions that are absolutely critical to the maintenance operation. These functions are so important that when the storeroom is operating in a best practices mode, the rest of the maintenance operation can excel. Put another way, if the storeroom is run improperly (such as poor inventory accuracy, parts unavailable when needed due to poor replenishment and procurement practices) the rest of the maintenance operation will not achieve high service levels of equipment availability and reliability. The Storeroom is a service provider and should be managed exclusively with that objective in mind.

Mill visits conducted during the pilot study revealed that most second generation mills (mills established in 1980s) do neither have a dedicated spare-parts inventory controller nor a separate spare-parts store room area. Parts were stored all over the mill shop floor area, including the maintenance shop. None of the mills had computerised inventory management system in place and spare part inventory purchase solely depended on the mill manager's decision; most mill managers held the portfolio of operations director for that matter. Range of spare-parts, material, and tools cost, per ton of CPO produced, was spread out; from a low of RM3 to a high of RM272. There is no figure available, from MPOC or literature on palm oil milling, to bench mark the collected data, in this regard. However, there is ample room for improvement and financial gains as evidenced in the cited literature. Performance of the spare-parts store room should be gauged, and improvements afforded through self-set targets. Improvement in spare-parts cost per ton of CPO produced provides a reasonable impetus to commence this undertaking. As none of the respondents practiced TPM in its entirety or similar maintenance strategy, they are missing out on the improvements and savings that can be achieved by adopting such 'waste reducing' maintenance strategies. This is one important area that warrants further research in palm oil mills. Maintenance storeroom is, primarily, a service provider to production and operations, following sections construe how it should be managed.

II. **The Maintenance Storeroom: Key to Efficient Maintenance Operation**

The Storeroom as Service Provider **-** If one follows the flow of technicians and materials in a typical maintenance operation, a common pattern emerges. In general, there is a central hub and the spokes of a wheel; where the hub is the storeroom, and the spokes are the paths to the equipment or machinery in the facility or site that are undergoing maintenance. The number of work centers on the site multiplies the actual material flow. This correlation illustrates the crucial role of the maintenance storeroom; to provide parts quickly when needed. This function places the storeroom in the position of a service provider, with the rest of the maintenance organization (and by extension, manufacturing operations) as the customers. Perhaps one of the main integrants of success for a service provider, besides fundamentally delivering what is promised, is to manage expectations of the customers. This is done in a deliberate way through various forms of communications so that not only does the customer understand what service they will receive, they also understand how the service will be performed. In the maintenance world, there is an implied expectation of parts availability. For many parts, that expectation can be easily met. But for some classifications of parts, that expectation is unrealistic either due to cost of the part, reliability profile (MTBF and MTTR), or other characteristics of the part. Those responsible for maintenance and the storeroom must communicate to the facilities and operations organizations the reasonable expectations of service from the storeroom. These expectations of parts availability are the result of analyzing the impact on downtime, the likelihood of failure, and the carrying costs of the parts. Ideally, the time to decide on whether parts should be stocked is when new equipment is placed in-service. Manufacturing and the parts suppliers can work with maintenance in recommending the spare parts to stock as the new equipment is being purchased. Thereafter, maintenance can use historical usage data in deciding adequate inventory levels, or even to discontinue carrying certain items. In a larger maintenance and parts organization, a parts inventory planner is the decision maker when it comes to the stocking level, timing of re-orders, and replenishment trigger levels of a part (York, 2003).

III. **The Importance of Inventory Accuracy** - One of the critical success factors for the storeroom is achieving a high level of inventory accuracy. Accurate inventory is defined as the correct part and the correct quantity physically in a storeroom location being the same as that shown on the inventory control system or CMMS. Minor variances between actual and system counts are tolerated, such as with nuts and bolts. However, if the part, quantity, or location is not correct when matched against the system, then that location is counted as an “error” for purposes of tabulating inventory accuracy. The consequences of inaccurate inventory include: high risk of an stock-out condition as parts will not be ordered on-time; parts will be flagged for re-ordering by the system even if not needed; maintenance technicians and machine operators will lose confidence in the inventory control system or CMMS, and benefits from using other functionality in the system will be lost; and encourage proliferation of bench stock (stock held on the floor or in cabinets/shelves outside the storeroom). It is critical that not only the storeroom operators understand the importance of inventory accuracy, maintenance technicians, maintenance planners, operations personnel, and plant management also understands the importance of inventory accuracy since these groups will be impacted adversely by inaccuracy of inventory. Achieving high levels of inventory accuracy requires recording of: all parts receipts against purchase orders or outside repair orders; receipts of parts returned to the storeroom that were previously issued to a work order but not actually used; parts serial numbers, lots, or other important information at the time of receipt; parts put away in locations; all parts issued to a work order, employee number, or other account; and routine and accurate cycle counts.

IV. **Storeroom Organization for Productivity** - The storeroom is like any other business area when it comes to productive operation, the area must be organized in a physical sense. The parts storage area is sized and equipped aptly for the types and volumes of parts to be handled by maintenance. Lighting in the area must be sufficient to permit counting of parts in the aisles, whether for parts issue to a work order or for cycle counting and the area must be free of debris and clutter in the aisles to permit personnel quick access to the locations. The locations must be labelled so that time searching for parts is minimized. Stepladders, stools, and carts must be parked in an area that is out of the main flow. The area needs to be physically separated from the main plant, either by walls or with a secured cage; this separation is to discourage theft and to enforce recording of parts receipts / issues for inventory accuracy purposes. Monitored controlled access procedures must be in-place for normal business hours and after-hours needs for parts; and there are distinct work elements within the storeroom, and they should be combined into jobs that make the most productive use of staff's time. Combining too many different work elements into a job is counterproductive and should be avoided.

V. **Slotting Inventory Correctly** - Slotting of inventory is the assigning of a part to a location based on the part's movement, amount of inventory to hold on-hand, and physical characteristics (such as size and weight). Real productivity savings in the storeroom can be gained from the correct slotting of parts. Parts that are slow movers should be stored near the back of the storeroom, and fast movers near the front of the storeroom for quicker access. For example, a motor that is a critical spare and needed once a year should be slotted in the rear of the storeroom, while filters and gaskets that may be needed for frequent preventive maintenance tasks should be located near the front of the storeroom. There are many different storage and retrieval methods that can be employed to handle parts, each can be befitting depending on the volumes and characteristics of the parts. For example, dense storage narrow aisle man-up vehicles may be appropriate for either heavy parts on shelves, or for small parts on shelves. Other alternatives for parts storage in the storeroom include a vertical lift module, which is a vertical carousel. The distinct feature of this technology is that it provides for parts coming to the operator, significantly reducing travel time to locate parts; common in automotive plants for stamping presses.

The less mechanized (but still very efficient) options for parts storage and slotting include case flow lanes, static shelves, and small parts bins. No matter which storage technology is chosen, the important issue is that parts history must be analyzed to determine the movement. There will be different payback points for each alternative as labo r and productivity savings offsets the capital investment.

Finally, another common element of slotting, regardless of which storage and retrieval methods or technology used, is that each location is unique and is referenced in the inventory control system or CMMS. Using unique locations enables the use of an automatic identification system to streamline parts handling. The introduction of automatic identification (auto ID), using barcode technology into the storeroom has resulted in a significant contribution to storeroom productivity, inventory accuracy, and error elimination. Whether for parts put away, parts picking, or cycle counting, using auto ID is now a best practice.

VI. **Preventive Maintenance (PM) Kit Building** - One of the functions of the storeroom is to provide parts, tools, and supplies for the technicians to perform preventive maintenance tasks. As a way to level out the storeroom workload and provide better service (higher availability of parts) to the technicians, the storeroom can build PM kits in advance of the scheduled PM time. This requires access to the PM schedule by the storeroom, and a way to track and hold parts inventory prior to issuing them to the PM work order.

One of the ways to do this is to use a mobile cart with multiple kitting bins (locations) on-board. The parts listed on the PM work order are picked from the storage locations, and are placed into one of the kit bins. These kit bin locations are an extension of the static storage locations, and the inventory control system or CMMS will track these kit bin locations with a “staged” status. When picking is completed, the entire cart is moved to a kitting hold area, and scanned into the hold location. When a PM is scheduled for work, the technician presents the PM work order to the storeroom. The system will show that the inventory has already been picked is in the kitting hold location. The kitting bin can be scanned to the work order, and the technician can take the PM kit to the job. The entire process of retrieving the parts for the PM, from the technician’s perspective, is very fast. In the event that an emergency work order situation arises, and the only part in stock has been picked to the kit bin, the system can locate the part and remove the part from the PM kit through a move transaction.

VII. Parts Transactions - Parts receipts should be recorded to offset either a purchase order or a work order for outside services, while parts issues should be used to tie a part to a work order, technician identification, or an account code. Failure to record these transactions will waste the efforts set forth at increasing storeroom efficiency, productivity, and accuracy. The maintenance organization must embrace the inventory control system or CMMS, use the transactions that are provided, and view it as the tool to a successful operation. In many storerooms, the discipline of entering these transactions breaks down under the pressures of the day, especially if there are emergencies that need to be addressed. Also, there can be a culture of “take what you need” that can undermine the efforts of increasing inventory accuracy and accountability. Management, through education, effort, and enforcement, can overcome these obstacles; cultural change is an ongoing process and not a one-time program.

VIII. **Measures and KPIs -** There are several measures and KPIs to gauge performance of storeroom operation, the major indicators are: Inventory accuracy (cycle count adjustment / total cycle counts); Percentage of stock-outs (number of stock-outs / total parts issues); Percentage of inactive inventory (parts inactive in the past year / total parts); and Parts to labor ratio (parts inventory value / maintenance labor cost). When measures and indicators are recorded over time, these become a benchmark for the organization. Continuous improvement efforts can then be launched to improve upon these standards, with the desired result of cost reduction and higher productivity. Without tracking performance, it is not possible for the storeroom to know whether improvements have indeed been worth the effort. JIT inventory management have only a limited ability to assist the efficiency of the maintenance process. Issues such as just-in-case inventory management are far more important. This has implications not only within the area of operations, but throughout the entire supply chain. Often the improvement of a supply chain is based on "how we buy," the probabilistic nature of asset maintenance means also that we need to be thinking about "why we buy" (Mather, 2008).

4.5.3 Maintenance Contracted Out

Briefly, maintenance outsourcing can be defined as a "managed process of transferring activities to be performed by others" and its main advantage is conceptually based on two strategic pillars. The use of domestic resources mainly for the core competencies of the company, and the outsourcing of all other (support) activities that are not considered strategic necessities and/or whenever the company does not possess the adequate competencies and skills (Campbell, 1995). Unfortunately, single cost-based decision processes remain the most used approaches by maintenance managers for making outsourcing decisions (Lyly-Yrjänäinen, Lahikainen, & Paranko, 2004). The cost dimension may be sufficient if maintenance is strictly considered a support functional cost center. However, following the new maintenance strategies such as TPM, and if maintenance is considered a stand-alone business unit, different approaches are necessary. Organisations need to realise, there is no single position regarding maintenance outsourcing that is correct for all. Nevertheless, there is enormous value in retaining core maintenance competencies in capital intensive industries by developing in house maintenance expertise on equipment that is vital to their manufacturing process. To successfully support physical assets, a high level of knowledge and skill needs to be present, along a strong sense of ownership for the performance of the assets. To have an environment that enunciates positive thinking and induces continuous improvement process into the way things are done, it is imperative to look at the pros and cons of maintenance outsourcing before making a decision. Many companies believe that the value of outsourcing prevails in bringing process, technology, and practices to their plant. In reality, most outsourcing organisations do not have a true understanding of the concepts of proactive, predictive, and condition based maintenance. Successful companies that invest in sustainable growth appreciate the strategic impact maintenance can have on their business and are prepared to invest in their own people; not incite encumbrance to a third party. While, in some situations, a business case may exist to outsource; examples might include lack of sufficient in-house skilled trades, nature of the equipment is highly specialized such as turbines, where an external organisation has the expertise and it is not cost effective to build it internally, nature of the equipment that requires maintenance is highly cyclical with extended periods of low maintenance demand, or the size of the facility is too small to justify the investment.

I. **Outsourcing -** there are two key strategic issues that determine the option between outsourced and internally provided services. The first factor is the potential for achieving a sustainable competitive edge by performing the work internally. If management perceives that excellence in performing certain maintenance services can be done cheaper, better or in a timelier manner and will enhance the company's competitiveness, such services should be carried out internally. The second factor is the degree of strategic vulnerability if the work is outsourced. If there is insufficient depth in the market, an overly powerful supplier can hold the company hostage. On the other hand, if the individual suppliers are too weak, they may not be able to supply quality and innovative services as good as the buyer could by performing the work internally (Quinn & Hilmer, 1994). Knowledge is another important dimension that affects vulnerability. It is extremely risky to outsource work when the company does not have the competence either to assess or monitor suppliers, or when it lacks the expertise to negotiate a sound contract. The caveat that companies should not outsource those activities that are crucial elements of their core competencies is often not heeded when outsourcing decisions are driven by cost-cutting and headcount-reduction criteria. As a result, control of activities critical to establishing the company's competitive advantage can be inadvertently ceded to suppliers. Another common misconception in making outsourcing decisions is to regard "core competencies" as "things that we do best". This equivocation is damaging as it encourages management to outsource activities with which it is having problems. If the company has difficulty in managing an internal supplier, it probably cannot communicate its requirements adequately to the external supplier. Thus, internal problems are traded with more sticky problems of dealing with external suppliers. It will be even more devastating if the problematic activity over which the company relinquishes control is a critical link in its current or future value-creation process. When an external supplier offers a significant cost-saving deal on the company's core activities, management should refrain from outsourcing them. Instead, the internal service provider should be challenged to improve its cost-effectiveness, using the supplier's offer as a benchmark of performance. Furthermore, one should not rule out the possibility that the supplier may be using a “loss-leader” tactic (Vindevogel, Dirk, & Wets, 2005) and enticing with favourable offer to the client might turn out to be a snare down the road. In terms of maintenance outsourcing, however, a set of additional potential and attractive benefits can be achieved. Such as to increase labour productivity, reduce maintenance costs, focus of in-house personnel on “core” activities, improve environmental performance, obtain specialist skills not available in house, and improve work quality. Nonetheless, outsourcing also involves a set of drawbacks that must be taken into account by the customer that include: loss of control and loss of a learning source, because an internal activity is externalised; loss of knowledge of the plant; possible dependencies on the supplier; variations in the quality of the product given to the customer; and problems among personnel, since they lose their functions. Magnitude of these benefits and risks, however, depends on the qualifications of the supplier and on the type of outsourcing contract negotiated. The idea of outsourcing is to achieve the optimal performance within a company and a supply chain. Outsourcing decisions, therefore, require life cycle analysis of anticipated changes concerning all relevant costs, including indirect ones, to avoid undesired surprises.

II. **Life Cycle Costing** (LCC): is an approach which aims at producing comprehensive cost information for decision makers by estimating the costs incurring in the future and by monitoring the costs during the life cycle. Despite the fact that at least one of the main objectives of outsourcing is to reach cost reductions, also in a longer term, the systematic utilization of cost management in outsourcing is quite rare. As a result, companies do not generally know the full financial effects of outsourcing. This, however, becomes increasingly important as the outsourcing trend continues. LCC is a tool that can be used when the outsourcing decision is being made. LCC is well aligned with outsourcing objectives of long term cost reductions; it seeks to identify long term costs. LCC communicates the costs as time-dependent variables; outsourcing of an activity may be cost effective at one point of the life cycle but ineffective at another point. These kinds of assessments are not possible without cost information on a life cycle basis. The management of fragmenting value chains requires relevant and comprehensive cost information that often extends the boundaries of a single firm. If companies fail to sufficiently track their own cost, which is often the case, they will face serious problems in evaluating the economical effects of outsourcing and new value chain designs (Sievänen, Suomala, & Paranko, 2001). There has also been an interest towards outsourcing of the ownership of individual assets or the whole process (Markeset & Kumar 2004). Suppliers of machines and equipment nowadays provide different services to their customers in addition to pure products during a product's whole life cycle, which generates a need to examine the cost effects of the changes in business from the supplier's point of view (Laine, Ojala, & Paranko, 2004). The range of these strategic alliances and the type of contracts negotiated can vary from simple parts availability programs or 'Operating Plant Service Agreements (OPSA)' to 'Long Term Programs (LTP)' with risks sharing elements and the value based payment methods.

It must be stated that the outsourcing of certain functions or services should not be considered as the equivalent of granted success. Strategic factors that can ensure a higher possibility of success in the process of moving from a centralised maintenance management to the outsourcing of certain services can be identified in the: strategic analysis evaluating feasibility of the entire project on the basis of the existing corporate constraints; assessment of those activities that should be managed in outsourcing and the selection of the service providers for their realisation; and acquiring managerial capabilities for monitoring and evaluating service provider and customer relationship (Embleton & Wright, 1998).

With almost 19 million tons of CPOproduction capacity per year, the oil palm mills, at five times the rate of CPO production, potentially generate 95 million tons of biomass available for power generation (MPOC, 2012). The primary objective of every palm oil mill that owns a power plant is to install and to operate their plant in a most cost-effective way in order to maximize their profits while ensuring a reliable power supply for their operations. Besides the investment costs for construction, the life cycle costs need to minimize; one of the major such cost involves operation and maintenance cost that cumulates in course of operation period of the power plant. Cost reduction by outsourcing of Operation and Maintenance (O&M) activities is one opportunity to meet such requirements.

III. **Business Case for Outsourcing**: Power generation equipment in Malaysian palm oil mills makes a good business case for outsourcing its maintenance. Factors that contribute to this decision are:

i. Remoteness of mills: most of the mills are deep in land and operate away from the national grid, still need un-interrupted and reliable power supply.
ii. Lack of in-house skilled workforce: power generating equipment is complex and highly specialized; qualified technicians are needed for the job to guarantee reliable and effective power generating equipment maintenance.
iii. Abundant free boiler fuel: 95 million tons of biomass is available to be used as fertilizer or boiler fuel, making steam production process economical.
iv. Worldwide rising cost of the energy production demands that mills do not load the national grid; surplus power could be sold back to national grid.
v. Most palm oil mills having over capacity or standby, redundant, power generating equipment; boilers and turbines.
vi. Aging power generating equipment needs to be replaced with efficient ones.
vii. Malaysian government is offering various incentives to facilitate the change.

Older power generating units are no longer considered effective for reliable and efficient power supply (Wan, Mahanim, Zulkifli, & Mori, 2010). When considering replacement of old power generating equipment, palm oil mills should consider the High-Pressure Boilers with Backpressure Turbine for Cost-Effective Power Generation, recommended by the US department of energy – Country Malaysia (USDOE, 2006).

A wide range of service products from the simple supply of spares to integrated asset management is offered. Due to the recent market developments, the focus is now, more and more on LTS products. The scope of such LTS products can vary according to customer demands. To optimize customer's benefit and to minimize customer's risk in the project several service products are being offered by the OEMs. A service package of O&M products can be customized as to meet customer's specific needs. Comprehensive maintenance programs for Steam Turbine, Power Train or for the whole Plant can be provided. Regarding power generation, a preferred approach is to outsource all of the steps, giving controls over the development of equipment maintenance strategies to the contractor. In this instance, the contract must be structured around the achievement of desired outcomes in terms of equipment performance, with the contractor being given latitude to achieve this to the best of his ability. It is of great importance to a power plant owner to be informed about the concept of how the fleet experience of an OEM/O&M contractor is introduced and available to his power plant.

73% of the survey respondents reported the equipment whose maintenance was outsourced: 77% of these mills outsourced their power generating equipment, primarily turbines and boilers, while 27% contracted out maintenance for decanters. *e*-maintenance concept has the potential to make the process of maintenance management of power generating equipment cost affective and, considerably, more efficient and reliable; this author has designed a conceptual model for *e*-maintenance of power generating equipment in palm oil mills, detailed in chapter five (5.4.3). Data for this sub IV showed a strong positive correlation to OEE; indicating efficiency in reliable power supply bolstered OEE.

4.6 Moderator – Maintenance Strategy; TPM

For a definition it is a linear causal relationship in which the variable X (maintenance inputs - IV), is presumed to cause the variable Y (OEE-DV). A moderator variable MV (maintenance strategy) is a variable that alters the strength of the causal relationship. A moderation analysis is an exercise of external validity in that the question is how universal is the causal effect; maintenance strategy is not mediating in this respect. Another way to think about this issue is that a moderator variable is one that influences the strength of a relationship between two other variables, and a mediator variable is one that explains the relationship between the two other variables. The reader might consult papers by Kraemer, Stice, Kazdin, Offord and Kupfer (2001) for a related but somewhat different approach to defining and testing of moderators. Frazier, Tix, and Barron (2004) provide a good introduction to the topic of moderation. Maintenance strategy is the moderator in this research. All the respondents reported PM as primary strategy practiced by the mills; 20% of the respondents also reported practicing TPM along PM. Follow up revealed that none of the respondents who claimed practicing TPM, did actually practice the strategy in full. All six of TPM elements are integral and complementary; any one element, removed from its partners will compromise its objective (4.6.1). As most of the mills followed, least effective, BDM and sporadic PM maintenance strategies, the moderating affect was minimal as shown by the poor rate of OEE.

4.6.1 TPM

TPM has been identified as a best in class manufacturing improvement process that has allowed manufacturing industries to greatly increase their levels of profitability and productivity. TPM has allowed these companies to focus on the efficiency of their production processes; it challenges the view that maintenance is no more than a function that operates in the background and only appears when needed. The objective of TPM is to generate a sense of joint responsibility between supervision, operators and maintenance workers, not simply to keep machines running smoothly, but also to extend and optimise their performance overall. The results are proving to be remarkable. This synopsises TPM's role in moderating; maintenance inputs are used efficiently and effectively to minimise waste and maximise return on investment.

The six key elements of TPM include: Improving equipment effectiveness by targeting the major losses; Involving operators in the daily, routine maintenance of their equipment; Improving maintenance efficiency and effectiveness; Training for everyone involved; Life-cycle equipment management and maintenance prevention design; and Winning with teamwork focused on common goals. The result of these six elements working together to improve equipment performance and reliability is TPM in a nutshell. No one element, removed from its partners, can create the effects achievable by this strategy, nor will any combination missing even one element. The six elements are interrelated and designed to support each other. It is perhaps the lack of this comprehensive approach that has resulted in 50% of TPM initiatives being abandoned since it was introduced to U.S. in 1986 (Williamson, 2001).

4.6.2 Four Rules of Toyota Production System: The logic behind TPM can be grasped more easily by having an understanding of the Toyota Production System, the tradition behind it. But, until recently, a working definition of the Toyota Production System has been hard to pin down. This is because the Toyota Production System is the accumulated result of a trial and error process over the course of five decades and has never been written down. Fortunately, two Harvard researchers, H. Kent Bowen and Steven Spear, spent four years studying this system, and have published their findings. In their article "Decoding the DNA of the Toyota Production System," the authors isolate the following four rules that govern the system: All work shall be highly specified as to content, sequence, timing, and outcome; Every customer-supplier connection must be direct, and there must be an unambiguous yes-no way to send requests and receive responses; The pathway for every product and service must be simple and direct; and Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization (Bowen & Spear, 1999).

The first three rules illustrate the actual processes of TPM and what roles each person involved in maintenance must play. The fourth rule expands this structure to comment on how to solve problems and improve overall performance. With that in mind, the first rule, "all work shall be highly specified as to content, sequence, timing, and outcome", dictates that anything done to maintain and improve equipment must be documented in procedures that every employee follows. This documentation should include detailed information on the parts used, labor hours involved, descriptions of the problems that arose, the estimated root causes of the problems and the corrective measures taken to solve the problem. It also means that maintenance work is governed by planned maintenance routines and that frequent joint production/maintenance planning and status meetings are scheduled to keep efforts focused.

The second rule, "every customer-supplier connection must be direct, and there must be an unambiguous yes-no way to send requests and receive responses", means that proper maintenance tools, parts, and supplies be made available, as they are needed. It also means that spare parts are adequately maintained and that maintenance requests are sent and acknowledged promptly. Visual systems and signals can be used to eliminate long drawn-out explanations and reading. Lastly, when proper repairs or improvements are made, those who requested them should sign off on them.

The third rule, which states that the "pathway for every product and service must be simple and direct" requires every equipment operator to know exactly where to go for help with an equipment problem. By extension, this means that every maintenance person knows on what equipment he is qualified to work and where he or she can get help when a problem exceeds their expertise. Finally, this rule necessitates that the documentation for specific equipment remain accessible to those who need it.

The fourth rule, "any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization" indicates that data should be collected, analyzed, and made available to make the improvements more efficient and effective. Additionally, informed people closest to the problem should work out possible solutions and conduct experiments to determine the workability of their solutions. Applying the logic of this rule also requires that formally experienced and trained problem solvers lead improvement effort and that changes are made in the equipment and supporting work processes and people are trained in the new methods.

As one can see, a great amount of discipline is required in the workplace to sustain the application of TPM strategies. Fields as diverse as aircraft assembly, petroleum exploration and even racecar equipment maintenance have successfully put TPM strategies into use, their only commonality being the high degree of discipline that each of these callings demand. The four rules described above define the disciplined approach that TPM requires to produce the optimum results. Implementing TPM means striving toward a vision of the ideal manufacturing situation, a vision that encompasses: zero; breakdowns, abnormalities, defects, and accidents. These three main categories of equipment-related losses; downtime, speed loss, and defect or quality loss, are also the main ingredients for determining OEE.

Ahmed, Hassan, and Taha (2005) in a case study of a Malaysian electronic company conclude that TPM improves equipment efficiency and effectiveness, reduces cycle time, inventory, customer complaints and enhances productivity. A survey of Malaysian SMEs revealed that TPM implementation has a positive and significant effect on organizational performance (Jantan, Nasurdin, Ramayah, & Ghazali, 2003). Companies that adopt TPM are seeing 50% reductions in breakdowns, 70% reductions in lost production, 50-90% reduction in set-ups and adjustments, 25-40% increase in capacity, 50% increase in labor productivity and 60% reduction in costs per maintenance unit (Koelsch, 1993). Palm oil mills are missing out on this opportunity. By adopting TPM as business wide strategy mills could, substantially, add to their bottom line, profits. Though the economic role of the moderator is established in theory as evidenced in the literature (2.5.5), this role could not be discussed or analyzed at length as all the responding mills practiced, strategies of 1960's, BDM supplemented by sporadic PM; none of the respondents practiced TPM in its entirety.

4.7 POME Generated and POME Treated

19.50% and 24.40% respondents reported "0" POME produced and POME treated, respectively. 80.50% of the respondents reported generating POME; 72% of the POME generated was reported as treated by the respondents. During the pilot test it was revealed that most of the second generation mills do not have a credible system of recording POME generation and treatment, this operation does not seem to be tightly regulated. Quantity of POME produced is measured using crude devices, such as "tipping barrels" and the number count data is not monitored properly, resulting in "speculative" or "Environment Protection Department (EPD) required" figure to be reported. Treatment methods are primitive and lack monitoring. 19.50% respondents reported having "0" POME generated, while the pilot study revealed that on average 60-65% of the FFB tonnage processed ends up as POME, due to the same amount of steam injected into the process (MPOC, 2010). This compromised data credibility and constrained the author from consequential analysis.

4.8 Practical Implications

This research study highlights the contributions of maintenance function to ensure enhanced equipment reliability, thereby affecting improvements in the manufacturing system performance. This study also highlights the implications of ineffectiveness of maintenance management in palm oil mills, which may be implemented in palm oil mills sector to improve their performance in Malaysia and in other parts of the world.

The research study identifies maintenance-related losses, sets up targets regarding maintenance performance improvements and developed guidelines for achieving enhanced manufacturing system performance through strategic maintenance initiatives in the palm oil mills. These guidelines can also be important to all concerned with maintenance and safety in various manufacturing enterprises. This model is generic in nature and can be applied to other industries as well.

4.9 Chapter Summary

Data analysis is a process of inspecting, cleaning, transforming, and modeling data with the goal of highlighting useful, suggesting conclusions, and supporting decision making. 41 usable responses were received, in response to direct mail survey sent to 373 Malaysian companies in operation out of the 434 registered with MPOB; 87.8% of the respondents belong to SMEs. Mills' Data collected through survey questionnaire was validated by triangulation. Central tendency was calculated using SPSS for; IVs, OER, OEE Factors, and OEE. The average OEE figure of 62% is below the, lower end, bench mark of 85%. Oil recovery rate is poor, averaging 20%, compared to 30% of mills with best practices. Total recoverable potential cost due to the inefficiencies of maintenance management system in Malaysian palm oil milling sector amounts to RM 114.56 billion per year; that is 12% of the 2011 Malaysian GDP of 305.83 billion US$. Though the Malaysian palm oil sector commands a healthy market share in global palm oil production and trade, the data analysis shows that there is a considerable room for improvement in the following segments. OEE of the ‘Palm Oil Milling’ sector is considerably lower compared to the benchmark of world performers. Average OER is 50% lower than the industry players who have best practices; small holding plantations are poor performers; overall land is underutilized; and considering the resources at the disposal of palm oil sector, their contribution to GDP is low.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Introduction

Strategic maintenance management provides the avenue for continuous improvement. Following sections of this chapter critically discuss the implications of the theoretical and regulatory pressures and conclude the research findings pertaining to maintenance management performance in Malaysian palm oil mills. Research objectives were all actualized, except concerning POME. Performance of maintenance management system at Malaysian palm oil mills was evaluated by measuring OEE; process of producing CPO was assessed in palm oil mills while IV and DV were analysed in detail. Cost savings in maintenance management system were identified and quantified. Theory-practice gaps were identified for three sub-IVs (Labor, Spare-Materials', & Outsourcing), MV (Strategy-TPM), and DV (OEE). Contribution to Knowledge, research findings, and research accomplishments are also included and elaborated on, in this chapter. POME (mill effluent) generated by the CPO processing was evaluated for its generation and disposal practices but could not be analysed due lacking credible data. DV – IV relationship and MV affect, is summarised in the following sections.

5.2 OEE

Average OEE figure of 62% arrived at in the final analysis is low compared to the world bench mark of 85% (Wireman, 2004); however, this could be treated as a starting point for improvement. This research study examines the importance of maintenance management performance evaluation, determines the effectiveness of OEE as a primary performance metric and explains its three main factors that make up the calculation process in the context of Malaysian palm oil mills; availability, performance, and quality. OEE is embodied in the first of the original ‘Pillars of TPM’; it guides all TPM activities and measures the results of these loss-focused activities. This use of OEE evolved into the current Focused Improvement Pillar, one of eight TPM Pillars (Nakajima, 1989). The goal of measuring OEE is to improve the effectiveness and reliability of equipment. Since equipment effectiveness affects shop floor employees more than any other group, it is appropriate for them to be involved in tracking OEE and in planning and implementing equipment improvements to reduce lost effectiveness. Collecting the data for OEE will teach the operator about the equipment, focus the operator’s attention on the losses, and grow a feeling of ownership of the equipment. The shift supervisor or line manager is often the one who receives the daily operating data from the operator and process it to develop information about the OEE. Working hands on with the data give the supervisor/manager basic facts and figures on the equipment, help the supervisor/manager give appropriate feedback to the operators and others involved in equipment improvement, and allow the supervisor to keep management informed about equipment status and improvement results.

OEE breaks the performance of a manufacturing unit into three separate but measurable components; Availability, Performance, and Quality. Each component points to an aspect of the process that can be targeted for improvement. OEE may be applied to any individual Work Center, or rolled up to Department or Plant levels. It is an important measure of efficiency and improvements and improved OEE has a direct positive effect on the profits; by understanding it and improving it, businesses are getting a greater

ROI. This tool also allows for drilling down for very specific analysis, such as a particular product or Part Number, Shift, or any of several other parameters. It also gives businesses a valid comparative measurement across their own plant, across sites, and potentially against their competitors.

Maintenance system management performance involves much more than measuring performance of physical assets. The process that delivers asset performance in support of existing business operations and contributing to long term success of the organisation must be managed as well. Capital intensive industries, such as palm oil mills, need to address the issue as a matter of strategic importance and measure maintenance performance holistically using tried and tested maintenance strategies such as TPM. Nakajima (1989) provides the roadmap for making the paradigm shift in managing maintenance function. To improve OEE, organisations need to better manage inputs, the contributing factors that influence OEE; labor, spare-parts & materials, and outsourced maintenance. What make an organisation tick are the hearts and minds of its people. When people have shared objectives aligned with those of the organisation, action plans are clearly communicated to those responsible for implementation. Work is structured to achieve fast response and minimise loss and efforts are reinforced by support systems. These people (who may include external partners such as suppliers and external service providers) will have the inherent motivation to make maintenance performance excellence a reality. Performance measurement is a hallmark of strategic maintenance management performance. However, the performance measures being tracked will only provide useful information for guiding management decisions and shaping desirable behaviour if they are linked to the adopted maintenance strategy. Following sections cover the three sub-IVs; labor, spare-parts, material & tools, and maintenance outsourced. These sub-IVs allocated as maintenance inputs are to be managed efficiently and effectively in order to maximise output.

5.3 Labor; Spare-parts, Material, & Tools; and Outsourced Maintenance

5.3.1 Labor: Malaysian Skilled Labor Market

Demand for skilled labor in Malaysia is going to rise considerably. There is a noticeable gap on the supply side as such it is crucial that all the major players that shape the skilled labor market including Government, businesses, training institutions, and communities should collaborate and come up with an overall master strategy to meet this challenge. To attain that goal Malaysia has to show significant improvement to overcome deficiencies detailed in section 4.5.1. Here are some recommendations:

i. Malaysia could establish long-term apprenticeship programs, based on Canadian model, and guidelines of Malaysian Qualification Agency (MQA), to train apprentices, and add them to skill labor pool. This will indubitably help businesses to meet their demand of skilled labor. Government of Malaysia, in its budget speech of 2011, indicated to set up a "Talent Corporation" in early 2012 to inhibit the country's growing "brain drain" that is impeding its vision of turning Malaysia into a high-income nation by 2020 (MIER, 2011). This is a step in the right direction, however, much depends on implementation of the policies; slogans and billboards won't work to solve the problems, concrete actions are needed.

Skilled labor wages in Malaysia are lower than other neighboring Southeast Asian countries and considerably lower than those in the United States and Canada; average pay of a skilled licensed technician in Canada is $34 per hour, compared to $3 per hour in Malaysia; besides wages, working environment needs to be improved dramatically. When it comes to safety, health, worker's rights, Malaysia falls short compared to the developed countries. Adverse government policies may also provide impetus to the skilled labor force to migrate, eliciting a "brain drain".

ii. Investors are currently waiting on legislation proposed in June of 2011 to offer amnesty to the existing illegal workers in Malaysia, thereby increasing the legal labor pool. For the state, the dramatic move will raise much-needed tax revenues, improve national security, reduce human trafficking, and most importantly, attract more foreign investment.

iii. CSR is not a priority for Malaysian companies. Though Malaysian government insists on compliance and expects transparency and accountability in corporate governance while Malaysian government itself falls short on both these accounts (White-Paper, 2010). It is time to revisit the corporate and civil governance structure to meet the demands of 21st century; an approach that makes governance in both these areas fair, consistent, credible, transparent, and accountable.

Just eight years remain before Vision 2020, Malaysia's blueprint for achieving fully industrialized status, is to take effect. The net result is a need to transform Malaysia's labor profile from one of non-skilled and semi-skilled to a highly skilled and professional work force. This then is the challenge for the country to maintain a significant supply of highly skilled people. Malaysia is a diverse, multicultural society with a growing economy. Multinational firms who establish operations in Malaysia may encounter some difficulty, initially, in finding qualified professionals to staff their operations and it might be necessary, to import staff from elsewhere; however, government efforts are in place to increase the availability of highly skilled human resources in the country, and educational efforts continue to increase skill levels. With average salary levels in the "middle of the pack" of Asia's emerging economies, Malaysia can represent an intriguing base of operations for multinational firms.

Competitiveness of an economy depends on many things; perhaps the most important single determinant is the level and improvement of workforce skills at all levels.

5.3.2 Spare parts Inventory Management

As evidenced by research findings, lack of proper store room facilities in palm oil mills has contributed to the inefficiency of CPO production process, confirmed by low OEE.

The spare parts inventories management in industrial plants represents a very complex problem due to the difficulties concerning data collection, the number of factors to be considered, and the large amount of the items involved. To dispense efficient and effective services it needs to focus on the best practices of spare parts management. In order to accomplish best practices the maintenance store room ought to adopt the idea that the storeroom is a service provider, organize the storeroom and staff for efficiency, ensure inventory accuracy, perform routine and daily cycle counting as part of the storeroom duties, properly slot parts depending on part volume and characteristics, and use auto ID and/or barcodes to streamline data entry and reduce errors. Build PM kits in advance to enable quick PM of equipment; record all parts moves, receipts, and issues on time; and create, track, and use measurements and KPIs. As each company is unique, so too are the storerooms; different storerooms will require their own combination of solutions. Details of the process have been provided in section 4.5.2. When the storeroom operates in a best practices mode, then it is easy to see productivity gains not only in the storeroom, but also throughout the organization.

5.3.3 Outsourcing Maintenance: Power Generating Equipment in Malaysian Palm Oil Mills

As the research results reveal, the present maintenance system for the power generating equipment, besides being burdened with transaction costs, is costing the mills in overcapacity and redundant equipment (turbines & boilers), individual mill's spare-parts inventory cost and additional labor costs.

Power generation markets deregulation prompted by rapid depletion of fossil fuel reserves as well as climate change and the push towards renewable energy sources, in particular biomass fuels, is impelling changes in the behavior of power producers. Increasing competition has caused power plants to switch from traditional time-based maintenance strategies to those based on a plant's operating condition. As competitive power production becomes standard operation procedure, the quality of power a company produces becomes the measure of its success. To achieve these demands cost reduction and technical innovation programs are implemented in power generation process. Furthermore according to the actual market conditions a higher flexibility in operating and maintaining the plants is necessary. The decision concerning the maintenance outsourcing was traditionally executed using cost-based decision models.

However, the dramatic change in the way maintenance function is viewed has challenged the validity of this approach. Outsourcing of maintenance of power generating equipment in palm oil mills offers a viable solution, as today, maintenance outsourcing decision is analysed in a different way, taking into account complex and extended sets of (tangible and/or intangible) strategic factors, detailed in section 4.5.3 (III). Palm oil mill managers need to be persuaded to bring in the outsourcing of palm oil mill power generating equipment into 21st century through the use of *e*-maintenance and IT based hardware & software tools available, using the Knowledge and experience of the OEM&OM service providers. This, besides helping the Malaysian government to achieve their MDGs, will ensure a reliable, flexible, and cost effective power supply to the palm oil milling sector for years to come.

5.4 Contribution to Knowledge

5.4.1 Identified Theory and Practice Knowledge Gap in Malaysian Palm Oil Mills' Maintenance System Management (Research Objective #5)

i. Maintenance Strategy

Theory: TPM has been identified as a best in class manufacturing improvement process that has allowed manufacturing industries to greatly increase their levels of profitability and productivity; result shows there is a significant and positive indirect relationship between TPM and manufacturing performance through JIT practices (McKone *et al.,* 2001).

Practice: BDM and PM were the only two strategies practiced by the survey respondents. Low OEE figure affirms the poor performance in palm oil mills as the TPM and OEE are not part of the maintenance strategy.

ii. OEE

Theory: OEE breaks the performance of a manufacturing unit into three separate but measurable components; Availability, Performance, and Quality. Each component points to an aspect of the process that can be targeted for improvement. It is an aggregated productivity measure that takes into consideration the six big losses that affect the productivity of equipment in production systems (Venkatesh, 2006). TPM helps to raise the OEE value by supplying a structure to facilitate the assessment of losses, and subsequently giving priority to dealing with the more serious offenders (Eti *et al.*, 2004).

Practice: None of the mills that participated in pilot study practiced TPM and did not measure OEE. 20% of the survey respondents, who reported practicing TPM, did not actually practice TPM in its entirety. OEE can appear improved by actions such as purchasing oversize equipment, providing redundant supporting systems, and increasing the frequency of overhauls. Investment in higher installed mill capacity, purchase of redundant standby critical equipment such as spare ‘boilers’, ‘presses’, ‘decanters’, and turbines can also distort OEE. 81% of respondents reported having an array of redundant equipment compensating for their operational inefficiencies, including all that reported practicing TPM.

iii. Labor

Theory: Respect of the worker; employees are assets and not liabilities, knowledgeable workers are the essential ingredients of the modern economy, people are an organization's most valuable resource, and that a manager's job is both to prepare people to perform and give them freedom to do so. Workers need to be provided with healthy, non-discriminatory work environment, equitable compensation, training & development and above all respect (Drucker *et al.,* 2008).

Practice: Following ILO conventions are not ratified: Freedom of Association and the Right to Organize; Abolition of Forced Labour; and Abolition of Discrimination on the Basis of Occupation. Reports on environmental breaches, workers human rights infringements, and ethical abominations are often compromised. Malaysian government has not set the minimum wage, yet, about 34% of Malaysians earn wages below RM700 per month, which is below the Malaysian poverty line benchmark of RM720. Majority of the palm plantation workers fall under this category. Prevailing compensation packages paid to Malaysian skilled workers are considerably subjacent compared to other countries, e.g. Singapore or Canada.

iv. Spare-parts, material & tools

Theory: Maintenance store room is a service provider, if it is run improperly (such as poor inventory accuracy, parts unavailable when needed due to poor replenishment and procurement practices) the rest of the maintenance operation will not achieve high service levels of equipment availability and reliability (York, 2003).

Practice: Pilot study revealed that most second generation mills neither have a dedicated spare-part inventory controller nor a separate spare-parts store room area. Parts were stored all over the mill, including the maintenance shop area. None of the mills had computerised inventory management system in place and spare part inventory purchase solely depended on the mill managers' decision. Range of spare-parts, material, and tools cost, per ton of CPO produced, was spread out; from a low of RM3 to a high of RM272. There is no figure available, from MPOC or literature on palm oil milling, to bench mark the collected data, in this regard (Figure 4.12)

v. Maintenance contracted out

Theory: Power generation equipment in Malaysian palm oil mills makes a good business case for outsourcing its maintenance, primarily, due to lack of in-house skilled workforce: power generating equipment is complex and highly specialized (4.5.3-III); older power generating units are no longer considered effective for reliable and efficient power supply (Wan *et al.*, 2010).

Practice: Most of the mills have outsourced maintenance for their power generating equipment; however, there is a room for improvement. The author has suggested an "*e*-maintenance concept for power generating equipment in Malaysian palm oil mills" 5.4.3

5.4.2 Modified 'Input-Output Model for the Enterprise System'

The author has modified Tsang's 'Input-output model for the enterprise system (Tsang, 2002). The modified model, MMPM, exalts practitioner's perspective (Figure 3.10). To ensure a reliable production system, it incorporates role of maintenance strategy that compliments maintenance function's performance by improving OEE through its three key inputs; Availability, Performance, and Quality (3.4.7).

5.4.3 *e*-maintenance network concept for 'Power Generating Equipment in Malaysian Palm Oil Mills'

Malaysia generated 95 million tons of biomass available for power generation in 2011 (MPOC, 2012). Malaysian government's renewable energy efforts promote the biomass power generation and co-generation in the palm oil mills with the aim to reduce GHG emissions, promote growth of power generation and co-generation, and reduce barriers that have hindered the adoption of biomass power generation and cogeneration technologies. Though the private maintenance service providers active in the Malaysian power generating market are providing this service, to some extent, their traditional way of handling the maintenance business, based on the transactional and price oriented business models, is not aligned to the new market requirements. To bridge the gap of policy and practice, the author recommends to introduce a generic, *e*-maintenance network concept for maintaining 'Power Generating Equipment' in palm oil mills.

e-maintenance is an emerging field in the maintenance management of expensive equipment such as turbines. CBM program for turbines would be very useful, based on remote sensing PdM techniques, such as vibration analysis and thermography, readings to be taken by embedded sensors that are satellite linked to remote data collection and analysis centers. Data so collected will determine the maintenance management priorities, avoiding premature and disastrous failures. Inventories can be located at strategic points to service vide clientele and the companies do not need to have spare – redundant turbines. Utilizing intelligent condition monitoring strategies and a supervisory on-line diagnostic system, the system will manage comprehensive on-line data acquisition; internet data transmission systems, task-related data analysis and an expert background knowledge base at, strategically located, Remote Power Generation Diagnostic Center (RPGDC).This will enable detailed diagnosis of the actual plant condition for the power plant and its key components. New approach will help reduce the transactional costs by establishing strategic alliances between the service suppliers on the one side and the palm oil mills on the other.

RPGDC is an essential part of the *e*-maintenance network that will enable operators to minimize the LCC of power plants and at the same time maximize the output of electrical energy. The drive to reduce LCC results among other things in the reduction of staff and labor costs, whereas the desire to maximize electrical output requires raising the availability, reliability and efficiency of the plant. The Power Plants covered under a long term service contract can be connected via satellite to the RPGDC established in strategic locations. The RPGDC has access to the data monitored continuously at the power plant for all important operation values such as temperatures, vibrations, operation hours, turbine start-up curves, and performance curves. Qualified and well experienced personnel monitor the data in RPGDC and analyze these values with the objective to determine the actual conditions of systems and installed components, and evaluate the power plant performance. If needed, the RPGDC has direct access to specialised OEM engineering know-how consultancy through specialists for Generator or Steam turbine. In case of detected abnormal trends, events or trips, recommendations for predictive maintenance actions can be given; The RPGDC is one of the important features for early detection and prevention of damages. A concept diagram showing the Flow of data between RPGDC, power generating equipment, field service centers, and supplier's remote power diagnostic centers, is shown in Figure 5.18.

RPGDC will be a modular built system to monitor, analyze and diagnose the complete turbine island. The advanced service product will be equipped with sophisticated remote expert diagnostic system, a foundation, for condition based maintenance strategies and optimization of the plant operations. The recommendations of RPGDC will form the basis for further operations, repairs and/or modernization of customer's equipment. RPGDC services will be established on national level with links to the global service centre of service suppliers. Its services will not be limited to a specific supplier but applicable to all kinds of power generating equipment including steam turbines and generators. MPOB and MPOC can take a leading role to get the palm oil mills involved and be instrumental in establishing this institution.

The goal of RPGDC would be to diagnose the operation of the turbine island for purpose of early detection of abnormal operating conditions. Hardware failures and instrumentation malfunctions may lead to abnormal conditions. Detection of these conditions would result in optimized operation, higher availability, and improved turbine island efficiency. This service will benefit operations by mitigating running of nominal conditions. It will also provide the original manufacturers' key information that can be used to further improve products and services such as increases in hardware life and durability, mitigation of collateral equipment damage through early detection, improvement in reliability, and optimization of maintenance durations. It will enable skilled OEM/O&M engineers and technicians to make timely recommendations to customers, who in turn can use this information to analyze and help assess future actions (Taud & Scheidel, 2004).

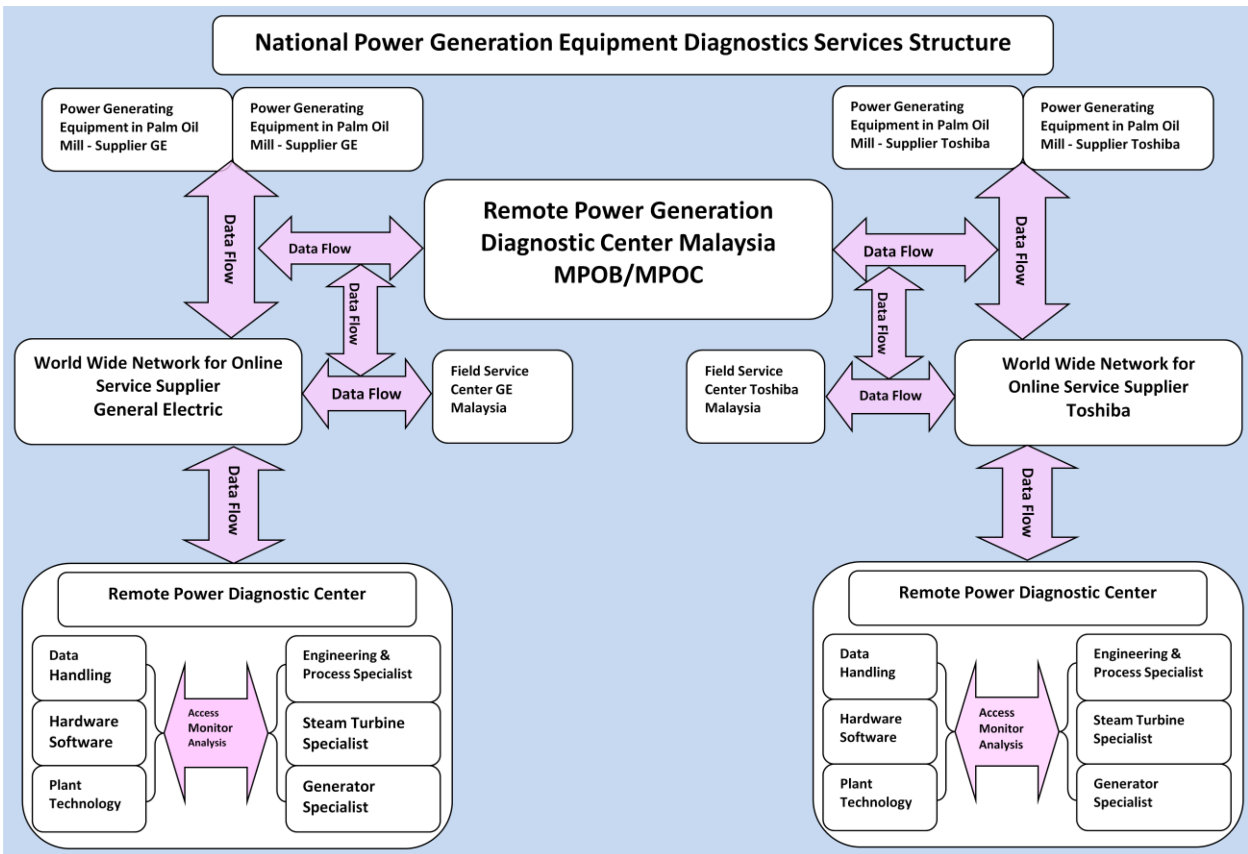


Figure 5.18
Diagram showing RPGDC Concept for Palm Oil Mills

The increasing competition in power markets is making cost-optimized power plant management indispensable. A significant cost factor is labor cost for plant staff. It is considered that 20 to 40% of the working hours are spent for finding, compiling and archiving information (Holger, 2003). The experiences of O&Ms show that the workload for information management can be limited to about 10% of the daily working hours, with the help of IT solutions readily available for CMMS. The functions offered should be in line with standard power plant practices (i.e. extensive adaptation is not necessary), and special needs can be readily integrated as required. The system is delivered in a reconfigured form with power-plant specific catalogues which consider the fleet experiences also derived from utilizing the fleet data storage collected through applied OEM and O&M systems. The system offers its users a 3 in 1 solution covering operation, maintenance and administration processes; from fault detection, through permit to work establishment up to spares cost control and inventory management that reduces the downtime for major overhauls. An important parameter to measure the stability of processes at a power plant is the downtime for major overhauls (Taud & Scheidel, 2004).

O&M Contracts with world leaders in turbine manufacturing brings experience of O&M of that organization, long term maintenance contracts experience, and a knowledge network sharing all relevant technical information through their home based back office. The knowhow of the customer together with the O&M contractor's experience ensures maximum long term asset protection. The contribution of the customer is the knowhow in regard to the regional power production requirements, and the long term experience in the local market pertaining to the power plant ownership. On the other hand, worldwide long term O&M experience is brought in by companies like GE, Siemens, Toshiba, Westinghouse, and many more. These synergy contributions from both parties allow a quicker interpretation of the O&M procedures and installation of the emanating engineering and administration processes.

5.5 Research Findings

i. Research Objective #1 : To evaluate performance of maintenance management system at the Malaysian palm oil mills by measuring OEE

The average OEE figure of 62% as shown in Figure: 4.6 is below the 85% benchmark (Wireman, 2004), however, this figure could have been subjacent as the data constituting three parts seems to have been compromised (3.4.5). OEE can appear improved by purchase of redundant standby critical equipment, such as spare ‘boilers’, ‘presses’, ‘decanters’, and turbines; 81% of respondents reported having an array of redundant equipment compensating for their operational inefficiencies (4.3).

ii. Research Objective #2: To evaluate palm oil milling process performance of producing CPO

Performance – typical items include: Minor stops; reduced speed or cycle time. Calculations regarding CPO produced vs. CPO could have been produced, are conciliated, idle time not reported and, generally, locally made, oil recovery equipment, such as presses and vibrating screens, is not efficient as oil recovery rate is poor, averaging under 20%, compared to 30% of mills with best practices (MPOB, 2010) while 2 – 4% CPO ends up in EFB and POME. Reduced speed or cycle time was not being recorded by any of the responding mills; the one speed mill line ran continuously, with or without FFB supply (4.3). There is a positive correlation between maintenance inputs and OEE (Figure 4.16). Likewise OEE inputs: availability and performance have a significant positive correlation with OEE - KPI for measuring DV (4.5 & Figure 4.17).

iii. Research Objective #3: To identify and quantify cost savings in the maintenance management system of palm oil mills by benchmarking palm oil mill's OEE with world class performers

With the total assets of Malaysian palm oil sector quoted (MPOC, 2010) at RM 93.3 billion; at 15% benefits recoverable rate, palm oil milling estimated at 10% of the sector, can potentially recover RM 1.4 billion (1.3.6).

Malaysian CPO production is 18.9 million tons/year at an OEE of 62%: this translates into 304,839 tons of CPO for 1% of OEE; for the gap of 23%, the figure is, astounding, 7,011,290 tons CPO per year, worth RM 22.44 billion, at prevailing rate of CPO per ton of RM 3200 (Figure 4.14). In addition, bridging the gap between national average of 4 tons/ha, and 8 tons/ha - the output of mills with best practices, has the potential to produce an additional 18.9 million tons of CPO worth over RM 60.48 billion; RM 83.4 billion in export earnings (4.4).

iv. Research Objective #4: To identify and quantify POME generated during palm oil processing and evaluate disposal practices for sustainability and environmental impact

19.50% and 24.40% respondents reported “0” POME produced and POME treated, respectively. 80.50% of the respondents reported generating POME, 72% of the POME generated was reported as treated by the respondents. During the pilot test it was revealed that most of the second generation mills do not have a credible system of recording POME generation and treatment. This operation does not seem to be tightly regulated. Quantity of POME produced is measured using crude devices, such as "tipping barrels" and the number count data is not monitored properly, resulting in "speculative" or EPD required" figure to be reported. Treatment methods are primitive and lack monitoring. 19.50% respondents report having "0" POME generated, while the pilot study revealed that on average 60-65% of the FFB tonnage processed ends up as POME, due to the same amount of steam injected into the process (MPOC, 2010). This compromised data credibility and constrained the author from consequential analysis (4.7).

5.6 Research Accomplishments

i. Offered realistic, shop level solutions to bridge the theory-practice gaps in maintenance inputs (IVs): Labor; Spare-parts, material & tools; Maintenance Outsourcing; and OEE (DV).

ii. Designed a generic OEE calculating template (Figure 5.19) for palm oil mills that, with minor modifications, can be adopted by other manufacturing organisations to benchmark their performance; identify gaps for improvement and thereby plan actions to improve processes. Divergence identified between current and desired performance by wielding OEE template would succor to bridge this gap (initial gap as pointed out in MPOB, 2010, presentation) is to double the CPO output from 4 to 8 tons/ha; improve OER from 20% to 30%, and the potential to double the foreign exchange earnings of palm oil, from present level of RM 83.4 billion per year.

Individual Mill			DAILY PRODUCTION LOG & OEE (Time in minutes)												September 2011		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Date	Time in Shift	Breaks & Lunch	Scheduled Maintenance Time	Meetings etc. Non Production Time	Setup & Adjustments	Minor Stoppages	Breakdowns	Speed Loss	Time Mill available for operation	Net Time Mill Worked	FFB Processed (Tons)	Total Production of CPO (Tons)	Out of Spec CPO & Slush oil recovery	Availability Rate	Performance Rate	Quality Rate	O E E = Availability x Performance x Quality Rate
19-Sep	480	45	60	10	10	10	30	30	365	315	131.25	23.44	2.75	0.86	0.81	0.88	0.62
20-Sep	480	45	10	5	8	15	20	40	420	377	157.08	26.68	2.50	0.90	0.92	0.91	0.75
21-Sep	480	45	30	15	9	9	25	20	390	347	144.58	25.89	2.95	0.89	0.90	0.89	0.71
22-Sep	480	45	20	5	11	12	30	35	410	357	148.75	25.49	3.00	0.87	0.88	0.88	0.68
23-Sep	480	45	15	10	8	8	35	25	410	359	149.58	26.44	3.25	0.88	0.92	0.88	0.70

Figure 5.19
Individual Mill Daily Production Log & OEE Template

iii. Designed a generic maintenance daily service log pro-forma (Figure 5.20) for use in the Malaysian palm oil mills to record daily maintenance activities and to develop repair history of the equipment for informed decisions regarding repair or replacement. With minor modifications, the template may easily be adopted by other manufacturing organisations.

Maintenance Daily Service Log (Template)											
1	2	3	4	5	6	7	8	9	10	11	12
2011	**Time of Service Call**	**Initial Report**	**Equipment Detail (Asset #)**	**Technician attending call (Employee #)**	**Actual Diagnosis and repair details**	**Time Equipment Up and Running**	**Time taken to repair (minutes)**	**Equipment Downtime**	**Work Order # issued for later repairs**	**Entered in CMMS**	**Remarks**
Sep-19	10:30	FFB conv. Stopped	#001	Ben #113	Motor # 25 limit switch was off adjusted bracket	11:00	20	30	#001	Y	New Bracket needed - order material
Sep-19	10:45	Sterilizer #A FFB not soft to spec	#004-A	Zul #125	low steam pressure replaced damaged door seal	11:45	45	60	#002	Y	Used last door seal - please order 3 Goodyear brand
Sep-19	11:30	Flue gases alarm is on	#012	Abdul #045	ID fan load switch tripped - lubed bearing to run it	11:45	10	20	#003	Y	Motor bearings shot new needed WO#003 issued
Sep-19	14:00	Vibrating Screen off	#008-B	Chen #096	Safety Switch damaged	14:55	45	60	#004	Y	switch in stock - Please order 2
Sep-19	15:30	Decanter is noisy	#007-C	Ravi #049	Anchor bolts were loose - tightened	15:50	15	15	#005	Y	for New bolts with lock washers

Figure 5.20
Maintenance Daily Service Log Template

iv. Introduced an *e*-maintenance concept for power generating equipment of palm oil mills; a complete frame work for establishing an *e*-maintenance system has been entailed in section 5.4.3 with a graphic sketch (Figure 5.18) depicting the links between different units and the flow of information among them.

v. Several recommendations have been made for the future research that will be enormously beneficial to the palm oil sector and, hence, for the Malaysian economy (5.8 & 5.10).

5.7 Generalization

i. None of the respondent palm oil mills are developing a maintenance performance management system that is clearly driven by business goals of their organisation since the mills surveyed are using BDM and PM as maintenance strategy. However, this is not linked to the performance.

ii. Performance measures are not indentified through structured and participative process.

iii. Strategic dimensions of asset management, such as maintenance service delivery options, acquisition, improvement, replacement, and disposal of physical assets are considered outside the scope of maintenance function in most of the mills; hence, performance in these aspects are often not tracked.

iv. Maintenance performance measures that relate to drivers of future performance improvement, innovation, organisational culture, employees capabilities are limited in use in mill's management systems.

v. Performance measure in common use is primarily confined to concerns of production and operations management: production rate; oil extraction rate; equipment availability; faults & breakdowns; and costs of human resources (workforce). Soft measures that relate to customer, employee, environment, and sustainability are hard to find in any of the mills.

vi. The alignment of maintenance at different levels of the organization is a common blind spot in maintenance management performance. This can be a serious issue for companies with large maintenance departments.

vii. Mills do not have a reward and recognition system that has a clear link with the maintenance performance function; shop floor employees are not highly regarded as assets and thus not well trained, rewarded, respected or appreciated.

viii. Sophisticated critical equipment, such as turbines, decanters, was outsourced for maintenance, by most mills.

ix. Lack of awareness among upper management that maintenance excellence has direct effect on organisations performance – sustainable profits.

x. Allocating of resources for maintenance is typically made through the operating budget. Managers therefore regard it as an expense; not an investment to prevent loss of service to customer and to ensure fast recovery of failed assets. Managers concentrate on near term issues, improving profits and reduction of maintenance cost.

xi. Visit to three, second generation, mills in the pilot study showed maintenance, production, and shop floor employees lack; safety conditions (no safety gear), general outlook (shabbily dressed), inadequate pay, lack of respect, subdued boss-employee relationship, no safety or fire prevention procedures apparent, no verifiable accident records kept on site.

xii. Most maintenance managers are engineers by training; they tend to hold the view that problems have conceptual and theoretical solutions that can be implemented in the real world. They tend to fit the humans to technology rather than the other way around; an appropriate way for operations and technology interface.

xiii. CSR is not a priority in most mills, reporting figures are compromised; data provided to the regulating authorities is not credible. Palm Oil milling sector needs to address the needs of all the stakeholders. The rapid introduction of new technology requires significant input from the suppliers and outside experts. Trusts, shared interest, collaboration for mutual benefits, are the essentials of partnership relationship; they are also the integrants of successful technology transfer. The adoption of a fair process embodying the three mutually reinforcing principles of: engagement (participation); explanation (open communication); and expectation clarity, is the key to drive out fear, earn the trust of those affected, and most importantly, to achieve alignment of goals to make changes happen (Kim & Mauborgne, 1997). Participation in learning to understand (analysis), discovering what to change (design), and in organizing to succeed (implement), is empowerment. Anything less is not likely to be as effective (Taylor & Felten, 1993).

xiv. Recycling of EFB is taken by 90% of the mills as dumping the EFBs in plantations. Only 10% of the respondents actually recycled EFB for value added products. Out of the 22% EFBs, 2% CPO is recovered and the fiber is processed into coir and sold for downstream industries. It is being marketed for RM 28/ton and the remaining crude fibre left is used as fuel for the boiler. A rough calculation for the amount not being recovered is RM 60 million per year; it is almost 30% of the annual cess money being collected from the mills (MPOA, 2011).

5.8 Recommendations for the Malaysian Palm Oil Milling Sector

i. It is essential that 'Benchmarks' be created for: oil recovery rate; per ton of CPO cost of inputs (labor; spare-parts, material, & tools; maintenance outsourced); energy consumed; steam consumed; mill effluent produced; and management.

ii. Trades training for the skilled labor force, with Mills' input, should be organised by the MPOB and MPOC. A proper trade's certification process should be part of the training structure. Canadian system of apprenticeship, training, and certification could serve as good model to adopt.

iii. Mills could use the templates of, maintenance daily log, and OEE, for calculations to garner equipment repair history and plan accordingly for improvements (Figure 5.19, 20).

iv. With the help of OEMs, an indigenous industry for manufacturing turbines and decanters is developed to ensure a reliable supply of this equipment to the industry; vital for the stability and self sufficiency of palm oil milling sector.

v. To help qualify for RSPO certification POME generation recording, by the mills, be automated. Simple inexpensive and sealed flow meters can be installed, that will bring credibility to mill effluent generation reporting and help regulate the process.

vi. CWORKS, a Malaysian Software for CMMS, is available; it can easily serve the needs of palm oil mills, and other manufacturing SMIs, to manage assets including machinery, equipment, and buildings etc. The software is very affordable considering price and technical post sales support. However, for starters, a free version is also available (CWORKS, 2011). MPOB could persuade the mills to use CWORKS; it will facilitate their R&D and regulatory duties.

vii. MPOB need to improve their relations with palm oil mills. Mills perceive “us-they” syndrome is prevalent, and that the Malaysian Government’s taxation policies and MPOB’s regulatory practices are discriminatory. This, somewhat hostile, relationship is not conducive to the future development of palm oil sector. Latest row between MPOB and the Mills was evident at the Round Table Conference (RT 9), held in Sabah, Borneo; the news has been covered in the local media, at length MPOB’s relations with their Indonesian counterparts are also strained; MPOB has been accused of non conciliatory and arrogant attitude that is detrimental to the regional palm oil sustainable development, almost fringing a ‘turf war’ syndrome (Star, 2011).

5.9 Research Limitations

i. This study did not examine the impact of maintenance management ineffectiveness on safety, health and the environment.

ii. Credible and verifiable data was not available for mill effluent generation and treatment; hence, neither the figures quoted in the literature could be verified, nor was sustainability analysis done.

5.10 Future Research Recommendations

I. Best Management Practices in Palm Oil Mills -Benchmarks for Productivity

Benchmarking is an objective and analytical technique that compares a firm's business processes with those of other companies that achieved recognition for excellence for a specific process or function. The goal is to identify and profile another organisation that achieved radical improvements, which significantly impacted their bottom line or reputation. Benchmarking is simply the process of measuring the performance of one's company against the best in the same or another industry, (Stevenson, 1996). Though benchmarks are moving targets, nevertheless, organisations need them in order to gauge their performance by comparing their own to the best in the industry. It is imperative for Palm oil sector to provide bench marks for the following inputs required per ton of CPO produced namely: FFB processed: OER; Energy consumed; Steam consumed; Management cost; Direct Labor cost; Maintenance Labor cost; Spare-parts, Material, & Tools cost; Outsourced Maintenance cost; Overheads cost; and Mill Effluent (POME) produced.

II. Equipment-level Maintenance Optimization: Retirement Planning and Asset Disposal Cost

Optimal retirement/replacement management is an important part of asset management as minimizing LCC is an important objective espoused by several organisations, which aims at reducing long term investment / maintenance costs. Effective retirement / replacement plan will reduce failures. However, extensive studies of the impact of replacement plan toward equipment reliability and economic cost should be conducted. Most of the prime movers being used in the industry, such as motors, are of obsolete old British design; they are like 'dinosaurs' of the breed. Over designed and extremely inefficient; they have long been replaced in the Western world with more energy efficient and sleek design motors. It is time these prime movers are phased out from the palm oil mills, in a progressively planned way, in order to make the industry efficient and sustainable in the long run.

III. Dormant Small Holding Plantations & Senile Palms

A term used for those plantations that are hardly productive, are small in size and tree height is at a stage that is hard to reach for the fruit; on top of that the owners, small farm holders, have no resources to revive these micro plantations through replanting using best management practices. Boarded up homes along the interior roads in western Malaysia evinces the abandonment of many of such farms whose owners have moved away in search of better prospects. The author visited one such farm in Perak state; this 20 plus hectare farm, comprised of several small parcels of two or more hectares, scattered across an area of three square kilometres. Owner had passed away and the sons were not interested in the business; one of the married daughters, who lived close, had contracted out the entire fruit pick up and sale operation at a meager price of RM 30 thousand per year. A properly maintained 20 hectare micro plantation, at 8 tons/ha, could produce160 tons per year of FFB; at the prevailing price of RM 640 per ton worth RM 102,400. This is not an uncommon phenomenon that can be seen throughout the interior of western peninsula. A research study needs to be initiated in order to identify the opportunity cost of dormant plantations that are dragging down the performance of small farmers' plantations. The potential recovery that can be made by reviving this segment of palm oil sector holds a substantial potential of income generation for small palm oil plantation holdings. Other areas that could prompt a research are; availability of senile palms and evaluating the potential, and socio-economic prospects of replanting the area where senile palms have been harvested.

Senile palms and small holding plantations constitute 40% share of small holdings in the oil palm plantations (MPOB, 2010); 50 % according to some estimates, are covered with senile palms waiting to be felled. At 136 palms per hectare for the 900 thousand hectares of unproductive small holding area, this amounts to over 122 million senile palms to be felled. The process of felling and replanting the senile palms could generate economic activities. Senile palms could be processed into low-end lumber, furniture, provide raw material for plywood & chipboards, or could be sold as logs. Replanting will provide business to palm nurseries and equipment manufacturers while creating jobs for businesses and workforce. In addition, replanting of the area with better species will enhance the output of these cash starved plantations; accrued social benefits will be an added bonus.

5.11 Chapter Summary

This research exalts practitioner's perspective and has determined that SMT axioms and TPM principles are not being applied to optimize productivity in palm oil mills. In order to ensure competitiveness and sustainability of its palm oil industry in the 21st century, it is obligatory for Malaysia to adopt best management practices in processing, manufacturing and maintenance that will improve yield, and Oil Extraction Rate. This research study demonstrates how efficient and effective maintenance management offers, besides cost savings, a wide scope of improvements for the palm oil industry that could help it to be competitive in the long run. The main contributions of this research study are: Identified theory and practice gaps pertinent to maintenance management in palm oil mills; Provided shop-level solutions to bridge those gaps; Modified 'Input-Output Model for the Enterprise System'; Designed a generic OEE calculating template and maintenance daily service log pro-forma for use in the Malaysian palm oil mills; and provided guidelines for establishing an *e*-maintenance system for power generating equipment in palm oil mills.

OEE and Lean have several key factors in common, but perhaps the most important is the concept of elimination of waste. OEE is attractive to managers as it produces a numeric metric that can be understood in an instant; it points to the pockets of inefficiencies in equipment operation and processes. OEE facilitates ambitious goal-setting, it is easily understood by equipment operators and its visual displays assist in recognition of exceptional performance by individuals. Suggested shop level solutions to bridge the theory-practice gaps in maintenance inputs and OEE can be applied to the palm oil milling sector. Use of the designed OEE and daily service log templates can help to make the palm oil milling process efficient and effective. The introduced *e*-maintenance concept for power generating equipment can ensure competitive uninterrupted quality power supply to the palm oil milling sector. Outsourcing of maintenance of power generating equipment in palm oil mills offers a viable solution to the Malaysian government to achieve their Millennium Development Goals and will ensure a reliable, flexible, and cost effective power supply to the palm oil milling sector for years to come. Research findings provide impetus to the palm oil mills to adopt best practices in the milling sector. Future research recommendations have the potential to provide sustainable better earnings for the palm oil sector.

REFERENCES

Achabal, D. D., Heineke, J. M., & McJntyre, S. H. (1984). Issues and perspectives on retail productivity. *Journal of Retailing, 60*(3), 107-127.

Adam, G., & Bode, A. (2000). *Ferndiagnose und Teleservicesystem für GUD-Kraftwerke, VDI-Bericht Nr. 1566*. Düsseldorf, Germany: VDI-Verlag.

Ahlmann, H. (1984). Maintenance effectiveness and economic models in the terotechnology concept. *Maintenance Management International, 4*, 131-139.

Ahlmann, H. (1995). *Maintenance research and development program*. Sweden: UTC.

Ahlmann, H. (1998). *The economic significance of maintenance in industrial enterprises*. Sweden: Lund Institute of Technology, Lund University.

Ahmad, A. L., Ismail, S., & Bhatia, S. (2003). Water recycling from palm oil mill effluent (POME) using membrane technology. *Desalination 157*, 87-95.

Ahmed, S., Masjuki, H., & Taha, Z. (2005). TPM can go beyond maintenance: excerpt from a case implementation. *Journal of Quality in Maintenance Engineering, 11*(1), 19-42.

Ahuja, I. P. S., Khamba, J. S., & Choudhary, R. (2006). Improved organizational behavior through strategic total productive maintenance implementation, IMECE2006-15783. Proceedings of the *2006 ASME International Mechanical Engineering Congress and Exposition (IMECE)*, Chicago, Illinois, November 5-10, 1-8.

Ahuja, I. P. S., & Khamba, J. S. (2007). An evaluation of TPM implementation initiatives in an Indian manufacturing enterprise. *Journal of Quality in Maintenance Engineering, 13*(4), 338-52.

Ahuja, I. P. S., & Khamba, J. S. (2008a). Total productive maintenance – Literature review and directions. *International Journal of Quality and Reliability Management*, *25*(7), 709-756.

Ahuja, I. P. S., & Khamba, J. S. (2008b). An evaluation of TPM initiatives in Indian industry for enhanced manufacturing performance. *International Journal of Quality and Reliability Management, 25*(2), 147-172.

Ahuja, I. P. S., & Kumar, P. (2009). A case study of TPM implementation at precision tube mill. *Journal of Quality in Maintenance Engineering, 15*(3), 241-258.

Alkin, M. C. (1990). *Debates on evaluation*. Thousand Oaks, CA: Sage. Publications Inc.

Al-Najjar, B., & Alsyouf, I. (2003). Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making. *International Journal of Production Economics, 84*(1), 85-100.

Al-Najjar, B., & Alsyouf, I. (2004). Enhancing a company's profitability and competitiveness using integrated vibration-based maintenance: A case study. *European Journal of Operational Research, 157*(3), 643-657.

Al-Najjar, B. (1997). Condition-based maintenance: Selection and improvement of a cost-effective vibration-based policy in rolling element bearings. *Unpublished doctoral dissertation*, Lund Institute of Technology, Lund University, Sweden.

Al-Najjar, B., & Alsyouf, I. (2000). Improving effectiveness of manufacturing systems using total quality maintenance. *Integrated Manufacturing Systems, 11*(4), 267-276.

Alsyouf, I. (2004). Cost effective maintenance for competitive advantages. *Published doctoral dissertation* (Terotechnology), School of Industrial Engineering, Växjö University Press, Acta Wexionensia, Växjö.

Alsyouf, I. (2007). The role of maintenance in improving companies' productivity and profitability. *International Journal of Production Economics, 105*(1), 70-78.

Altrichter, H., Feldman, A., Posch, P., & Somekh, B. (2008). *Teachers investigate their work: An introduction to action research across the professions (2nd ed.)*. London: Routledge, p. 147.

Andersen Consulting (1993). *The lean enterprise benchmarking project*. London: Andersen Consulting.

Andersen Consulting (1994). *World-wide manufacturing competitiveness study – The second lean enterprise report*. London: Andersen Consulting.

Antras P. (2003). Firms, contracts, and trade structure. *Quarterly Journal of Economics 118*(4), 1375-1418.

APEC (2011). Towards seamless Asia-pacific Economy, *New Straits Times*. Retrieved December 31, 2011, from http://www.nst.com.my/

APOC (2010). American Palm Oil Council, *Palm Oil development and performance in Malaysia*, MPOB & APOC Presentation to USITC Washington DC, Feb. 3, 2010

Argenti, J. (1997). Stakeholders: The case against. *Long Range Planning, 30*(3), 442-445.

Ashayeri, J. (2007). Development of computer-aided maintenance resources planning (CAMRP): A case of multiple CNC machining centers. *Robotics and Computer-Integrated Manufacturing, 23*(6), 614-623.

Ashton, C. (1997). *Strategic performance measurement*. London: Business Intelligence Ltd.

Asian Development Bank (ADB) (2006). *Technology overview – Palm oil waste management*. Retrieved December 31, 2011, from http://www.adb.org/ Documents/Reports/Consultant/ 36557.

Asmild, M., Paradi, J. C., Reese, D. N., & Tam, F. (2007). Measuring overall efficiency and effectiveness using DEA. *European Journal of Operational Research, 178*(1), 305-321.

Atkinson, A. A., Waterhouse, J. H., & Wells, R. B. (1997). A stakeholder approach to strategic performance measurement. *Sloan Management Review, 38*(3), 25-37.

Backlund, F., & Akersten, P. A. (2003). RCM introduction: Process and requirements management aspects. *Journal of Quality in Maintenance Engineering, 9*(3), 250-264.

Bakerjan, R. (1994). *Tool and manufacturing Engineers' handbook: Continuous improvement (4th ed.)*. NJ: ASME.

Bamber, C. J., Sharp, J. M., & Hides, M. T. (1999). Factors affecting successful implementation of total productive maintenance: A UK manufacturing case study perspective. *Journal of Quality Engineering, 5*(3), 162-181.

Bamber, C., Castka, P., Sharp, J., & Motara, Y. (2003). Cross-functional team working for overall equipment effectiveness. *Journal of Quality in Maintenance Engineering, 9*(3), 223-239.

Banks, R. L., & Wheelwright, S. C. (1979). Operations versus strategy – Trading tomorrow for today. *Harvard Business Review, May/June,* 112-120.

Banverket (2007). *Annual report 2006*. Retrieved December 31, 2011, from http://publikationswebbutik.vv.se/upload/5856/100194_banverkets_annual_report_2006.pdf

Barnard, C. I. (1962). *The functions of the executive*. Cambridge, MA: Harvard University Press.

Barney, J. (1992). Integrating organisational behaviour and strategy formulation research: A resource-based analysis. In P. Shrivastava, A. Huff, & J. Dutton (Eds.), *Advances in strategic management, Volume 8*. Greenwich, CT: JAI Press, 39-62.

Basiron, Y. (2000). *Advances in palm oil technology, Volume 1*. Malaysia: MPOB, 234-245.

Basiron, Y. (2007). Palm oil production through sustainable plantations. *European Journal of Lipid Science and Technology 109*, 289-295.

Basiron, Y. (2008a). Malaysian palm oil: Dynamics and prospects. A plenary presentation at the *Malaysia-India Palm Oil Trade Fair and Seminar*, Mumbai, India.

Basiron, Y. (2008b). Creating fine balance for development, food, security and environmental sustainability. *Palm Oil Blog*. Retrieved July 13, 2011, from http://www.ceopalmoil.com/

Basiron, Y., & Chan, K. W. (2004). The role of R&D strategies in food safety, GAP, DMP and GDP in the Malaysian palm oil industry. Paper presented at the *EUREPGAP ASIA 2004 Conference*, Kuala Lumpur, Malaysia, 17.

Basiron, Y., & Chan, K. W. (2008). Sustainability reporting in the oil palm industry. In S. Gurmit, K. H. Lim, L. Teo, & K. W. Chan (Eds.), *Sustainable production of palm oil – A Malaysian perspective*, Kuala Lumpur: Malaysian Palm Oil Association, 109-132.

Basri, M. W., Chan, K. W., & Basiron Y. (2002). Advances in research and development for the sustainability of the oil palm industry in Malaysia. Keynote paper delivered at the *Agriculture, Biotechnology and Novel oil Crops (ABNO) Module of the International Oils and Fats Congress*, organised by the Malaysian Oil Scientists and Technologists Association (MOSTA), 7-10 October 2002, pp. 19.

Ben-Daya, M., & Duffuaa, S. O. (1995). Maintenance and quality: The missing link. *Journal of Quality in Maintenance Engineering, 1*(1), 20-26.

Berliner, C., & Brimson, J. A. (1988). *Cost management for today's advanced manufacturing: The CAM-I conceptual design*. Boston, MA: Harvard Business School Press.

Bernama (2010). *www.bernama.com*. Retrieved July 13, 2011, from http://www.palmoilhq.com/PalmOilNews/malaysias-felda-gets-sustainability-certification-report/

Bevilacqua, M., & Braglia, M. (2000). The analytic hierarchy process applied to maintenance strategy selection. *Reliability Engineering and System Safety, 70*, 71-83.

Bititci, U. S., Carrie, A. S., & McDevitt, L. (1997). Integrated performance measurement systems: A development guide. *International Journal of Operations and Production Management, 17*(5), 522-534.

Bititci, U. S., Turner, T., & Begemann, C. (2000). Dynamics of performance measurement systems. *International Journal of Operations and Production Management, 20*(6), 692-704.

Bititci, U. S., Mendibil, K., Martinez, V., & Albores, P. (2005). Measuring and managing performance in extended enterprises. *International Journal of Operations and Production Management*, *25*(4), 333-353.

Blanchard, B. S. (1997). An enhanced approach for implementing total productive maintenance in the manufacturing environment. *Journal of Quality in Maintenance Engineering, 3*(2), 69-80.

Blischke, W. R., & Murthy, D. N. P. (2000). *Reliability*. New York, NY: John Wiley and Sons.

Bogdan, R. C., & Biklen, S. K. (2006). *Qualitative research in education: An introduction to theory and methods (5th ed.)*. Boston: Allyn and Bacon.

Bourne, M. C. S., Mills, J. F., Bicheno, J., Hamblin, D. J., Wilcox, M., Neely, A. D., & Platts, K. W. (2000). Performance measurement system design: Testing a process approach in manufacturing companies. *International Journal of Business Performance Measurement, 1*(2), 154-170.

Bowditch, J., & Buono, A. (2005). *A Primer on Organizational Behavior.* Hoboken, NJ: John Wiley and Sons.

Bowen & Spear (1999). Decoding the DNA of the Toyota Production System. *Harvard Business Review, September-October*.

Boyd, L. H., & Gupta, M. C. (2004). Constraints management: what is the theory? *International Journal of Operations and Production Management*, *24*(4), 350-371.

Braglia, M., Carmignani, G., Frosolini, M., & Grassi, A. (2006). AHP-based evaluation of CMMS software. *Journal of Manufacturing Technology Management, 17*(5), 585-602.

Brah, S. A., & Chong, W. K. (2004). Relationship between total productive maintenance and performance. *International Journal of Production Research*, *42*(12), 2383-2401.

Braven, H. (1998). *Labour and monopoly capital: The degradation of work in the twentieth century*. New York, NY, USA: Republication by Monthly Review Press, ISBN 0853459401.

Bruce, K. (2006). Henry S. Dennison, Elton Mayo, and human relations historiography. *Management and Organizational History, 1*, 177-199.

Business Times (2008). Malaysian palm oil growers to pay windfall tax. *Business Times*, June 6, 2008. Retrieved August 16, 2011, from http://www.btimes.com.my

Butler, R. A. (2006). Why is palm oil replacing tropical rainforests? Why are biofuels fuelling deforestation? *Mongabay News*, April 25, 2006. Retrieved August 16, 2011, from http://news.mongbay.com.

Butler, R. A. (2007a). Eco-friendly palm oil could help alleviate poverty in Indonesia palm oil is not a failure as a biofuel. *Mongabay News*, April 3, 2007. Retrieved August 16, 2011, from http://news.mongabay.com/2007/0403-oil_palm.html

Butler, R. A. (2007b). Palm oil doesn't have to be bad for the environment. *Mongabay News*, April 4, 2007. Retrieved August 16, 2011, from http://news.mongabay.com/2007/0404-oil_palm.html

Byrne, D. (2005). *Social exclusion*. Maidenhead: Open University Press

Camp, R. C. (1989). *Benchmarking – The search for industry best practices that lead to superior performance*. Milwaukee, WI: ASQS Quality Press.

Campbell, J. D. (1995). *Uptime: Strategies for excellence in maintenance management*. Portland, OR: Productivity Press.

Campbell, J. D., & Jardine, A. K. S. (2001). *Maintenance excellence: Optimizing equipment life-cycle decisions*. New York, NY: Marcel Dekker.

Carter, C., Finley, W., Fry, J., Jackson D., & Willis, L. (2007). Palm oil markets and future supply. *European Journal of Lipid Science and Technology, 109,* 307-314.

Chan, F. T. S., Lau, H. C. W., Ip, R. W. L., Chan, H. K., & Kong, S. (2005). Implementation of total productive maintenance: A case study. *International Journal of Production Economic, 95*, 71-94.

Chand, G., & Shirvani, B. (2000). Implementation of TPM in cellular manufacturing. *Journal of Material Processing Technology, 103*, 149-154.

Chandler, A. D. (1977). *The visible hand - Managerial revolution in American business*. Boston, MA: Harvard University Press.

Chandler, A. D. (1962). *Strategy and structure: Chapters in the history of the industrial enterprise*. Cambridge, MA: Harvard University Press.

Chaneski, W. S. (2002). Total productive maintenance – An effective technique. *Modern Machine Shop, 75*(2), 46-48.

Chemicals X, NV. (1991). Some aspects of measuring maintenance performance in the process industry. *Journal of Quality in Maintenance Engineering, 4*(1), 6 – 11.

Cho, D., & Parlar, M. (1991). A survey of maintenance models for multi-unit systems. *European Journal of Operations Research, 51*, 1-23.

Choi, T. Y., & Hartley, J. L. (1996). An exploration of supplier selection practices across the supply chain. *Journal of Operations Management, 14*(4), 333-343.

Cleveland, G., Schroeder, R. G., & Anderson, J. C. (1989). A theory of production competence. *Decision Sciences, 20*(4), 655-668.

Coetzee, J. (1998). *Maintenance*. Hatfield: Maintenance Publishers.

Cooke, F. L. (2000). Implementing TPM in plant maintenance: Some organisational barriers. *International Journal of Quality and Reliability Management, 17*(9), 1003-1016.

Cooper, R. (1987a, b). The two-stage procedure in cost accounting: Part 1. *Journal of Cost Management*, 39-51.

Cox, J. F., Blackstone, J. H., & Schleier, J. G. (2003). *Managing operations: A focus on excellence*. Great Barrington, MA: North River Press.

Cross, K. F., & Lynch, R. L. (1988/89). The SMART way to sustain and define success. *National Productivity Review, 8*(1), 23-33.

CWORKS (2011). Retrieved January 31, 2012, from http://www.cworks.com.my/cw_download.asp

Dale, E. (1973). *Management, theory, and practice*. McGraw-Hill Publication, NY.

Damiana, C., & Ghirardo, G. (2010). Maintenance management in Italian manufacturing firms. *Journal of Quality in Maintenance Engineering, 16*(2), 156-180.

Das, D. (2001). Total predictive maintenance: A comprehensive tool for achieving excellence in operational systems. *Industrial Engineering Journal, 30*(10), 15-23.

Davenport, T. H. (2007). *Thinking for a living: How to get better performances and results from knowledge workers*. New York, NY: Harvard Business School Press.

Davies, A. (1998). *Handbook of condition monitoring: Techniques and methodology*. London: Chapman & Hall.

De Groot, P. (1995). Maintenance performance analysis: A practical approach. *Journal of Quality in Maintenance Engineering, 1*(2), 4-24.

De Jong, E. (1997). *Maintenance practices in small to medium sized manufacturing enterprises (SMEs)*. Monash University, Australia: National Key Centre for Advanced Materials Technology.

De Ron, A. J., & Rooda, J. E. (2005). Equipment effectiveness: OEE revisited. *IEEE Transactions on Semiconductor Manufacturing, 18*(1), 190-196.

De Ron, A. J., & Rooda, J. E. (2006). OEE and equipment effectiveness: An evaluation. *International Journal of Production Research, 44*(23), 4987-5003.

Dekker, R., & Scarf, P. A. (1998). On the impact of optimization models in maintenance decision making: The state of the art. *Reliability Engineering and System Safety, 60*(2), 111-119.

Dekker, R., Wildeman, R. E., & van der Duyn Schouten, F. A. (1997). Review of multi-component models with economic dependence. *Zor/Mathematical Methods of Operations Research, 45*, 411-435.

Dekker, R. (1996). Applications of maintenance optimization models: A review and analysis. *Reliability Engineering and System Safety, 51*, 229-240.

Delzell, J., & Pithan, J. (1996). RCM process yields surprising results. *Power Engineering, 100*(11).

Denzin, N. (2006). *Sociological methods: A sourcebook (5th ed.)*. NY: McGraw-Hill. ISBN 9780-202308401.

DFAT (2011). Retrieved January 31, 2012, from http://www.dfat.gov.au/geo/fs/mlay.pdf

DiStefanso, R. S. (2005). *Elevating maintenance and reliability practices – The financial business case, 1-13*. Soutbury, CT: Management Resources Group Inc.

Dixon, J. R., Nanni, A. J., Jr., & Vollmann, T. E. (1990). *The new performance challenge: Measuring operations for world-class competition*. Homewood, IL: Business One Irwin.

Dossenbach, T. (2006). Implementing total productive maintenance: A successful TPM program will help you eliminate defects, machine breakdowns and accidents. *Wood and Wood Products, 111*(2), 29-32.

Doyle, P. (1994). Setting business objectives and measuring performance. *Journal of General Management, Winter, 20*(2), 1-19.

Dunn, S. (2009). Retrieved July 13, 2011, from http://www.plantmaintenance.com/articles/outsourcing_crit_issues.pdf

Drucker, P. F. (1954). *The Practice of Management*. New York: HarperCollins, pp. 62-63.

Drucker, P. (1977). *An introductory view of management.* New York, NY: Harper College Press.

Drucker, P. F. (1992). *Managing for the Future.* Oxford: Butterworth-Heinemann, p. 299.

Drucker, P. F., (1994). The theory of business, *Harvard Business Review, September-October*.

Drucker, P. F., Collins, J., Kotler, P., Kouzes, J., Rodin, J., Rangan, V. K., et al. (2008). *The five most important questions you will ever ask about your organization*, p. xix. Retrieved July 13, 2011, from http://info.emeraldinsight.com/drucker/index.htm

Drury, H. B. (1915). *Scientific management: A history and criticism*. New York, NY: Columbia University.

DuBrin, A. J. (2007). *Human relations interpersonal job-oriented skills (9th ed.)*. New Jersey: Pearson Prentice Hall.

Dwight, R. (1999). Searching for real maintenance performance measures. *Journal of Quality in Maintenance Engineering, 5*(3), 258-275.

Dwyer, J. (1999). More than a maintenance technique. *Works Management, 52*(9), 15-16.

Eisenberger, M.-L. (2008). *Goethe-Institute e. V., Online Editorial Team*. Retrieved August 27, 2011, retrievable from: http://www.goethe.de/ins/de/enindex.htm/online-redaktion

Embleton, P. R., & Wright, P. C. (1998). A practical guide to successful outsourcing. *Empowerment in Organizations, 6*(3), 94-106.

Erdos, P. L., & Morgan, A. J. (1983). *Professional mail surveys*. Melbourne, FL: Krieger Publishing Co.

Erl, T. (2006). *Service-oriented architecture: concepts, technologies, and design*. Upper Saddle River, NJ: Pearson Education.

Eti, M. C., Ogaji, S. O. T., & Probert, S. D. (2004). Implementing total productive maintenance in Nigerian manufacturing industries. *Applied Energy, 79*, 385-401.

EUREPGAP (n.d.). Retrieved July 13, 2011, from http://www.eurep.org

Evans, M. (2008). *MRO spares optimization*. Kuala Lumpur: Marcus Evans Malaysia.

FAO (2002). Small scale palm oil processing in Africa. *FAO Agricultural Services Bulletin, 148*, 1-56.

Ferdows, K., & DeMeyer, A. (1990). Lasting improvements in manufacturing performance: In search of a new theory. *Journal of Operations Management, 9*(2), 168-184.

Feurer, R., & Chaharbaghi, K. (1995). Performance measurement in strategic change. *Benchmarking for Quality, Management, and Technology, 2*(2), 64-83.

Filippini, R. (1997). Operations management research: Some reflections on evolution, models and empirical studies, *International Journal of Operations and Production Management, 17*(7), 655-670.

Finlow-Bates, T., Visser, B., & Finlow-Bates, C. (2002). An integrated approach to problem solving: linking K-T, TQM and RCA to TPM. *The TQM Magazine, 12*(4), 284-289.

Finpro (2001). *Bio Asia II, loppuraportti, Thaimaa ja Malesia*. Retrieved July 13, 2011, from http://www.doria.fi/bitstream/handle/10024/45293/isbn9789522147585.pdf?sequence=1

Fitzgerald, L., Johnston, R., Brignall, T. J., Silvestro, R., & Voss, C. (1991). *Performance measurement in service businesses*. London: The Chartered Institute of Management Accountants.

Fitzgerald, L., & Moon, P. (1996). *Performance measurement in service industries: Making it work*. London: The Chartered Institute of Management Accountants.

Fleming, S. A. (2006). FAA's proposed plan for implementing a reliability centered maintenance process for air traffic control equipment: GAO-07-81R. *GAO Reports*, 1-16.

Flynn, B. B., Sakakibara, S., Schroeder, R. G., Bates, K. A., & Flynn, E. J. (1990). Empirical research methods in operations management. *Journal of Operations Management, 9*(2), 250-284.

Flynn, B. B., Schroeder, R. G., & Sakakibara, S. (1994). A framework for quality management research and an associated measurement instrument. *Journal of Operations Management, 11*(4), 339-366.

Frazier, P. A., Tix, A. P., & Barron, K. E. (2004). Testing moderator and mediator effects in counseling psychology research. *Journal of Counseling Psychology, 51*, 115-134.

FRBD (2011). *Federal Reserve Bank of Dallas, Public Affairs Department*, Retrieved July 13, 2011, from http://www.dallasfed.org/

Friedman, V. (2008). Data visualization and info-graphics in: Graphics. *Monday Inspiration, January 14*.

Friendly, M. (2008). *Milestones in the history of thematic cartography, statistical graphics, and data visualization*. Retrieved July 13, 2011, from http://www. datavis.ca/gallery/

Fry, T. D., & Cox, J. F. (1989). Manufacturing performance: Local versus global measures. *Production and Inventory Management Journal, 2nd Quarter*, 52-56.

Galloway, D., & Waldron, D. (1989, a). Throughput accounting part 3 – A better way to control labour costs. *Management Accounting*, 32-41.

Galloway, D., & Waldron, D. (1988, b). Throughput accounting part 1 – The need for a new language for manufacturing. *Management Accounting*, 34-35.

Gardiner, S. C., & Blackstone, J. H., Jr. (1994). The evolution of the theory of constraints. *Industrial Management, May/June*, 13-16.

Garg, A., & Deshmukh, S. G. (2006). Maintenance management: Literature review and directions. *Journal of Quality in Maintenance Engineering, 12*(3), 205-238.

Gasperz, V. (2003). *Sistem Manajemen Kinerja Terintegrasi: Balanced Scorecard dengan Six Sigma untuk Organisasi Bisnis dan Pemerintah*. Jakarta: PT Gramedia Pustaka Utama.

Geanuracos, J., & Meiklejohn, I. (1993). *Performance measurement: The new agenda*. London: Business Intelligence.

Geraerds, W. M. S. (1992). The EUT maintenance model. *International Journal of Production Economics, 24*, 209-216.

Gershon, R. (2001). *Telecommunications management: Industry structures and planning strategies*. Mahwah, NJ, USA: Lawrence Erlbaum Associates.

Gertsbakh, I. B. (1997). *Models of preventive maintenance*. North Holland, Amsterdam. Retrieved July 13, 2011, from http://ieeexplore.ieee.org/xpl/freeabs_all.jsp? arnumber=5970578

Ghalayini, A. M., & Noble, J. S. (1996). The changing basis of performance measurement. *International Journal of Operations and Production Management, 16*(8), 63-80.

Gits, C. W. (1986). On the maintenance concepts for technical system: II. Literature review. *Maintenance Management International, 6*, 96-181.

Gits, C. (1991). *Maintenance concept and control, in maintenance and logistics: Towards integrated control (in Dutch)*. Samson/Nive: Eindhoven University of Technology, 181-215.
Gits, C. (1992). Design of maintenance concepts. *International Journal of Production Economics, 24*(3), 217-226.
Goldratt, E. M., & Cox, J. (1986). *The goal: Beating the competition*. Hounslow: Creative Output Books.
Goldratt, E. M., & Cox, J. (1984). *The Goal*. Croton-on-Hudson, NY: North River Press.
Gomes, C. F., Yasin, M. M., & Lisboa, J. V. (2006). Performance measurement practices in manufacturing firms: An empirical investigation. *Journal of Manufacturing Technology Management, 17*(2), 144-167.
Gosavi, A. (2006). A risk-sensitive approach to total productive maintenance. *Automatica, 42*(8), 1321-1330.
Gotoh, F. (1991). *Equipment planning for TPM*. Portland, OR: Productivity Press Inc.
Gupta, D., Gunalay, Y., & Srinivasan, M. M. (2001a). The relationship between preventive maintenance and manufacturing system performance. *European Journal of Operational Research, 132*(1), 146-162.
Gupta, R. C., Sonwalker, J., & Chitale, A. K. (2001b). Overall equipment effectiveness through total productive maintenance. *Prestige Journal of Management and Research, 5*(1), 61-72.
Hall, R. W. (1983). *Zero inventories*. Homewood, IL: Dow-Jones Irwin.
Haller, H. S. (1993). *Managing with profound knowledge: A management process based on the Deming management theory.* Cleveland, OH: Harold S. Haller & Company.
Handfield, R. B., & Melnyk, S. A. (1998). The scientific theory-building process: A primer using the case of TQM. *Journal of Operations Management, 16*(4), 321-339.
Hansen, R. C. (2001). *Overall equipment effectiveness – A powerful tool for increased profits*. New York, NY: Industrial Press Inc.
Hansson, J., Backlund, F., & Lycke, L. (2003). Managing commitment: Increasing the odds for successful implementation of TQM, TPM or RCM. *International Journal of Quality and Reliability Management, 20*(9), 993-1008.
Hammer, M., & Champy, J. (1993). *Re-engineering the corporation: A manifesto for business revolution*. London: Nicholas Brealey.
Hammer, M., & Stanton, S. A. (1995). *The Reengineering Revolution*. New York: Harper Business.
Hayes, R. H., & Wheelwright, S. C. (1979). Link manufacturing process and the product life cycle. *Harvard Business Review, 57*(1), 133-140.
Hayes, R. H., & Abernathy, W. J. (1980). Managing our way to economic decline. *Harvard Business Review, 62*, 67-101.
Helms, M. M. (1996). Perspectives on quality and productivity for competitive advantage. *The TQM Magazine, 8*(3), 5-10.
Hipkin, I. B., & Cock, C. D. (2000). TQM and BPR: Lessons for maintenance management. *Omega – The International Journal of Management Science, 28*(3), 277-292.
Hiromoto, T. (1988). Another hidden edge: Japanese management accounting. *Harvard Business Review*, 22-26.

Ho, C. T. (2007). Performance measurement using data envelopment analysis and financial statement analysis. *International Journal of Operational Research, 2*(1), 26-38.

Ho, C. T., & Zhu, D. S. (2004). Performance measurement of Taiwan's commercial banks. *International Journal of Productivity and Performance Management, 53*(5), 425-433.

Holden, P. E., Fish, L. S., & Smith, H. L. (1941). *Top management organization and control: A research study of the management policies and practices of thirty leading industrial corporations*. California/London: Stanford University Press.

Holger, I. (2003). *Customized operation and maintenance for fossil power plants*. Germany: Siemens AG, Power Generation.

Holmberg, K. (2001). *Competitive reliability 1996-2000, Technology Programme Report 5/2001, Final Report*. Helsinki: National Technology Agency.

Holmgren, M. (2005). Maintenance-related losses at the Swedish Rail. *Journal of Quality in Maintenance Engineering, 11*(1), 5-18.

Hopwood, A. G. (1984). *Accounting and human behaviour*. Englewood Cliffs, NJ: Prentice-Hall.

Hum, S. H., & Leow, L. H. (1996). Strategic manufacturing effectiveness: An empirical study based on the Hayes-Wheelwright framework. *International Journal of Operations and Production Management, 16*(4), 4-18.

Hummels D., Ishii J., & Yi, K. (2001). The nature and growth of vertical specialization in world trade. *Journal of International Economics, 54*(1), 75-96.

IBM Consulting and London Business School (1993). *Made in Britain - the true state of Britain's manufacturing industry*. London: IBM Consulting and London Business School.

IBM Consulting and London Business School (1994). *Made in Europe - a Four Nations Best Practice Study*. London: IBM Consulting and London Business School.

Idris, Z. (2003). *Effluent related fee in the palm oil industry of Malaysia*. Document submitted to ESCAP Virtual Conference. Available at: http://www.unescap.org/drpad/vc/conference/ bg_my_14_erf.htm

IEC (2004). *60300 (3-14): Dependability management – Part 3-14: Application guide – Maintenance and maintenance support*. Geneva: International Electro-technical Commission.

IEC (2006). *Application guide – Maintenance and maintenance support*. Geneva: International Electro-technical Commission.

Igwe, J. C., & Onyegbado, C. C. (2007). A review of palm oil mill effluent water treatment. *Global Journal of Environmental Research, 1*(2), 54-62.

IPM (1992). *Performance management in the UK – An analysis of the issues*. London: IPS/IMS.

Ireland, F., & Dale, B.G. (2001). A study of total productive maintenance implementation. *Journal of Quality in Maintenance Engineering, 7*(3), 183-191.

ISO/IEC (2008). *15288: Systems and software engineering – System life cycle processes*. Geneva: International Organization for Standardization and International Electro-Technical Commission.

ISO (2009). Retrieved July 13, 2011, from http://www.iso.org/iso/pressrelease.htm?refid=Ref1263

Ismail, A. R., Ismail, R., Zulkifli, R., Makhtar, N. K., & Deros, B. M. (2009). A study on implementation of preventive maintenance programme at Malaysia palm oil mill. *European Journal of Scientific Research, 29*(1), 126-135.

Ismail, M., & Rossi, A. (2010). *A compilation of bio-energy sustainability initiatives*. Rome: Food and Agriculture Organization of the UN (FAO).

Jambekar, A. B. (2000). A systems thinking perspective of maintenance, operations, and process quality. *Journal of Quality in Maintenance Engineering, 6*(2), 123-132.

Jantan, M., Nasurdin, A. M., Ramayah, T., & Ghazali, A. S. (2003). Total Productive Maintenance and organizational performance: A preliminary study. *Jurnal Ekonomi dan Bisnis, 2*(3), 337-356.

Jardine, A. K. S., & Buzacott, J. A. (1985). Equipment reliability and maintenance. *European Journal of Operations Research, 19*, 96-285.

Jardine, A., Fan, Z., & Hong, Y. (1996). Enhancing system reliability through maintenance decision making systems. *IEEE International Conference Proceedings, Journal of Quality in Maintenance Engineering, 12*(2), 133 – 149.

Johnson, H. T. (1975). Management accounting in an early integrated industrial: E. I. du Pont de Nemours Powder Company, 1903-1912. *Business History Review, XLIV*(2, Summer), 184-204.

Johnson, H. T. (1981). Towards an understanding of nineteenth century cost accounting. *The Accounting Review, LVI*(3, Winter), 510-518.

Johnson, H. T. (1972). Early cost accounting for internal management control: Lyman Mills in the 1850s. *Business History Review, XLVI*(4, Winter), 466-474.

Johnson, H. T., & Kaplan, R. S. (1987). *Relevance lost: The rise and fall of management accounting*. Boston, MA: Harvard Business School Press.

Johnson, H. T. (1978). Management accounting in an early multidivisional organization: General Motors in the 1920s. *Business History Review, LII*(4, July), 490-517.

Johnson, H. T. (1992). *Relevance regained*. New York, NY: The Free Press.

Johnston, R., & Pongatichat, P. (2008). Managing the tension between performance measurement and strategy: Coping strategies. *International Journal of Operations and Production Management, 28*(10), 941-967.

Jonsson, P., & Lesshammar, M. (1999). Evaluation and improvement of manufacturing performance measurement systems – The role of OEE. *International Journal of Operations and Production Management, 19*(1), 55-78.

Judenberg, J. (1994). Applications maintenance outsourcing an alternative to total outsourcing. *Journal of Information Systems Management, 11*(Fall), 34-38.

Juric, Z., Sanchez, A. I., & Goti, A. (2006). Money-based overall equipment effectiveness. *Hydrocarbon Processing, (International edition), 85*(5), 43-45.

Kaplan, R. S. (1983). Measuring manufacturing performance: A new challenge for managerial accounting research. *Accounting Review, 58*(4), 686-703.

Kaplan, R. S. (1984). The evolution of management accounting. *The Accounting Review, 59*(3), 390-418.

Kaplan, R. S. (1984). Yesterday's accounting undermines production. *Harvard Business Review, 62*, 95-101.

Kaplan, R. S., & Norton, D. P. (1992). The balanced scorecard – Measures that drive performance. *Harvard Business Review, 70*(1), 71-79.

Kaplan, R. S. (1986). Accounting lag: The obsolescence of cost accounting systems. *California Management Review, 18*(2), 174-199.

Karlsson, V. (2005). An overall view of maintenance. *European Railway Review, 11*(3), 11-17.

Katsicas, S. K. (2009). *Computer and Information Security Handbook*. Amsterdam, NL: Morgan Kaufmann Publications Elsevier Inc.

Keegan, D. P., Eiler, R. G., & Jones, C. R. (1989). Are your performance measures obsolete? *Management Accounting USA*, 45-50.

Keh, H. T., Chu, S., & Xu, J. (2006). Efficiency, effectiveness, and productivity of marketing in services. *European Journal of Operational Research, 170*(1), 265-276.

Kelly, J. (1982). *Scientific management, job redesign, and work performance*. New York, NY: Academic Press.

Kennerley, M., & Neely, A. (2002). A framework of the factors affecting the evolution of performance measurement systems. *International Journal of Operations and Production Management, 22*(11), 1222-1245.

Kennerly, M., & Neely, A. (2003). Measuring performance in a changing business environment. *International Journal of Operation and Production Management, 23*(2), 213-229.

Killichi, M. (2006). *Operational flexibility for steam turbines based on service contracts with diagnostics tools, Power Gen Europe 2006 Cologne, Ref. 306*. Germany: Siemens Power Generation.

Kim, W. C., & Mauborgne, R. (1997). Fair process: Managing in knowledge economy. *Harvard Business Review, 75*(4), 65-75.

Koelsch, J. R. (1993). A dose of TPM: Downtime needn't be a bitter pill. *Manufacturing Engineering, 72 (2), 63-66.*

Kraemer, H. C., Stice, E., Kazdin, A., Offord, D., & Kupfer, D. (2001). How do risk factors work together? Moderators, mediators, independent, overlapping, and proxy risk factors. *American Journal of Psychiatry, 158*, 848-856.

Krishnamurthy P. (2008). *CDM in the oil palm sector*. Retrieved December 29, 2011, from http://www.kyotoenergy.net/content.php?langue=english&cle_menus

Kumar, M., Antony, J., Singh, R. K., Tiwari, M. K., & Perry, D. (2006). Implementing the Lean Sigma framework in an Indian SME: A case study. *Production Planning and Control*, *17*(4), 407-423.

Kutucuoglu, K., Hamali, J., Irani, Z., & Sharp, J. (2001). A framework for managing maintenance using performance measurement systems. *International Journal of Operations and Production Management*, *21*(1/2), 173-194.

Kutucuoglu, K. Y., Hamali, J., & Sharp, J. M. (2002). Enabling BPR in maintenance through a performance measurement system framework. *The International Journal of Flexible Manufacturing Systems, 14*(1), 33-52.

Kuwaiti, M. E. (2004). Performance measurement process: Definition and ownership. *International Journal of Operations and Production Management*, *24*(1), 55-78.

Kyoto Energy (2008). *CDM opportunities in the palm oil industry*. Retrieved April 11, 2011, from http://www.kyotoenergy.net/cdm%20palm%20oil%20industry.html

Lane, F. (2006). *IDC: World created 161 billion gigs of data in 2006*. Retrieved December 20, 2011, from http://business.newsfactor.com/story.xhtml?story_id=013000F26JUS

Laine, T., Ojala, M., & Paranko, J. (2004). Expanding forward in the value chain? Earnings logics of service products. Paper presented at the *13th International Working Seminar on Production Economics*, IGLS, Austria.

Lawrence, J. J. (1999). Use of mathematical modelling to give your TPM implementation effort an extra boost. *Journal of Quality in Maintenance Engineering, 5*(1), 62-69.

Lee, W.-R., Beruvides, M. G., & Chiu, Y. D. (2007). A study on the quality-productivity relationship and its verification in manufacturing industries, *Engineering Economist*. Retrieved August 16, 2011, from http://findarticles.com/p/articles/mi_6713/is_2_52/ai_n29359095/pg_6/

Lenzerini, M., (2002). Data integration: A theoretical perspective. *PODS*, 233-246.

Lingle, J. H., & Schiemann, W. A. (1996). From balanced scorecard to strategy gauge: Is measurement worth it? *Management Review*, (March), 56-62.

Liyanage, J. P., & Kumar, U. (2000). Measuring maintenance process performance using the balanced scorecard. Proceedings of *15th European Maintenance Conference (Euromaintenance 2000)*, Gothenburg, March 7-9, 25-32.

Liyanage, J. P., & Kumar, U. (2003). Towards a value-based view on operations and maintenance performance management. *Journal of Quality in Maintenance Engineering, 9*(4), 333-350.

Ljungberg, O. (1998). Measurement of overall equipment effectiveness as a basis for TPM activities. *International Journal of Operations and Production Management, 18*(5), 495-507.

Lonsdale, C., & Cox, A. (1998). *Outsourcing: A business guide to risk management tools and technique*. Boston, USA: Earlsgate Press.

Luce, S. (1999). Choice criteria in conditional preventive maintenance: Short paper. *Mechanical Systems and Signal Processing, 13*(1), 163-168.

Luxhoj, J. T., Riis, J. O., & Thorsteinsson, U. (1997). Trends and perspectives in industrial maintenance management. *Journal of Manufacturing Systems, 16*(6), 437-453.

Lyly-Yrjänäinen, J., Lahikainen, T., & Paranko, J. (2004). Cost effect of component commonality: Pros and cons of an innovation. Paper presented at the *Thirteenth International Working Seminar on Production Economics*, Congress Igls, Igls/Innsbruck.

Lynch, R. L., & Cross, K. F. (1991). *Measure up – The essential guide to measuring business performance*. London: Mandarin.

MACC (2010, 2011). *Malaysian Anti-Corruption Commission: Annual reports*. Retrieved April 11, 2012, from http://www.sprm.gov.my/

Madu, C. N. (2000). Competing through maintenance strategies. *International Journal of Quality and Reliability Maintenance, 17*(9), 937-948.

Maggard, B. N., & Rhyne, D. M. (1992). Total productive maintenance: A timely integration of production and maintenance. *Production and Inventory Management Journal, 33*(4), 6-10.

Malhotra, M. K., & Grover, V. (1998). An assessment of survey research in POM: From constructs to theory. *Journal of Operations Management*, *16*, 407-425.

Markeset, T., & Kumar, U. (2004). Dimensioning of product support: Issues, challenges, and opportunities. Paper presented at the *Reliability and Maintainability – RAMS Symposium*.

Mather, D. (2008). *Asset resource planning*. New York, NY: Industrial Press Inc.

Mayo, E. (1933 & 2001). *The human problems of an industrial civilization: Early sociology of management and organizations*. Vancouver, BC, Canada: Routledge.

McCutcheon, D. M., & Meredith, J. R. (1993). Conducting case study research in operations management. *Journal of Operations Management, 11*(3), 239-256.

McKone, K., & Wiess, E. (1998). TPM: Planned and autonomous maintenance: Bridging the gap between practice and research. *Production and Operations Management, 7*(4), 335-351.

McKone, K. E., Roger, G. S., & Kristy, O. C. (1999). Total productive maintenance: A contextual view. *Journal of Operations Management, 17*(2), 123-144.

McKone, K. E., Schroeder, R. G., & Cua, K. O. (2001). The impact of total productive maintenance practices on manufacturing performance. *Journal of Operations Management*, *19*(1), 39-58.

Meredith, J. R., Raturi, A., Amoako-Gyampaeh, K., & Kaplan, B. (1989). Alternative research paradigms in operations. *Journal of Operations Management, 8*(4), 297-326.

Meyer, M. W., & Gupta, V. (1994). The performance paradox. In B. M. Straw, & L. L. Cummings (Eds.), *Research in organizational behaviour*. Greenwich, CT: JAL Press.

MIDA (2011). *Investment profile Malaysia*, *prepared under the auspices of the Malaysian Investment Development Authority*. Retrieved December 31, 2011, from www.mida.gov.my

MIER (2009, 2010, 2011). *Malaysian Institute of Economic Research (MIER) – Outlook for 2012*. Retrieved December 31, 2011, from http://www.mier.org.my/outlook/

Miller, J. G., & Vollmann, T. E. (1985). The hidden factory. *Harvard Business Review*, *September/October*, 142-150.

MIM (2009). *Malaysian Institute of Management*. Retrieved April 11, 2011, from http://www.mim.org.my/

Mintzberg, H. (1978). Patterns in strategy formulation. *Management Science*, *24*(9), 934-948.

Mishra, P. R., Anand, D., & Kodali, R. (2006). Development of a framework for world-class maintenance systems. *Journal of Advanced Manufacturing Systems, 5*(2), 141-165.

Mishra, R. P., Anand, G., & Kodali, R. (2007). An AHP model for quantification of benefits of world-class maintenance systems. *International Journal of Industrial and Systems Engineering*, *2*(2), 166-194.

Mobley, K. R. (2011). *Business Excellence and Reliability, Life Cycle Engineering in Charleston, S. C. E.* Retrieved December 19, 2011, from http://www.lce.com/R_Keith_Mobleys_Introduction_to_Reflections_on_Excellence_383-item.html

Monden, Y. (1993). *Toyota production system: An integrated approach to just-in-time.* Norcross, GA: Industrial Engineering and Management Press.

Mongana Report (1955). *MONGANA Report, Volume 1 and 2: Coopérative des Producteurs et exportateurs de l'huile de palme du Congo Belge*.

Moubray, J. (1991). *Reliability centered maintenance*. Oxford: Butterworth and Heinemann.

Moubray, J. (2000). FLM to select suitable maintenance strategy in process industries using MISO model. *Journal of Quality in Maintenance Engineering, 11*(4), 359-374

Moubray, J. (2003). *21st century maintenance organization: Part I – The asset management model, Maintenance Technology*. Barrington, IL: Applied Technology Publications.

Mouzas, S. (2006). Efficiency versus effectiveness in business networks. *Journal of Business Research, 59*(10/11), 1124-1132.

MPOA (2011). Retrieved December 31, 2011, from http://www.mpoa.org.my/v2/index.php

MPOB (2004b). Palm Oil Update. January 2004. 24. *MPOB, Bangi*, 63 pp. Retrieved from: http://mpob.gov.my/en/component/content/article/114/404-group-members

MPOB (2005). Retrieved July 13, 2011, from http://www.mpob.org.my

Malaysia Palm Oil Council (MPOC) (2007a). *Sustainable palm oil – for profit, people and the planet*. Retrieved July 13, 2011, from http://www.malaysiapalmoil.org/life/practices.asp.

MPOB (2008). Review of the Malaysian palm oil industry. *MPOB, Bangi*. Retrieved July 13, 2011, from http://mpob.gov.my/en/component/content/article/114/404-group-members

MPOB (2008, 2009, 2010). Retrieved July 13, 2011, from http://www.mpob.org.my

Malaysian Palm Oil Council (MPOC) (2010). *The palm oil*. Retrieved July 13, 2011, from http://www.mpoc.org.my/main_palmoil_01.asp.

Murray, M., Fletcher, K., Kennedy, J., Kohler, P., Chambers, J., & Ledwidge, T. (1996). Capability assurance: A generic model of maintenance. Proceedings of *2nd International Conference of Maintenance Societies*, Melbourne, Australia 1-5.

Nakajima, S. (1988). *Introduction to total productive maintenance (TPM)*. Cambridge, MA: Productivity Press.

Nakajima, S. (1989). *TPM development program: Implementing total productive maintenance*. Portland, OR: Productivity Press.

Neely, A., & Austin, R. (2002). Measuring performance: the operations perspective. In A. Neely (Ed.), *Business performance measurement*. Cambridge: Cambridge University Press.

Neely, A., Gregory, M., & Plats, K. (1995). Realizing strategy through measurement. *International Journal of Operations and Production Management, 14*(3), 140-153.

Neely, A., Adams, C., & Crowe, P. (2001). The performance prism in practice. *Measuring Business Excellence*, *5*(2), 6-11.

Neely, A., Adams, C., & Kennerley, M. (2002). *The performance prism*. Englewood Cliffs, NJ: Prentice-Hall.

Neely, A. D., Mills, J., Platts, K. Gregory, M., & Richards, H. (1994). Realising strategy through measurement. *International Journal of Operations and Production Management, 14*(3), 140-152.

Neely, A. D. (1998). *Measuring business performance: Why, what and how*. London: The Economist Books.

Neely, A. D., Mills, J. F., Gregory, M. J., Richards, A. H., Platts, K. W., & Bourne, M. C. S. (1996). *Getting the measure of your business*. London: Findlay.

Neste Oil (2008). *NExBTL diesel, raw materials*. Retrieved August 16, 2011, from http://www.nesteoil.com/

Niebel, B. (1985). *Engineering maintenance management*. New York, NY: Marcel Dekker.

Nikander, S. (2008). Greenhouse gas and energy intensity of product chain: Case transport fuel. *Unpublished Master thesis*. Helsinki University of Technology, Finland.

Noon, M., Jenkins, S., & Lucio, M. M. (2000). FADS, techniques and control: The competing agendas of TPM and Tecax at the Royal Mail (UK). *Journal of Management Studies, 37*(4), 499-519.

O'Donoghue, T., & Punch K. (2003). *Qualitative educational research in action: Doing and reflecting*. Vancouver, BC, Canada: Routledge, p.78.

O'Leary, Z. (2004). *The essential guide to doing research*. Thousand Oaks, CA: SAGA Publications Limited.

Oh, E. (2004). Sustainable palm oil production. *The Star Online, Bizweek (November 20, 2004)*, 1-4.

Oke, S.A. (2005). An analytical model for the optimisation of maintenance profitability. *International Journal of Productivity and Performance Management, 54*(2), 113-136.

Ollila, A., & Malmipuro, M. (1999). Maintenance has a role in quality. *The TQM Magazine, 11*(1), 17-21.

Olve, N., Roy, J., & Wetter, M. (1999). *Performance drivers: A practical guide to using the balanced scorecard*. UK: John Wiley and Sons.

OPIEJ (2002). *Oil Palm Industry Economic Journal*, 2(2).

Otley, D. (1998). Performance management, a framework for management accounting research. *Management Accounting Research Group Conference*, Aston, Birmingham, September.

Ozcan, Y. A. (2008). *Health care benchmarking and performance evaluation: An assessment using data envelopment analysis (DEA)*. New York, NY: Springer Science+ Business Media.

Palm Oil Industrial Cluster (POIC) (2008). *Malaysian palm oil biodiesel export market*. Retrieved February 22, 2011, from http://www.etawau.com.

Panapanaan, P., Helin, T., Kujanpää, M., Soukka, R., Heinimö, J., & Linnanen, L. (2009). *Sustainability of palm oil production and opportunities for Finnish technology and know-how transfer, Research Report 1*. Lappeenranta, Finland: LUT Energy, Lappeenranta University of Technology.

Patterson, J. W., Kennedy, W. J., & Fredendall, L. D. (1995). Total productive maintenance is not for this company. *Production and Inventory Management Journal, 36*(2), 61-64.

Patterson, J. W., Fredendall, D. L., Kennedy, W. J., & McGee, A. (1996). Adapting total productive maintenance to Asten, Inc. *Production and Inventory Management Journal*, *37*(4), 32-37.

Pearson, G. J. (1985). The strategic discount, John Wiley and Sons. The Theory of the Business. *Harvard Business Review, September-October*, 119-128.

Pintelon, L., & Gelders, L. (1992). Maintenance management decision making. *European Journal of Operational Research, 58*, 301-317.

Pintelon, L., & Puyvelde, F. V. (1997). Maintenance performance reporting systems: Some experiences. *Journal of Quality in Maintenance Engineering, 3*(1), 4-15.

Pintelon, L., Gelders, L., & VanPuyvelde, F. (2000). *Maintenance management*. Leuven: Uitgeverij Acco.

Pintelon, L., Pinjala, S. K., Vereecke, A. (2006). Evaluating the effectiveness of maintenance strategies. *Journal of Quality in Maintenance Engineering*, *12*(1), 7-20.

Poku, K. (2002). Small-scale palm oil processing in Africa, *FAO Agriculture Services Bulletin 148*. Retrieved May 1, 2011, from http://www.fao.org/docrep/005/ Y4355E/y4355e00.htm

Post, F. H., Nielson, G. N., & Bonneau, G. P. (2002). Data visualization: The state of the art. *Proceedings of the 4th Dagstuhl Seminar on Scientific Visualization*, Research paper TU delft, 2002.

Potter, C. (2006). Psychology and the art of program evaluation. *South African Journal of Psychology, 36*(1), 82-102.

Pride, D. (2006). Oil palm land schemes alleviating rural poverty, *Palm Oil Truth Foundation*. Retrieved March 18, 2011, from http://www.palmoiltruthfoundation .com

Pramod, V. R., Devadasan, S. R., & Jagathy Raj, V. P. (2007). Receptivity analysis of TPM among internal customers. *International Journal of Technology, Policy, and Management, 7*(1), 75-88.

Quinn, J. B., & Hilmer, F. G. (1994). Strategic outsourcing. *Sloan Management Review, 35*, 43-55.

Rao, T. (2006). *Successful CDM projects in Malaysia*. Kuala Lumpur, Malaysia: Danish Management Group.

Ramachandran, H. (2005). *Biodiesel set to ignite palm oil's prospects press release for business times*. Malaysia: National Economic Action Council.

Raouf, A. (1994). Improving capital productivity through maintenance. *International Journal of Operations and Production Management, 14*(7), 44-52.

Ravishankar, G., Burczak, C., & Vore, R. D. (1992). Competitive manufacturing through total productive maintenance, *Semiconductor Manufacturing Science Symposium (ISMSS 1992)*, IEEE/SEMI International, 15-16 June, 85-89.

Reed, R., & DeFillippi, R. J. (1990). Causal ambiguity, barriers to imitation, and sustainable competitive advantage. *Academy of Management Review, 15*(1), 88-102.

Rhyne, D. M. (1990). Total plant performance advantages through total productive maintenance. *Journal of Applied Sciences, 5*(5), 938-951, 2005.

Richardson, P. R., & Gordon, J. R. M. (1980). Measuring total manufacturing performance. *Sloan Management Review*, *Winter*, 47-58.

Riis, J. T., & Thorsteinsson, U. (1997). A situational maintenance model. *International Journal of Quality and Reliability Management, 14*(4), 349-366.

Ritzer, G. (2000). *The McDonaldization of society (3rd ed.)*. Thousand Oaks, CA: Sage Publications Inc.

Robinson, C. J., & Ginder, A. P. (1995). *Implementing TPM: The North American experience.* Portland, OR: Productivity Inc.

Rossi, P. H., Lipsey, M. W., & Freeman, H. E. (2004). *Evaluation: A systematic approach (7th ed.).* Thousand Oaks: Sage.

Round Table on Sustainable Palm Oil FACT SHEET (2012), pp. 3-4, retrieved from: http://www.rspo.org/sites/default/files/RSPOFACTSHEETFINALRT91.pdf

Russell, C. (2001). Shovel maintenance gains from improved designs. *Tools and Techniques, 106*(8), S7.

Sangameshwran, P., & Jagannathan, R. (2002). Eight pillars of TPM. *Indian Management, 11,* 36-37.

Scarf, P. S. (1997). On the application of mathematical models to maintenance. *European Journal of Operations Research, 63*, 493-506.

Schmenner, R. W. (1988). Escaping the black holes of cost accounting. *Business Horizons, January-February*, 66-72.

Schmenner, R. W., & Swink, M. L. (1998). On theory in operations management. *Journal of Operations Management, 17*(1), 97-113.

Schmidt, J. (2007). Life cycle assessment of rapeseed oil and palm oil. *Unpublished PhD dissertation*, Ålborg University, Denmark.

Schönberger, L. (1986). *World class manufacturing: The lessons of simplicity applied*. New York, NY: The Free Press.

Schuchardt, F., Darnoko, D., Herawan, T., Erwinsyah, & Gurintno, P. (2001). Use of empty fruit bunch from oil palm for compost production and waste water drying. *Workshop on the Environment of Oil Palm*, 19-20 June 2001. Medan, Indonesia.

Schuman, C. A., & Brent, A. C. (2005). Asset life cycle management: Towards improving physical asset performance in the process industry. *International Journal of Operations and Production Management, 25*(6), 566-579.

Scudder, G. D., & Hill, C. A. (1998) A review and classification of empirical research in operations management. *Journal of Operations Management 16,* 91-101.

Seng, O. Y., Jantan, M., & Ramayah, T. (2005). Implementing total productive maintenance (TPM) in Malaysian manufacturing organization: An operational strategy study. *The ICFAI Journal of Operations Management, IV*(2), 53-62.

Seth, D., & Tripathi, D. (2005). Relationship between TQM and TPM implementation factors and business performance of manufacturing industry in Indian context. *International Journal of Quality and Reliability Management, 22*(2/3), 256-277.

Shamsuddin, A., Hassan, M. H., & Zahari, T. (2005). TPM can go beyond maintenance: Excerpt from a case implementation. *Journal of Quality in Maintenance Engineering, 11*(1), 19-42.

Shamsuddin, A., Hassan, M. H., & Zahari, T. (2004). State of implementation of TPM in SMIs Malaysia. *Journal of Quality in Maintenance Engineering, 10*(2), 93-106.

Sharma, R. K., Kumar, D., & Kumar, P. (2005). FLM to select suitable maintenance strategy in process industries using MISO model. *Journal of Quality in Maintenance Engineering, 11*(4), 359-374.

Shirose, K. (1995). *TPM team guide*. Portland, OR: Productivity Press.

Sheu, C., & Krajewski, L. J. (1994). A decision model for corrective maintenance. *International Journal of Production Research, 32*(6), 1365-1382.

Sheu, D. D. (2006). Overall input efficiency and total equipment efficiency. *IEEE Transactions on Semiconductor Manufacturing*, *19*(4), 496-501.

Shirkie, R., & Ji, S. C. (1983). *Oil upon the waters: Palm oil wastes in Malaysia*. Ottawa, Canada: IDRC Publication.

Simeh, M. A., & Kamarudin, M. F. (2009). An overview of Malaysian palm oil market share in selected markets. *Oil Palm Industry Economic Journal*, *9*(1)/2009.

Sievänen, M., Suomala, P., & Paranko, J. (2001). Activity-based costing and product profitability. Paper presented at the *5th International Seminar on Manufacturing Accounting Research*, Pisa, Italy.

Sivasothy, K., Basiron, Y., Anhar, S., Ramli, T., Tan, H., & Mohammad, S. (2006). Continuous sterilization: The new paradigm for modernizing palm oil milling. *Journal of Oil Palm Research,* (Special Issue - April 2006), 144-152.

Smith, G. (2006). Palm oil: Deforestation diesel, *Wren Media and the New Agriculturalist*. Retrieved March 17, 2011, from http://www.new-ag.info/06-6/focuson/focuson6.html.

Skinner, W. (1969). Manufacturing – missing link in corporate strategy. *Harvard Business Review*, *47*(3), 136-145.

Skinner, W. (1974). The decline, fall, and renewal of manufacturing. *Industrial Engineering*, 32-38.

Slack, N., & Lewis, M. (2008). *Operations strategy*. Harlow: Pearson Education Ltd.

Slack, N., Chambers, S., Harland, C., Harrison, A., & Johnston, R. (1995). *Operations management*. London: Pitman.

SME News (2010). Retrieved April 11, 2011, from http://www.malaysiasme.com.my/index.php/SME-News

Söderholm, P., Holmgren, M., & Klefsjö, B. (2007). A process view of maintenance and its stakeholders. *Journal of Quality in Maintenance Engineering*, *13*(1), 19-32.

Sord, B. H., & Welsch, G. A. (1962). *A survey of management planning and control practices*. New York, NY: Controllership Foundation.

Star (2011). Retrieved November 22, 2011 from http://biz.thestar.com.my/news/story.asp?file=/2011/11/22/

Stevenson, W. (1996). *Productions/Operations Management (5th ed.)*. Scarborough, Canada: Irwin Publishing Company.

Suito, K. (1998). Total productivity management. *Work Study, 47*(4), 117-127.

Swamidass, P. M. (1991). Empirical science: New frontier in operations management research. *Academy of Management Review, 16*(4), 793-814.

Swanson, L. (2001). Linking maintenance strategies to performance. *International Journal of Production Economics, 70*(3), 237-244.

Swanson, L. (2003). An information-processing model of maintenance management. *International Journal of Production Economics*, *83*(1), 45-64.

Tan, K. T. (2007). Palm oil: Addressing issues and towards sustainable development, *Renew Sustain Energy Review*. doi:10.1016/j.rser.2007.10.001.

Taneja, S., Pryor, M. G., & Toombs, L. A. (2011). Frederick W. Taylor's scientific management principles: Relevance and validity. *Journal of Applied Management and Entrepreneurship, 16*(3), 60-78.

Taneja, S., Pryor, M. G., Humpheries, J. H., & Toombs, L. A. (2011). Where are the new organization theories? Evolution, development and theoretical debate. *International Journal of Management, 28*(3), 959-978.

Tajiri, M., & Gotoh, F. (1992). *TPM implementation*. New York, NY: McGraw-Hill.

Taud, R., & Scheidel M. (2004). *Use and experience with gas turbine on-line diagnostics.* Barcelona, Spain: Power Gen Europe.

Taylor, F. W. (1903). *Shop management*. New York, NY: Harper & Brothers.

Taylor, F. W. (1911). *The principles of scientific management*. New York, NY: Harper & Brothers.

Taylor, J. C., & Felten, D. F. (1993). *Performance by design: Socio-technical systems in North America*. Englewood Cliffs, NJ: Prentice Hall.

Teoh, C. H. (2002). *The palm oil industry in Malaysia – From seed to frying pan*. Selangor, Malaysia: WWF-Switzerland.

Teresko, J. (1992). Time bomb or profit center? *Industry Week, 241*(3), 52-57.

Tripathi, D. (2005). Influence of experience and collaboration on effectiveness of quality management practices: The case of Indian manufacturing. *International Journal of Productivity and Performance Management, 54*(1), 23-33.

Thomas, R. (2005). *Reliability practices – Dofasco document*. Ontario, Canada: Ivara Corporation.

Timme, S. G., & Christine, T. (2003). The real cost of holding inventory. *Supply Chain Management Review*, (July/August), 31-37.

Toomey, G. (2006). Harnessing the power of maintenance. *Power Engineering, 110*(3), 42-49.

Tsang, A. (1995). Condition-based maintenance: Tools and decision making. *Journal of Quality in Maintenance Engineering, 1*(3), 3-17.

Tsang, H. C. A. (1998). A strategic approach to managing maintenance performance. *Journal of Quality in Maintenance Engineering, 4*(2), 87-94.

Tsang, A. H. C., Jardine, A. K. S., & Kolodny, H. (1999). Measuring maintenance performance: A holistic approach. *International Journal of Operations and Production Management, 19*(7), 691-715.

Tsang, A. H. C., & Chan, P. K. (2000). TPM implementation in China: A case study. *International Journal of Quality and Reliability Management, 17*(2), 144-157.

Tsang, H. C. A. (2002). Strategic dimensions of maintenance management. *Journal of Quality in Maintenance Engineering, 8*(1), 7-39.

Tsarouhas, P. (2007). Implementation of total productive maintenance in food industry: A case study. *Journal of Quality in Maintenance Engineering, 13*(1), 5-18.

Tsuchiya, S. (1992). *Quality maintenance: Zero defects through equipment management*. Portland, OR: Productivity Press.

Turney, P. B. B., & Anderson, B. (1989). Accounting for continuous improvement. *Sloan Management Review*, (Winter), 37-47.

USDOE/GO-102006-2267 (2006). *Industrial Technologies Program Energy Efficiency and Renewable Energy*, U.S. Department of Energy Washington, DC 20585-0121. Retrieved April 11, 2011, from www.eere.energy.gov/industry

United States Department of Agriculture (USDA) (2007). *Commodity intelligence report 2008*. Retrieved April 11, 2011, from http://www.pecad.fas.usda.gov/highlights/2007/12/Indonesia_palmoil/

United States Department of Agriculture (USDA) (2010). *Indonesia: palm oil production prospects continue to grow*. Retrieved December 29, 2011, from http://www.pecad.fas.usda.gov/highlights/2010/12/Indonesia_palmoil/

Valdez-Flores, C., & Feldman, R. M. (1989). A survey of preventive maintenance models for stochastically deteriorating single unit systems. *Naval Research Logistics Quarterly, 36,* 46-419.

Van Noortwijk, J. A., Dekker, R., Cook, R. M., & Mazucchi, T. A. (2002). On the use of expert opinion for maintenance optimization, *IEEE Transactions on Reliability, 41*(1992), 427-432.

Venkatesh, J. (2006). An introduction to total productive maintenance. *Malaysia Labour Review 2009*, *3*(2), 47-62.

Vickery, S. K. (1991). A theory of production competence revisited. *Decision Sciences, 22*(3), 635-643.

Vindevogel, B., Dirk V. P., & Wets, G. (2005). Why promotion strategies based on market basket analysis do not work? *Expert Systems with Applications, 28*(3), 583-590.

Vineyard, M., Amoako-Gyampah, K., & Meredith, J. (2000). An evaluation of maintenance policies for flexible manufacturing systems: A case study. *International Journal of Operations and Production Management, 20*(4), 409-426.

Wahid, M. B., Chan Kook Weng, C. K., & Masri, R. (2009). Palm oil: Nature's gift to Malaysia and Malaysia's gift to the world oil palm industry, *Economic Journal*, *9*(1)/2009.

Ward, P. (1997). Investing in tomorrow's company, The Foundation for Performance Measurement UK Meeting, 12 March, *International Journal Business Performance Management, 5*(1), 1-24.

Waeyenbergh, G., & Pintelon, L. (2002). A framework for maintenance concept development. *International Journal of Production Economics, 77*(3), 299-313.

Watson, K. J., Blackstone, J. H., & Gardiner, S. C. (2007). The evolution of a management philosophy: The theory of constraints. *Journal of Operations Management, 25*(2), 387-402.

Wan Asma, I., Mahanim, S., Zulkifli, H., Othman S., & Mori, Y. (2010). *Malaysian Oil Palm Biomass Regional Workshop on UNEP/DTIE/IETC*, 2-5 March 2010, Osaka, Japan. Retrieved April 2011, from http://gec.jp/gec/en/Activities/FY2009/ietc/wab/wab_day2-3.pdf

Weber, A., & Thomas, R. (2005). *Measuring and managing the maintenance function, reliability practices Dofasco*. Ontario, Canada: Ivara Corporation.

Westbrook, R. (1994). Priority management: a new theory for operations management. *International Journal of Operations and Production Management, 14*(6), 4-24.

White-Paper (2010). *Corporate Social Responsibility Report, Embassy of Norway in KL, Malaysia*. Retrieved June 3, 2011, from http://www.norway.org.my/News_and_events/Business/Bedriftenes-Samfunnsansvar/

Willmott, P. (1994). Total quality with teeth. *The TQM Magazine, 6*(4), 48-50.

Williamson, R. M. (2001). TPM: An often misunderstood equipment improvement strategy, *Maintenance Technology Magazine*. Retrieved June 20, 2011, from http://www.mtonline.com/current/04-00tpm2.html

Wireman, T. (1990). *World class maintenance management*. New York, NY: Industrial Press.

Wireman, T. (1991). *Total productive maintenance: An American approach*. New York, NY: Industrial Press.

Wireman, T. (2003). *Benchmarking best practices in maintenance management*. New York, NY: Industrial Press.

Wireman, T. (2004). *Benchmarking best practices in maintenance management Performance*. New York, NY: Industrial Press.

Womack, J. P., Jones, D. T., & Roos, D. (1990). *The machine that changed the world*. New York, NY: Rawson Associates.

Wouters, M., & Sportel, M. (2005). The role of existing measures in developing and implementing performance measurement systems. *International Journal of Operations and Production Management*, *25*(11), 1062-1082.

Wren, D. A. (2004). *The evolution of management thought (5th ed.)*. New York: John Wiley and Sons.

Wu, H., Liu, Y., Ding, Y., & Liu, F. (2004). Methods to reduce direct maintenance cost for commercial aircraft. *Aircraft Engineering and Aerospace Technology, 76*(1), 118.

Yam, R. C. M., Tse, P., Ling, L., & Fung, F. (2000). Enhancement of maintenance management through benchmarking. *Journal of Quality in Maintenance Engineering*, *6*(4), 224-240.

Yamashina, H. (1995). Japanese manufacturing strategy and the role of total productive maintenance. *Journal of Quality in Maintenance Engineering, 1*(1), 27-38.

Yang, Y., Liang, S., & Danyluk, S. (1999). Application of a specialized capacitance probe in bearing diagnosis. *Wear*, *225*(2), 1215-1221.

York C. (2003). Paper Presented at IMC-2003 the *18th International Maintenance Conference*, Netexpress Inc., York, PA. Retrieved on 28 August 2010 from http://www.reliabilityweb.com/art04/zeiler.pdf

Yusoff, S., & Hansen, S. (2007). Feasibility study of performing a life cycle assessment on crude palm oil production in Malaysia. *International Journal of Life Cycle Assessment 12*(1), 50-58.

Appendix - A

SURVEY QUESTIONNAIRE for Malaysian palm oil mills (Part One)

Mill: Name, Address, Phone, Email:
____

Contact Person's Name, Position:
____

Mill's Capacity (FFB t/h) – Approved Capacity: _________ **Installed Capacity:** _______**Year mill started:** _________

Shift Structure: Days/week ___ Shifts/day ___ Hours/shift ____ Breaks/shift ___ Planned maintenance/shift ______

Maintenance Department Information - please put 'X' in the applicable box

Maintenance workforce fulltime: Skilled ___________**Semi-skilled** _________ **Planner (in office)** _____________

Maintenance strategy practiced at your mill (Legend in foot note): **BDM**☐ **PM**☐ **TPM**☐ **RCM**☐ **CBM**☐

EFB - Do you recycle your empty fruit bunches: Yes☐ No☐ **Does your mill operates on single line or more:** ___

Name mill equipment that is contracted out for preventive maintenance (PM): _____________________________

Name equipment that you have extra as 'stand by' for emergency use, such as turbine, boiler, Vibrating Screens, Separator, Press & Digester, etc:
____

Part Two - Historical data collection: This part is to provide data on Maintenance Inputs for the **'Financial Year 2010'** and will be utilized: To calculate overall equipment effectiveness (OEE) for the 'Crude Palm Oil' (CPO) overall extraction process, for complete 'Palm Oil Mill Sector; and assessment of POME disposal practices under Department of Environment regulations.

Figures on Maintenance yearly Inputs (Cost in Ringgits), CPO Production (Tons), Equipment Downtime (Hours), and Mill Effluent (POME) Generated & Treated (Tons) - Figures for the Financial Year 2010		
#	**Input Category Description**	Figures for the **Financial Year 2010**
1	Labour - Maintenance Workforce only (cost in Ringgits)	
2	Spares parts, Materials & Tools (cost in Ringgits)	
3	Maintenance Work Contracted out (cost in Ringgits)	
4	FFB Processed in the year 2010 (Tons)	
5	CPO Produced in the year 2010 (Tons)	
6	Out of spec CPO sold at Discount rate in 2010 (Tons)	
7	Slush oil produced in the year 2010 (Tons)	
8	Total Mill Hours Worked in the year 2010	
9	Total Mill Down Time in hours in the year 2010	
10	Mill Effluent (POME) produced in the year 2010 (Tons)	
11	Mill Effluent (POME) treated in the year 2010 (Tons)	

Comments:
____

Appendix - B

SURVEY QUESTIONNAIRE – Head Offices palm Oil Mills **Part One**

Head Office: Telephone Number _________________ Contact Person _________________ Email address ____________________

Name, Address, Phone, & email:
Mill#1____

Mill #2 ____

Mill's Capacity (FFB t/h): Mill #1________ Mill #2________Year started production: Mill #1 _____________ Mill #2 _____________

Shift Structure: Days/week _______ Shifts/day ______ Hours/shift ______ Breaks/shift _____ Planned maintenance/shift _______

Maintenance Department Information - please put 'X' in the applicable box

Maintenance workforce fulltime: Skilled _______________Semi-skilled ________________ Planner (in office) _______________

Maintenance strategy practiced at your mill (Legend in foot note): **BDM**☐ **PM**☐ **TPM**☐ **RCM**☐ **CBM**☐

EFB - Do you recycle your empty fruit bunches: Yes☐ No ☐ **Does your mill operates on single line or more:** _____________

Name mill equipment that is contracted out for preventive maintenance (PM): ____

Name equipment that you have extra as 'stand by', such as turbine, boiler, Vibrating Screens, Separator, Press & Digester, etc:

____

Part Two - Historical data collection: This part is to provide data on Maintenance Inputs for the **'Financial Year 2010'** and will be utilized: To calculate overall equipment effectiveness (OEE) for the 'Crude Palm Oil' (CPO) overall extraction process, for complete 'Palm Oil Mill Sector; and assessment of POME disposal practices under Department of Environment regulations.

Figures on Maintenance yearly Inputs (Cost in Ringgits), CPO Production (Tons), Equipment Downtime (Hours), and POME Generated & Treated (Tons) - Figures for the Financial Year 2010

#	Input Category	Mill # 1	Mill # 2
1	Labour - Maintenance only (cost in Ringgits)		
2	Spares parts, Materials & Tools (cost in Ringgits)		
3	Maintenance Work Contracted out (cost in Ringgits)		
4	FFB Processed in the year 2010 (Tons)		
5	CPO Produced in the year 2010 (Tons)		
6	Out of spec CPO sold at Discount rate in 2010 (Tons)		
7	Slush oil produced in the year 2010 (Tons)		
8	Total Mill Hours Worked in the year 2010		
9	Total Mill Down Time in hours in the year 2010		
10	Mill Effluent (POME) produced in the year 2010 (Tons)		
11	Mill Effluent (POME) treated in the year 2010 (Tons)		

Note: In case you do not keep separate record for the items, please report them in consolidated form

Comments:

____

COB COLLEGE OF BUSINESS SINTOK MALAYSIA	**UNIVERSITI UTARA MALAYSIA** COB – School of Technology Management & Logistics 06010 - Sintok, Kedah, Malaysia

Appendix - C

1 December, 2011

The Manager Palm Oil Mill

I am a PhD candidate at the Universiti Utara Malaysia. Presently, I am in the process of collecting data for my research project, in field of 'Technology Management'. Information about me, my supervisors, and a 'Non-Disclosure Agreement' statement is given below.

Research Title: "Maintenance Management Performance Evaluation: A Study of Malaysian Palm Oil Mills"

Researcher: Nazim Baluch, student # 92963, (H/P 012-460-2713 nazimbaluch@gmail.com) Mailing Address: J-108 Maybank Residence, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia

Supervisors: Prof. Ir. Dr. Che Sobry bin Abdullah and Assoc. Prof. Dr. Shahimi bin Mohtar

Non-Disclosure Agreement

This research project guarantees respondent confidentiality. Information being solicited through this survey questionnaire is for research purpose only. All of your responses will be kept strictly confidential, reported only in aggregate and used only for research purposes. The researcher will not use the disclosed confidential information of the company in a manner that either confers commercial benefit on the receiving party or places the disclosing party at a commercial disadvantage. Your personal information will not be sold or traded to anyone.

Orientation: The one-page questionnaire comprises of two parts

Part one pertains to background information of the responding organisation and general information of its maintenance department and Part two pertains to historical data collection for the financial year 2010: Maintenance Inputs, to be reported in Malaysian Ringgits and CPO production to be reported in tons; mill effluent (POME) production & treatment in tons; and Mill's downtime in hours.

Please fill the, enclosed, one-page 'SURVEY QUESTIONNAIRE FORM' and send it back to me in postage paid self addressed envelope enclosed, or a scanned copy of it by email.

Thank you for your cooperation

Nazim Baluch

COB COLLEGE OF BUSINESS SINTOK MALAYSIA	**UNIVERSITI UTARA MALAYSIA** College of Business – Technology Management 06010 - Sintok, Kedah, Malaysia

Appendix - D

September 4, 2011 **PLEASE KEEP THIS PAGE FOR YOUR RECORD**

In-Charge Corporate Communications

I am a PhD research student at the Universiti Utara Malaysia. Presently, I am in the process of collecting data for my research project, in field of 'Technology Management'.

For your records: My particulars; Information about my supervisors; and a 'Non-Disclosure Agreement' statement is provided below.

Research Title: "Maintenance Management Performance Evaluation: A Study of Malaysian Palm Oil Mills"

Researcher: Nazim Baluch, student # 92963, (H/P 012-460-2713, nazimbaluch@gmail.com) Mailing Address: Maybank Residence # J-108, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia

Supervisors: Prof. Ir. Dr. Che Sobry bin Abdullah and Assoc. Prof. Dr. Shahimi bin Mohtar

Non-Disclosure Agreement

This research project guarantees respondent confidentiality. Information being solicited through this survey questionnaire is for research purpose only. All of your responses will be kept strictly confidential, reported only in aggregate and used only for research purposes. The researcher will not use the disclosed confidential information of the company in a manner that either confers commercial benefit on the receiving party or places the disclosing party at a commercial disadvantage. Your personal information will not be sold or traded to anyone.

Orientation: The two-page questionnaire comprises of two parts

Part one pertains to background information of the responding organisation and general information of its maintenance department and Part two pertains to historical data collection for the financial year 2010: Maintenance Inputs, to be reported in Malaysian Ringgits and CPO production to be reported in tons; POME production & treatment in tons; and Mill's downtime in hours. You may copy the questionnaire to accommodate info on the number of mills being reported

Please provide information, at random, for two of your mills, by filling the, enclosed, two-page 'SURVEY QUESTIONNAIRE FORM' and mail it back in the addressed & postage paid envelop provided; I will be glad to share the findings of my research with you, if you so desire.

Thank you for your cooperation

Nazim Baluch

Pilot Study Observations and Notes **Appendix - E**

Mills participated in the Pilot Study

I. Kuala Lumpur Kepong Bhd., KKS BATU LINTANG, 09800 SERDANG, KEDAH, MALAYSIA Contact Person: Mr. Lim Chian, Mill Manager - Tel/Fax: 04-4077316

II. Taclico Company Sdn. Bhd. , Mukim Padang Meha, 09400 PADANG SERAI, KEDAH, MALAYSIA Contact Person: Ir. Lim Thuan Swee, Mill manager - Tel: 04-4855603, Fax: 04-4855366

III. United Palm Oil Industries, 878, Jalan Bandar Baru, 14300 Nibong Tebal, Pinang, Malaysia Contact Person: Mr. Beh Swee Chaik, Director Operations, Tel: 604-5931121, Fax: 604-5932218

Commonalities: Notes & Observations

1. MPOB (2010) classification of mills as per FFB tons/h processing capacity: small <15; Medium 15-60; Large >60 (SMEs <60)
2. An hour, minimum, daily is spent for boiler start-up and other adjustments
3. There are minor stoppages in all the mills but may not be recorded: 1/2 hour per shift would be minimum operational loss from minor stops
4. Mills generally worked two, 8-hour, shifts, and 6 days a week, per year
5. First hour CPO production is usually wet, excessive moisture, some mills collect is separately while others dump it in the same tank with good CPO – at the end of the day it does affect the quality
6. Average industrial use of steam is 65% of the FFB processed that ends up as mill effluent, POME
7. FFB processing capacity: approved and installed capacity is not always the same; mills may run at higher than the approved capacity
8. Some mills recover slush oil from the POME settling ponds; others release it without slush oil recovery, after the due holding time is passed
9. Average maintenance skilled and semi-skilled persons are paid RM 1500 & 1000 per month respectively
10. Mills critical equipment is, more or less, similar throughout the industry
11. All the three participants had their power generating equipment contracted out for maintenance
12. One of the Mills had high spare-parts expenditure; mills sometimes put equipment purchase under this account to avoid going through long sanction procedures of capital purchase
13. OER averaged 20% among the mills
14. One mill recycled EFBs: out of 22% of EFBs, they recovered 2% CPO; and produced dry fibre that was baled and sold at RM 28 per ton to downstream industries
15. Relations with MPOB and MPOC were indifferent; mills viewed these institutions as bureaucratic adversaries
16. All three mills were incredulous about the surveys from universities: it was waste of time for them; nothing ever came back to them that was of some benefit to the industry

List of General Palm Oil Mill Equipment

Appendix – F

1	FFB Conveyors	9	Fibre Cyclones
2	Other Conveyors	10	Boilers
3	Cranes / Hoists	11	Boiler water treatment plant
4	Sterilisers	12	ID Fan for boiler flue gases
5	Threshers / Auto feeders	13	Power Supply (Turbines)
6	Presses / Digesters	14	CPO Pumps & Pipe line system
7	Decanters / Sludge Separators	15	POME Treatment Plant
8	Vibrating Screens		

Mill ID	Year Started	Maint. Strategy Practiced	FFB Processing Capacity tons/h	Maint. Planner	Maintenance Manpower Skilled	Labour Cost in MR	Spare-parts, Material, and Tools	Maintenance Work Contracted Out	FFB Processed	CPO Produced (Good Quality)	Total Slush oil & out of spec CPO Produced	Total Mill Hours Worked	Total Mill Downtime	POME produced
1	1979	PM	28	2	6	418,355	6,802,319	52,975	120,000	25,000	1,750	4,500	700	75,000
2	1960	PM	20	1	2	191,600	453,944	973,827	76,513	16,241	1,274	4,027	649	45,907
3	1992	PM	30	2	3	114,139	719,464	125,080	67,665	14,110	2,020	2706	834	57,329
4	1972	PM	40	0	9	648,204	1,132,398	1,903,109	220,560	44,781	3,051	5873	600	143,364
5	1935	PM	40	3	6	247,120	723,477	180,869	137,120	29,700	2,654	3,640	645	97,284
6	1983	PM	30	0	4	472,560	1,007,974	308,850	102,652	19,276	1,690	4,173	680	61,591
7	1997	PM	30	0	3	100,000	1,268,307	429,695	119,757	22,534	1,693	4,133	1091	97,387
8	1981	PM	120	0	8	375,698	4,224,019	789,313	398,000	75,393	6,819	5,076	770	301,343
9	1997	PM	40	0	2	50,924	2,941,492	133,838	294,311	64,034	2,611	7,209	781	299,000
10	1983	PM	54	0	0	180,000	1,020,000	800,000	266,470	52,655	3,801	5,000	650	135,900
11	1980	PM	90	0	5	215,000	3,526,548	931,637	397,049	79,547	5,409	4,671	610	277,934
12	1963	PM	60	0	0	235,000	2,194,403	1,093,337	216,574	49,405	4,106	5,277	611	160,934
13	1970	PM	20	0	4	95,660	85,000	60,000	32,000	6,464	1,412	1764	610	20,800
14	1985	PM	30	0	11	236,280	3,990,518	105,520	109,268	23,127	2,023	3,187	891	113,297
15	1978	PM	40	3	8	70,390	1,151,445	1,016,012	137,150	28,488	2,733	3,669	600	89,148
16	1981	PM	85	0	13	400,790	1,473,681	756,246	216,430	44,554	6,124	2,550	600	140,680
17	1986	PM	54	1	6	225,000	436,000	1,231,300	302,430	57,600	3,085	5,900	630	196,580
18	1981	PM	35	2	10	358,185	971,553	433,030	118,559	24,143	2,138	3,431	629	118,559
19	1992	PM	60	0	5	114,161	2,344,274	2,067,754	205,355	42,863	3,757	4,562	681	63,946
20	2008	PM	60	0	6	122,543	155,552	1,412,707	260,380	52,176	3,882	4,357	630	169,247
21	1976	PM	54	0	6	150,000	1,452,580	691,581	188,690	40,271	3,839	3,655	600	122,649
22	1984	PM	60	0	5	272,400	1,875,020	1,500,000	227,000	43,266	3,611	6,000	630	158,900
23	1997	PM	60	0	10	160,000	1,350,000	1,240,000	225,000	42,750	3,920	4,500	720	135,000
24	2008	PM	90	1	20	1,000,000	3,800,000	300,000	400,000	84,000	5,770	6,000	800	280,000
25	1970	PM	60	1	8	303,600	3,719,550	1,061,105	299,428	59,442	3,914	5819	630	119,771
26	1975	PM	40	1	5	194,000	485,000	242,500	97,000	20,855	2,900	2,919	638	63,050
27	1995	PM	60	1	2	170,961	1,299,414	1,793,939	265,700	57917	4,035	4,467	600	198,477
28	1985	PM	54	0	5	231,000	1,350,000	1,350,000	345,910	67,671	3,249	6,406	647	224,842
29	1995	PM	60	1	3	120,000	2,244,000	897,600	214,415	44,880	3,768	5,595	696	223,581
30	2000	PM	45	1	10	165,553	1,957,350	127,324	184,716	39,147	2,861	3,915	666	98,611
31	1992	PM	35	2	2	693,525	902,835	563,575	181,996	36,635	2,114	5,119	604	170,580
32	1999	PM	60	1	5	180,000	2,337,600	888,288	221,715	46,752	3,796	4,420	620	50,994
33	1995	PM	70	0	10	212,079	2,460,728	0	394,574	82,617	4,397	5,917	624	256,473
34	1977	PM	54	1	5	99,692	180,962	182,171	179,390	38,133	4,133	5,034	720	134,558
35	1978	PM	60	2	6	123,200	1,890,000	637,146	178,945	33,534	3,574	2,983	600	116,314
36	1997	PM	60	2	8	324,000	702,000	486,000	270,000	55,000	4,467	6,000	1416	187,000
37	1995	PM	45	1	6	250,800	1,826,500	750,800	245,226	47,120	2,784	5,544	600	159,397
38	1977	PM	45	1	3	115,439	1,017,884	693,894	224,890	44,934	2,697	5,162	646	134,439
39	2005	PM	40	1	4	168,000	291,421	2,282,779	204,137	42,990	2,643	4,821	763	122,482
40	1996	PM	60	1	6	275,684	101,845	315,073	150,286	32,055	3,839	3,971	628	86,844
41	1995	PM	55	3	9	270,000	188,329	700,739	185,070	36,881	3,288	3,663	600	60,074

OER and OEE Calculation

Appendix – H

Mill ID	FFB Processing Capacity tons/h	Total Mill Hours Worked (up-time)	Mill Downtime Reported	1 h/d start up & 1/2 p/shift minor stop	Total Mill Downtime	FFB Processed	CPO Produced (Good Quality)	Oil Extraction Rate (OER)	CPO production per hour	Out of spec and slush oil produced	Out of spec CPO first hour production/300d	Total Out of spec & slush oil produced	Availability Rate = Uptime÷(uptime + downtime)	Performance Rate = CPO Produced ÷CPO could be produced	Quality Rate = Good CPO÷(good CPO+bad CPO)	OEE = availability × performance × quality rate
1	28	4,500	100	600	700	120,000	25,000	0.2083	5.83	0	1750	1750	0.87	0.82	0.93	0.67
2	20	4,027	49	600	649	76,513	16,241	0.2123	4.25	0	1274	1274	0.86	0.82	0.93	0.65
3	30	2706	234	600	834	67,665	14,110	0.2085	6.26	143	1877	2020	0.76	0.64	0.87	0.43
4	40	5873	0	600	600	220,560	44,781	0.2030	8.12	615	2436	3051	0.91	0.85	0.94	0.72
5	40	3,640	45	600	645	137,120	29,700	0.2166	8.66	55	2599	2654	0.85	0.80	0.92	0.62
6	30	4,173	80	600	680	102,652	19,276	0.1878	5.63	0	1690	1690	0.86	0.71	0.92	0.56
7	30	4,133	491	600	1091	119,757	22,534	0.1882	5.64	0	1693	1693	0.79	0.76	0.93	0.56
8	120	5,076	170	600	770	398,000	75,393	0.1894	22.73	0	6819	6819	0.87	0.57	0.92	0.45
9	40	7,209	181	600	781	294,311	64,034	0.2176	8.70	0	2611	2611	0.90	0.92	0.96	0.80
10	54	5,000	50	600	650	266,470	52,655	0.1976	10.67	600	3201	3801	0.88	0.87	0.93	0.72
11	90	4,671	10	600	610	397,049	79,547	0.2003	18.03	0	5409	5409	0.88	0.84	0.94	0.69
12	60	5,277	11	600	611	216,574	49,405	0.2281	13.69	0	4106	4106	0.90	0.61	0.92	0.51
13	20	1764	10	600	610	32,000	6,464	0.2020	4.04	200	1212	1412	0.74	0.67	0.82	0.41
14	30	3,187	591	300	891	109,268	23,127	0.2117	6.35	118	1905	2023	0.78	0.89	0.92	0.64
15	40	3,669	0	600	600	137,150	28,488	0.2077	8.31	240	2493	2733	0.86	0.80	0.91	0.63
16	85	2,550	0	600	600	216,430	44,554	0.2059	17.50	875	5249	6124	0.81	0.81	0.88	0.58
17	54	5,900	30	600	630	302,430	57,600	0.1905	10.28	0	3085	3085	0.90	0.86	0.95	0.74
18	35	3,431	29	600	629	118,559	24,143	0.2036	7.13	0	2138	2138	0.85	0.83	0.92	0.65
19	60	4,562	81	600	681	205,355	42,863	0.2087	12.52	0	3757	3757	0.87	0.65	0.92	0.52
20	60	4,357	30	600	630	260,380	52,176	0.2004	12.02	275	3607	3882	0.87	0.87	0.93	0.71
21	54	3,655	0	600	600	188,690	40,271	0.2134	11.52	382	3457	3839	0.86	0.82	0.91	0.64
22	60	6,000	30	600	630	227,000	43,266	0.1906	11.44	180	3431	3611	0.90	0.57	0.92	0.48
23	60	4,500	120	600	720	225,000	42,750	0.1900	11.40	500	3420	3920	0.86	0.72	0.92	0.57
24	90	6,000	200	600	800	400,000	84,000	0.2100	18.90	100	5670	5770	0.88	0.65	0.94	0.54
25	60	5,819	30	600	630	299,428	59,442	0.1985	11.91	341	3573	3914	0.90	0.77	0.94	0.66
26	40	2,919	38	600	638	97,000	20,855	0.2150	8.60	320	2580	2900	0.82	0.68	0.88	0.49
27	60	4,467	0	600	600	265,700	57,917	0.2180	13.08	111	3924	4035	0.88	0.87	0.93	0.72
28	54	6,406	47	600	647	345,910	67,671	0.1956	10.56	80	3169	3249	0.91	0.91	0.95	0.79
29	60	5,595	96	600	696	214,415	44,880	0.2093	12.56	0	3768	3768	0.89	0.57	0.92	0.47
30	45	3,915	66	600	666	184,716	39,147	0.2119	9.54	0	2861	2861	0.85	0.90	0.93	0.71
31	35	5,119	4	600	604	181,996	36,635	0.2013	7.05	0	2114	2114	0.89	0.91	0.95	0.77
32	60	4,420	20	600	620	221,715	46,752	0.2109	12.65	0	3796	3796	0.88	0.73	0.92	0.59
33	70	5,917	24	600	624	394,574	82,617	0.2094	14.66	0	4397	4397	0.90	0.86	0.95	0.74
34	54	5,034	120	600	720	179,390	38,133	0.2126	11.48	689	3444	4133	0.87	0.58	0.90	0.46
35	60	2,983	0	600	600	178,945	35,534	0.1986	11.91	0	3574	3574	0.83	0.83	0.91	0.63
36	60	6,000	816	600	1416	270,000	55,000	0.2037	12.22	800	3667	4467	0.81	0.61	0.92	0.45
37	45	5,544	0	600	600	245,226	47,120	0.1921	8.65	190	2594	2784	0.90	0.89	0.94	0.76
38	45	5,162	46	600	646	224,890	44,934	0.1998	8.99	0	2697	2697	0.89	0.86	0.94	0.72
39	40	4,821	163	600	763	204,137	42,990	0.2106	8.42	116	2527	2643	0.86	0.91	0.94	0.74
40	60	3,971	28	600	628	150,285	32,055	0.213	12.80	0	3839	3839	0.86	0.54	0.89	0.42
41	55	3,663	0	600	600	185,070	36,881	0.199	10.96	0	3288	3288	0.86	0.79	0.92	0.62
													35.36	31.59	37.80	25.22
mean													0.86	0.77	0.92	0.62