SUSTAINABLE MAINTENANCE PERFORMANCE MEASUREMENT SYSTEM FOR AUTOMOTIVE INDUSTRY

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

MAY 2017

To my beloved husband, mother, father, and two wonderful children.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful. I am thankful to Allah for granting me persistence and strength to complete this thesis.

I would like to express my sincere appreciation and deep gratitude to my supervisors, Dr. Azanizawati Bt Ma'aram and Professor Dr. Awaluddin bin Mohamed Shaharoun, for their transferred knowledge, encouragement, advice, and support. With their professional assistance and guidance, I could manage to get this thesis completed.

This thesis would not have been also possible without the support from my experts and respondents who contributed a lot during discussion, interview, and survey, especially Prof. Dr. I.S. Jawahir of University of Kentucky; Assoc. Prof. Aditya Parida of Lulea University of Technology; En. Zamri Isa, BSc, MBA of Delloyd Industries (M) Sdn Bhd, Malaysia; the team from SIRIM's Total Productive Maintenance (TPM) certification and recognition scheme; Proton; and Perodua.

I am really thankful to Universiti Teknologi Malaysia (UTM) for funding my PhD research through International Doctoral Fellowship (IDF) Program. I also wish to express my gratitude to all UTM staffs for their assistance.

I owe my deepest gratitude to my lovely husband, H. Ridha Satria, ST. who has made available his support in a number of ways, my beloved parents, H. Sy. Dt. Bdr. Nan Hitam, Hj. Evi Susiany, and Hj. Yusnar who sincerely pray for my success and give the best support throughout this study. To my wonderful heroes, M. Afief Muzhaffar and M. Fatih Ghifary, thank you darlings for supporting your Ummi. I

wish to thank my entire family for providing the constant support and understanding. Lani, Bonny, Nana, Rosa, etek Tira, and uni Dr. Rahmi and family.

I am heartily thankful to both my best friends in BATC of UTMKL, uni Elita Amrina and Azila Raja Mamat for sharing of PhD work, family, and our live. To my colleagues in UTMKL, En Zarak Shaifuddin bin Zamrah who gets my respondents available, mba Myrna, for encouraging me throughout the years.

Last but not least, my sincere grateful to the group called as “4 Sekawan”, pak Yusuf and family, pak Irfan and family, and pak Farchan and family, for giving the continued support and bringing cheer to our live in Bintulu.

ABSTRACT

This study is motivated to embed sustainability issues for maintenance management implementation in the automotive industry as one of the capital intensive industries. Maintenance objectives at the operational level should be aligned with corporate sustainability goals by defining key performance indicators at every level in a company. However, very few studies have attempted to link sustainability initiatives with maintenance performance and there is no standard set of Sustainable Maintenance Performance (SMP) measures. This research aims to bridge the gap by developing a balanced hierarchical SMP measurement framework. This framework consists of 78 indicators where 14 indicators were identified to be at the corporate level, 21 indicators at the tactical level, and 43 indicators at the functional level, respectively. A survey was conducted with 200 sent questionnaires, 101 were usable leading to a response rate of 50.5%. Statistical analyses were applied in order to determine reliability and validity requirements from the survey. Exploratory Factor Analysis (EFA) was conducted to determine the underlying structure among the SMP indicators and to obtain the significant indicators. Nine perspectives have been identified with 71 indicators as compared to the initial framework which has 8 perspectives with 78 indicators. The Partial Least Squares - Structural Equation Modeling (PLS-SEM) as a Confirmatory Factor Analysis (CFA) was conducted in order to validate the results of EFA. The measurement and structural evaluation results verified the SMP indicators' reliability and validity. Analytic Hierarchy Process (AHP) was applied in identifying the cause and effect relationship amongst the SMP measures through a hierarchical structure. Furthermore, AHP through pairwise comparison was also assigned to determine the critical measures by defining the relative important weights of each measure. The AHP results indicated that environmental is the most important factor in evaluating SMP for Malaysian automotive companies, followed by economic and social, respectively. Moreover, AHP also recommended the top five important indicators in evaluating SMP, i.e. total of lubricants consumption, total of greenhouse gas emissions, maintenance program achievement, stakeholder complaints, training hours per employee, and employee complaints. In the end, this research has also established a measurement guideline for measuring SMP which consists of three main procedures. A Microsoft Excel-based tool for SMP measurement was also developed to assist organizational efforts and reduce time. The results of this study are expected to lead to better understanding and provide new insight in developing a SMP measurement system which benefits both researchers and practitioners. Finally, this work is of most interest to the public and private sectors which need to incorporate sustainability issues into their corporate objectives and to assess its implementation. Future researchers are suggested to build a SMP measurement system through a real case study.

ABSTRAK

Kajian ini adalah bermotivasi untuk menerapkan isu kemampanan untuk perlaksanaan pengurusan penyelenggaraan dalam industri automotif sebagai salah satu industri intensif modal. Objektif penyelenggaraan di peringkat operasi hendaklah selaras dengan strategi perniagaan di peringkat korporat dengan mengenalpasti petunjuk prestasi utama di setiap peringkat. Namun, terlalu sedikit kajian yang cuba mengaitkan inisiatif kemampanan dengan prestasi penyelenggaraan dan tiada set standard petunjuk prestasi penyelenggaraan berterusan (SMP). Kajian ini bertujuan untuk merapatkan jurang dengan membangunkan rangka kerja pengukuran hirarki SMP seimbang. Rangka kerja ini terdiri daripada 78 petunjuk prestasi, 14 petunjuk di peringkat korporat, 21 petunjuk di peringkat taktikal, dan 43 petunjuk di peringkat operasi. Satu kaji selidik telah dijalankan dengan 200 borang soalselidik yang telah diedarkan, 101 digunapakai dengan kadar respon 50.5%. Analisis statistik telah digunakan untuk menentukan keperluan kebolehpercayaan dan kesahihan daripada kaji selidik tersebut. Analisis Penerokaan Faktor (EFA) telah dijalankan untuk menentukan struktur asas kepada petunjuk SMP dan mendapatkan petunjuk yang penting. Sembilan perspektif dengan 71 petunjuk telah dikenal pasti berbanding dengan SMP permulaan iaitu 8 perspektif dengan 78 penunjuk. Kuasa-Paling Sedikit Separa – Pemodelan Persamaan Struktur (PLS-SEM) selaku analisis pengesahan faktor telah dijalankan bagi mengesahkan keputusan EFA. Pengukuran dan penilaian struktur telah mengesahkan kebolehpercayaan dan kesahihan petunjuk SMP. Seterusnya, Proses Hierarki Analisis (AHP) telah digunakan untuk mengenal pasti perhubungan sebab-akibat petunjuk SMP. Selain itu, AHP melalui perbandingan berpasangan juga telah digunakan untuk menentukan petunjuk kritikal dengan menentukan wajaran kepentingan relatif bagi setiap petunjuk. Keputusan AHP menunjukkan bahawa alam sekitar adalah faktor yang paling penting dalam penilaian SMP bagi syarikat automotif di Malaysia, diikuti dengan faktor ekonomi dan faktor sosial. Selain itu, AHP juga mencadangkan lima petunjuk yang penting dalam penilaian SMP, iaitu jumlah penggunaan pelincir, jumlah pelepasan gas rumah hijau, pencapaian program penyelenggaraan, aduan pihak berkepentingan, jumlah jam latihan bagi setiap pekerja, dan aduan pekerja. Akhirnya, kajian ini mencadangkan satu garis panduan untuk mengukur SMP yang terdiri daripada tiga prosedur utama. Kajian ini juga membangunkan alat pengukuran SMP menggunakan Microsoft Excel untuk membantu organisasi dan menjimatkan masa. Keputusan kajian ini dijangka akan membawa kepada pemahaman yang lebih baik dan memberikan pengetahuan baru dalam membangunkan sistem pengukuran SMP yang bermanfaat kepada penyelidik dan pengamal. Akhirnya, kajian ini akan menarik minat sektor awam dan swasta yang memerlukan penerapan isu kemampanan dalam objektif korporat mereka dan menilai pelaksanaannya. Penyelidik akan datang dicadangkan untuk membina sebuah sistem pengukuran SMP melalui kajian kes sebenar.

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LIST OF ABBREVIATIONS

AASA	-	The association of academies of sciences in Asia
AHCSM	-	Analytic hierarchy constant sum method
AHP	-	Analytic hierarchy process
AVE	-	Average variance extracted
BSC	-	Balanced scorecard
CFA	-	Confirmatory factor analysis
CMMS	-	Computerized maintenance management system
CR	-	Consistency ratio
CV	-	Commercial vehicles
EFA	-	Exploratory factor analysis
ERV	-	Equipment replacement value
HCM	-	Hierarchical component model
KMO	-	Kaiser-Meyer-Olkin measure of sampling adequacy
MAA	-	Malaysian automotive association
MAI	-	Malaysia automotive institute
MCDM	-	Multi-criteria decision making
MITI	-	Malaysian ministry of international and trade industry
MPM	-	Maintenance performance measurement
MTBF	-	Mean time between failures
MTTR	-	Mean time to repair
NAP	-	National automotive policy
OEE	-	Overall equipment effectiveness
OMPM	-	Operation and maintenance performance management
PCA	-	Principal components analysis
PERODUA	-	Perusahaan otomobil kedua Sdn. Bhd.
PLS-SEM	-	Partial least squares - structural equation modeling
PMS	-	Performance measurement system

PPE	-	Personal protective equipment
PROTON	-	Perusahaan otomobil nasional Bhd.
PV	-	Passenger vehicles
PVAMD	-	Proton vendors association member directory
ROI	-	Return on investment
SEM	-	Structural equation modeling
SME	-	Small medium enterprise
SMM	-	Sustainable maintenance management
SMP	-	Sustainable maintenance performance
SMPM	-	Sustainable maintenance performance measurement
SMRP	-	The society for maintenance and reliability professionals
STV	-	Subjects to variables
TIV	-	Total industry volume
TOEE	-	Total overall equipment effectiveness
TPM	-	Total productive maintenance
WIP	-	Work in progress
QFD	-	Quality function deployment

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

The use of advanced technology in the manufacturing companies has made maintenance management function even more critical in achieving the corporate objectives (Zuashkiani *et al*., 2011). In the early 1900s, maintenance was regarded as a necessary evil that should be minimized as much as possible (Garg and Deshmukh, 2006; Sharma *et al.*, 2011). Rather than being regarded as a competitive resource, it was considered as a cost-driving necessity (Salonen and Deleryd, 2011). Companies never look at maintenance as a vital investment which must be done in order to increase the process reliability to become a world-class manufacturing company (Ahuja and Kumar, 2009). This view was caused by the company's failure to identify the impact (direct and indirect) of maintenance function on the objectives of company or as a source of profit (Jonsson, 1997; Aoudia *et al.*, 2008).

However, in the twentieth century the maintenance function has grown to be considered as a crucial part of business success (Parida and Kumar, 2006). It creates competitive advantages which give the company the ability to compete with others. Moreover, maintenance management system has crucial effects on all aspects of company's performance including cost, environmental, and safety.

Previous studies revealed that maintenance management has a positive relationship with enhancement of company's competitiveness (Madu, 2000; Pintelon *et al.*, 2006). Chelsom *et al.* (2005) stated that maintenance cost is a crucial factor in

manufacturing company's profitability because it may contribute between 2 to 10 percent of the business's profit. Similarly, the research in a Swedish paper mill proved maintenance as a profit generating function (Alsyouf, 2007). Improving the equipment availability by 1 percent enables profit to grow by 2 to 4 percent in several industrial sectors (Gebauer *et al.*, 2008). In addition, proper maintenance execution can assist the company to enhance productivity with high-quality level (Rotab Khan and Darrab, 2010). Moreover, Chelsom *et al.* (2005) stated that in the current manufacturing business practices (automation, flexible manufacturing systems, lean manufacturing and just in time operation), maintenance needs to be integrated with other business functions for ensuring machine reliability in order to achieve efficient production and high-quality products.

A number of studies also revealed that there are effects of maintenance management systems to the environmental and safety aspects. Tang *et al.*, (2015) have conducted maintenance research in the oil and gas sector and they stated that equipment failures during oil and gas exploration and development may lead to disasters and, in turns, have negative impacts on human safety and environmental pollution. However, on the other hand, effective maintenance management systems can lead to energy saving, thus reducing environmental pollution (Al-Ghanim, 2003).

Pintelon and Muchiri (2009) argued that maintenance management systems have critical effects on plant safety. The correct maintenance implementation can increase safety level with enhancing effective communication between maintenance workers and plant operators (Holmgren, 2005). In contrast, Hale *et al.* (1998) revealed that the lack of maintenance management contributed to 40% of major accidents, where 80% of those occurred during the maintenance executions and 20% in routine operations.

The value added created by maintenance management needs to be planned, controlled, and improved using a proper Maintenance Performance Measurement (MPM) framework (Simões *et al*., 2011). A formal MPM framework allows the company to identify problems and take appropriate and corrective actions. Several researchers have developed MPM frameworks which focused more on traditional

maintenance performance measures (financial-based) and concentrated at the operational or functional level only. Thus the impact of maintenance management in achieving overall corporate objectives was overlooked (Parida, 2006). Upon these shortcomings, this research focused on a balanced and integrated MPM framework, which considers financial and non-financial measures and at the same time ensuring the alignment between maintenance objective and corporate objectives.

This alignment will enable corporate objectives cascaded down on the entire organization levels by defining key performance indicators at each level including operational or functional level (Mather, 2005). Therefore, maintenance workforce at the functional level will be enabled to carry out their roles in a way that will contribute significantly to the business objectives and able to understand how they can achieve these objectives. However, there is a lack of research that provides sufficient answers on how maintenance management can contribute in achieving business objectives (Parida, 2006).

The Balanced Scorecard (BSC) is a popular approach for measuring performance in the manufacturing and service companies. Moreover, Parida (2012) stated that different asset performance assessment frameworks need to be developed in line with the BSC in order to ensure the alignment between maintenance executions at the functional level and business objectives at the corporate level in a balanced manner.

The BSC offers an advantage which enables the employee to be part of the company performance enhancement process since it contains the business strategies of the entire organization levels. Therefore, business strategies will be able to be translated into routine maintenance executions. The BSC has been adapted by previous researchers in developing performance measurement frameworks including in the MPM frameworks, such as Tsang (1998), Tsang *et al*. (1999), Kutucuoglu *et al.* (2001), Liyanage and Kumar (2003), Mather (2005), Alsyouf (2006), Parida and Chattopadhy (2007), Liyanage *et al.* (2009), and Parida (2012).

Alsyouf (2006) stated that the scarcity of natural resources and the market sentiment about environmental problems have caused sustainability to become an important issue among researchers and practitioners. In addition, Daily and Huang (2001); Despeisse *et al.*, (2013) argued that stakeholder's pressure, stricter national regulation, and international environmental standards are the external drivers which forced companies to take into account the sustainability issues in their business's strategy. Similarly, Keijzers (2002) stated that it was due to the regulation that initially pushes the company to consider sustainability issues in order to reduce wastes and emissions. However, in the next phase, the sustainable business strategy will lead the company to become eco-efficiency and resource productivity.

Liyanage (2007) suggested that it is essential to integrate sustainability issues into all support business functions, including maintenance management of the assets which is important but assumed having less contribution in improving company sustainability. Poor quality of maintenance management execution will lead to negative impacts on the environment, safety, as well as economic (Aoudia *et al*., 2008; Raouf, 2009). In response to these issues, maintenance management needs Sustainable Maintenance Performance Measurement (SMPM) system where the three factors of sustainability (economic, environmental, and social) will all be considered, and no longer focus solely on economic factor (Ratnayake and Markeset, 2012). However, only a few previous researchers have regarded sustainability issues in their research and clarified how to integrate these issues into a MPM system.

One of the most important and strategic industry sectors in the world is the automotive industry (Lettice *et al*., 2010). According to Habidin and Yusof (2013), automotive manufacturing companies are one of the main drivers for the development of advanced technology and continuous improvement activities. They reflect the technology capability of the nation. Furthermore, the automotive industry will surely guarantee the existence of inter-industry linkage since they bring together various components produced by their suppliers.

According to Alsyouf (2006), sustainable maintenance is a crucial management issue for high-capital and high-risk industries, such as automotive

industry. The automotive industry has contributed to economic and social development around the world. However, this industry and its supply chain have caused global environmental problems (Orsato and Wells, 2007; Nunes and Bennett, 2010). Hence, the commitments of stakeholder and supplier of this industry to consider sustainability issues in their business strategies are very crucial for sustainability around the world (González *et al.*, 2008).

The Malaysian automotive industry is one of the important and strategic industry sectors. This industry has become the third largest amongst ASEAN countries in terms of both total number of production and sales where 666,674 units were manufactured in 2015 (MAA, 2016). It has contributed to the GDP by 3.2% and 550,000 workforces were employed in this sector by 2012. On 20 January 2014, the Malaysian Ministry of International and Trade Industry (MITI) has announced their estimation that this industry would contribute as high as 10% to the GDP and provide employment opportunities of 150,000 by 2020 (MITI, 2014).

According to the Association of Academies of Sciences in Asia (AASA) (2011), Malaysia is one of the top 24 highest energy consumers in Asia causing to be Malaysia among the top 20 carbon dioxide emission producer. Malaysian automotive industry generated of 5.69% scheduled waste by 2010 which is leading this industry as the top five scheduled waste producer (Department of Environment Malaysia, 2010).

MITI (2014) has declared the objectives of newest National Automotive Policy (NAP). The objectives are:

"to promote a competitive and sustainable domestic automotive industry including the national automotive companies; promote increase in value-added activities in a sustainable manner".

In order to respond to these issues, Malaysian automotive companies need to take into account sustainability issue in their business strategy and assess its implementation using a balanced and integrated SMPM system.

1.2 Problem Statement

Today, maintenance management is considered as a crucial support function in the success of businesses. The automotive companies need to develop a balanced and integrated MPM framework for measuring the value-added created by maintenance management process. In fact, some of the previous researchers have developed MPM frameworks which were more concentrated on traditional maintenance performance measures (financial view point).

Recently, automotive industry as a capital-intensive manufacturing companies have been exerted to reduce negative impacts on the environment and at the same time need to realize their contribution to economic and social development. Therefore, it is crucial to embed sustainability issues into maintenance management of the assets which is a significant factor in achieving the status of a sustainable company (Kaur *et al.,* 2012). Although literature on sustainability is rapidly growing, there are limited studies that have been conducted on how to incorporate sustainability issues into a MPM system in a balanced manner. Several previous studies were limited and focused on specific factors such as economic, environmental or social only rather than integrating all relevant factors.

The other main issue in developing MPM framework is the alignment between maintenance objectives at the operational level and overall business objectives at the corporate level. It is important to ensure this alignment by defining the indicators at each level. The clear alignment allows practitioners to translate business strategies into maintenance daily activities and at the same time enables maintenance workforces at the operational level to improve their value created aligned to corporate objectives. Many researchers and practitioners have been developing MPM frameworks, mostly at the operational level or the functional level only, without considering its effect in achieving corporate objectives that related to maintenance management.

Hence, there is a need to assess the application of sustainable maintenance management using a balanced and integrated SMPM framework, which considers all

relevant factors of sustainability, and at the same time ensures the alignment between corporate objectives and maintenance objectives. It is strongly believed that the findings from this study can help manufacturing companies, especially automotive companies to become more competitive and more sustainable in the global environment.

1.3 Research Questions

The research questions are as follows:

i. How to embed sustainability issues into a Maintenance Performance Measurement (MPM) framework?
ii. What are the Sustainable Maintenance Performance (SMP) measures which can be applied for automotive companies?
iii. How does maintenance management contribute to a company's competitive strategies?
iv. What measures of Sustainable Maintenance Performance (SMP) that will contribute significantly to business strategies that related to maintenance management?
v. How the automotive companies measure the level of implementation of sustainable maintenance?

1.4 Research Objectives

The research objectives are as follows:

i. To develop a set of balanced and integrated Sustainable Maintenance Performance (SMP) measures (factors, perspectives, and indicators) for automotive companies.
ii. To develop a Sustainable Maintenance Performance Measurement (SMPM) framework that allows the linking for strategy to operational or functional level.

iii. To identify the critical measures in achieving company objectives that related to maintenance management.

iv. To develop a measurement system with a guideline of Sustainable Maintenance Performance Measurement (SMPM) for automotive companies.

1.5 Research Scopes

The scopes of this study are limited to the following:

i. The sector of research is confined to automotive companies. The research questionnaires were applied to Malaysian automotive companies.

ii. The research was focused on sustainability issue in maintenance management.

1.6 Significance of the Research

Murthy et al. (2002) highlighted that maintenance management of assets and facilities are amongst the vital function for business's survival and success, and hence it must be strategically managed. Maintenance management needs an appropriate MPM framework in order to plan, control, and improve the outcome of the maintenance process (Parida, 2006). The MPM frameworks have been developed by previous researchers. Unfortunately, they tended to focus on financial measures and concentrate at either operational level or functional level only. The effect of the maintenance management performance on the business strategies was rarely studied.

Furthermore, sustainability issue has emerged as one crucial issue for automotive companies. In the future, companies must attempt to become more eco-friendly and resource productivity in order to create competitive advantages to win the competition. It is an unavoidable choice to consider sustainability issues in all

organization activities, including maintenance management (Jasiulewicz-Kaczmarek and Drozyner, 2011).

From all these issues, this research has developed a SMPM framework for automotive companies which considers three factors of sustainability (economic, social, and environmental) in a balanced manner, and at the same time cascaded the indicators into three hierarchies (corporate, tactical, and functional level). It is believed that a balanced and integrated framework benefits company in creating competitive advantages in order to become a sustainable company. Moreover, a hierarchical manner will ensure that maintenance objectives have direct linkage and clear impact on the business strategies or for profit generating.

It is strongly believed that the findings of this research will enable the automotive company practitioners to make the best and accurate decisions related to assets and facilities management, e.g. allocation of capital. Since this research applied Analytic Hierarchy Process (AHP) to define the weight of each measure. It also enables practitioners to know which measures have important effects on the corporate objectives compared to other measures.

This study will also develop a Microsoft Excel-based application for SMPM system. This application facilitates decision makers to obtain real-time information in making effective and efficient decisions within short and limited time. Finally, the results of this study are expected to lead to better understanding and provide new insights in developing SMPM system which benefits to both researchers and practitioners.

1.7 Outline of the Thesis

This thesis consists of seven chapters. The first chapter describes the introduction to the research. It explains the background of the research, problem statement, research questions, research objectives, research scopes, and significance of the research.

Chapter 2 presents a critical review related to maintenance management and sustainability. It begins with a review of maintenance management objectives, importance and evolution of MPM systems in manufacturing companies, sustainable manufacturing and maintenance management, reviews on previous SMPM systems and SMPM hierarchy in manufacturing companies, automotive industry and sustainability, and overview of AHP method.

The research methodology applied in conducting this study is explained in Chapter 3. This chapter begins with a discussion on the overall structure of research methodology, detail description of survey methodology, and development of SMPM system guideline.

Chapter 4 presents the statistical analysis results of the data from the full survey. The analysis starts with the general descriptive statistic of the respondent companies. This is followed by the results and analysis of company's motivation in implementing sustainable maintenance management. The next section recapitulates and analyzes the results of reliability test. Furthermore, the results of Exploratory Factor Analysis (EFA) and the Partial Least Squares – Structural Equation Modeling (PLS-SEM) are summarized and analyzed to prove the validity test requirement of the data.

The development of a SMPM guideline is presented in Chapter 5. It starts with determining the weight of each measure using AHP method. It follows with determining the data scaling guideline and normalization. Finally, a Microsoft Excel-based application that was developed is presented as a tool for developing and measuring SMP achievement.

Chapter 6 discusses findings of the research, how these findings relate to previous studies. Lastly, Chapter 7 presents the conclusions of research, limitations of the study, and recommendations for future research.

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