SUSTAINABLE MANUFACTURING PERFORMANCE EVALUATION TOOL FOR AUTOMOTIVE COMPANIES

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Dedicated with love and gratitude to my beloved mother, late father, brothers, sisters, and son.

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ABSTRACT

In response to the growing sustainability concerns, manufacturing companies have to formulate a set of measures to evaluate sustainable manufacturing performance, aimed at integration of sustainability aspects. Sustainability is generally evaluated by dimensions of environment, economic, and social, known as the triple bottom line (TBL) of sustainability. However, while the literature on sustainability is rapidly growing, only few studies have attempted to integrate sustainability into manufacturing performance evaluation. There is also no consensus yet on a standard set of sustainable manufacturing performance measures. This study aims to integrate sustainability into manufacturing performance by incorporating manufacturing performance measures with sustainable manufacturing measures. As a result, a set of initial measures for sustainable manufacturing performance evaluation believed to be suitable for automotive companies have been proposed, consisting of three factors divided into nine dimensions and a total of 41 subdimensions. In order to validate the initial measures with industry practices, a survey was conducted on the automotive companies in Malaysia. It was found that all the initial measures are highly important and thus proposed as the key measures of sustainable manufacturing performance evaluation for automotive companies. A sustainable manufacturing performance evaluation tool for automotive companies was then developed using a hybrid Multi Criteria Decision Making (MCDM) technique. Interpretive Structural Modeling (ISM) methodology was applied to determine the structural relationships and inter-relationships amongst all the performance measures and Analytic Network Process (ANP) methodology was employed to determine the important weights of each of the performance measures by summarizing the opinions of the experts. While the tool provides a systematic approach for quantitative assessment of sustainable manufacturing performance, it is not entirely automated. Thus, for that purpose, a software-based tool named SUSMAP was subsequently developed using PHP and MySQL. Two case studies have been conducted to validate the tool. Results from the case studies suggested that the SUSMAP is easy to use and applicable to evaluate sustainable manufacturing performance in automotive companies. The tool can be used by companies for self-assessment as well as benchmarking. It shows the existing performance level on strengths and weaknesses, and where improvements need to be made. It is hoped that the proposed sustainable manufacturing performance measures and the associated SUSMAP tool can aid the automotive companies to achieve successful implementation of sustainable manufacturing so as to compete in a much more sustainable manner.

ABSTRAK

Dalam tindak balas kepada keperihatinan kelestarian yang semakin meningkat, syarikat perkilangan perlu membentuk satu set ukuran untuk menilai prestasi kelestarian perkilangan, yang bertujuan untuk mengintegrasikan aspek kelestarian. Kelestarian umumnya dinilai oleh dimensi alam sekitar, ekonomi, dan sosial, yang dikenali sebagai garis bawah berganda tiga (TBL) daripada kelestarian. Walau bagaimanapun, sementara literatur tentang kelestarian berkembang pesat, hanya sedikit kajian yang berusaha untuk mengintegrasikan kelestarian ke dalam penilaian prestasi perkilangan. Masih tidak terdapat persetujuan kepada satu set ukuran prestasi kelestarian perkilangan yang standard. Kajian ini bertujuan untuk mengintegrasikan kelestarian ke dalam prestasi perkilangan dengan menggabungkan ukuran prestasi perkilangan dengan ukuran kelestarian perkilangan. Hasilnya, satu set ukuran awal untuk penilaian prestasi kelestarian perkilangan yang dipercayai sesuai untuk syarikat automotif telah dicadangkan, yang terdiri daripada tiga faktor yang dibahagi menjadi sembilan dimensi dan sejumlah 41 subdimensi. Untuk mengesahkan ukuran awal tersebut dengan amalan industri, satu kajian soal selidik dijalankan di syarikat automotif di Malaysia. Didapati semua ukuran awal adalah sangat penting dan oleh kerana itu dicadangkan sebagai ukuran utama untuk penilaian prestasi kelestarian perkilangan bagi syarikat automotif. Satu alat bagi penilaian prestasi kelestarian perkilangan untuk syarikat automotif telah dibangunkan dengan menggunakan satu teknik hibrid pengambilan keputusan multi kriteria (MCDM). Kaedah permodelan struktur berinterpretif (ISM) telah diaplikasikan untuk menentukan hubungan struktur dan hubungan timbal balik diantara semua ukuran prestasi dan kaedah proses rangkaian analitik (ANP) telah digunakan untuk menentukan pemberat kepentingan untuk setiap ukuran prestasi dengan merumuskan pendapat dari pakar. Walaupun alat ini menyediakan suatu pendekatan sistematik untuk penentuan kuantitatif prestasi kelestarian perkilangan, namun ia tidak sepenuhnya automatik. Oleh itu, satu perisian berdasarkan alat ini yang dinamakan SUSMAP telah dibangunkan dengan menggunakan PHP dan MySQL. Dua kajian kes telah dijalankan untuk mengesahkan alat ini. Keputusan daripada kajian kes ini mencadangkan SUSMAP adalah mudah digunakan dan terpakai untuk menilai prestasi kelestarian perkilangan dalam syarikat automotif. Alat ini boleh digunakan oleh syarikat untuk penilaian diri serta ukur rujuk. Alat ini menunjukkan tahap prestasi yang ada atas kekuatan dan kelemahan, dan dimana pembaharuan perlu dilakukan. Diharapkan ukuran prestasi kelestarian perkilangan yang dicadangkan dan kaitannya dengan alat SUSMAP dapat membantu syarikat automotif untuk mencapai kejayaan dalam pelaksanaan kelestarian perkilangan sehingga mampu bersaing dalam keadaan yang lebih lestari.

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LIST OF ABBREVIATIONS

AHP	Analytic hierarchy process
ANP	Analytic network process
CI	Consistency index
CR	Consistency ratio
FMM	Federation of Malaysian Manufacturers
HTML	Hyper text markup language
ISM	Interpretive structural modeling
MCDM	Multi criteria decision making
MICMAC	*Matrice d'impacts croises-multiplication appliqué a un classemen*
MVF	Multi vehicle factory
PHP	PHP hypertext preprocessor
PMS	Performance measurement system
PVA	Proton vendor association
RDBMS	Relational database management system
RI	Random consistency index
SM	Sustainable manufacturing
SMP	Sustainable manufacturing performance
SPSS	Statistical package for the social sciences
SQL	Structured query language
SSIM	Structural self interaction matrix
TBL	Triple bottom line

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CHAPTER 1

INTRODUCTION

1.1 Background of the Research

Sustainability has become an increasingly important issue amongst industries worldwide. Many companies are directing their resources to minimize the environmental impact of their products and operations. There is a growing awareness among manufacturing companies of the need to consider the triple bottom line of sustainability consisting of economic, social, and environmental performance. Developing sustainable approaches to manufacturing companies has been regarded as a critical global concern (Ijomah *et al.*, 2007).

Companies today are facing the challenges not only to manufacture of quality products but also of environmental-friendly products. Manufacturing companies are striving to achieve sustainability through changes in their products, processes, and systems (Sutherland *et al*., 2008). The implementation of sustainable manufacturing offers a cost effective route in improving the economic, environmental, and social performance as the three pillars of sustainability (Pusavec *et al.*, 2010). It has been reported that those companies adopting sustainable practices are able to achieve better product quality, higher market share, and increased profits (Nambiar, 2010). Sustainable manufacturing practices have also been seen to be positively associated with competitive outcomes (Rusinko, 2007).

In recent years, manufacturing companies have adopted various strategies to minimize the impact of their operations and products on the natural environment (Vachon and Klassen, 2008). They should control the environmental impacts of their

manufacturing activities globally in order to achieve sustainable global manufacturing (Kumazawa and Kobayashi, 2003). Therefore, in the last few years a growing range of manufacturing companies have included the environmental principles into their operations.

For manufacturing companies, sustainability has emerged as a new competitive requirement and a means to achieve differentiation in the market (Shahbazpour and Seidel, 2006). In addition, sustainability concern is regarded as an important order winning factor (Menguc and Ozanne, 2005). Increasing concerns to sustainability driven by legislation, public interest, and competitive opportunity (Linton *et al*., 2007) have forced manufacturing companies to inevitably consider sustainability into their strategies and activities.

In response to the growing sustainability concerns, manufacturing companies have to formulate measures to evaluate sustainable manufacturing performance, aiming at integration of sustainability aspects. Generally, sustainability is evaluated on the dimensions of environment, social, and economic, while manufacturing performance is evaluated on the dimensions of quality, cost, delivery, and flexibility. It has been suggested that environmental requirements must be considered as equal partners to the traditional requirements of cost and quality (Kaebernick *et al.*, 2003). In sustainability context, manufacturing costs, energy consumption, waste management, environmental impact, operational safety, and personal health should be considered in the same equal level (Kopac, 2009). Thus, it is necessary to incorporate the sustainability dimensions into the manufacturing performance dimensions, resulting sustainable manufacturing performance measures.

Although literature on sustainability is abundant and growing, very few studies have actually integrated sustainability into manufacturing performance. Sustainability has been integrated into manufacturing management areas such as product development (Kara *et al.*, 2005; Mien *et al.*, 2005), supply chain management (Koplin *et al*., 2007; Vachon and Klassen, 2008; Morali and Searcy, 2010), lean manufacturing (Herrmann *et al*., 2008), green design and manufacturing (Ranky, 2010), and supplier evaluation and selection (Ladd and Badurdeen, 2010). In addition, recent studies have also attempted in developing the criteria for sustainable

manufacturing performance. Vachon and Klassen (2008) combined four traditional dimensions of manufacturing performance namely quality, cost, delivery and flexibility with environmental performance, resulting in a total of 16 dimensions of sustainable manufacturing performance. Rusinko (2007) proposed a total of 24 measures of environmentally sustainable manufacturing practices. Fan *et al*. (2010) investigated sustainable manufacturing indicators in both industry and academic and then proposed a total of six factors with divide into 32 dimensions to measure sustainable manufacturing. However, there is no single set of standard measures to evaluate the sustainable manufacturing performance.

The automotive industry is one of the most important and strategic industry in manufacturing sector for major economies including Japan, United States, Europe, China, Korea, India, and also Malaysia is not left behind. Automotive industry has been regarded as an important industrial driver of industrial development, design, marketing, the provider of technological capability and generator of inter-industry linkages, since it brings together various components, which are manufactured by suppliers in other industries (Chin and Saman, 2004).

Sustainability has certainly become one of the critical issues for the automotive industry. The automotive industry has made remarkable positive contributions to the world economy and people's mobility, but its products and processes are a significant source of environmental impact (Nunes and Bennett, 2010). The automotive industry constitutes a product system that directly and indirectly relates to economic wealth creation as well as impacts on the natural and human environment along all phases of the product life cycle (Warren *et al*., 2001). It can be concluded that automotive industry plays an important role for the economic, environmental and social development in the context of sustainability. Thus, there is a need to evaluate sustainable manufacturing performance in this industry.

1.2 Problem Statement

The automotive companies are under intense pressure to reduce environmental impacts of their products and operations. For sustainability, it should be achieved a balance amongst the triple bottom line involving the economic development, environmental protection, and social equity. It is a big challenge for the automotive companies to give serious attention on sustainability.

Although sustainability issues have been widely growing for many years, only few studies have been conducted on incorporating sustainability into manufacturing performance. There is yet to be a standard set of sustainable manufacturing performance measures. Although some studies have investigated measures for sustainable manufacturing performance, only few have integrated the triple bottom line of sustainability consisting of environmental, social, and economic performance. Most studies only focused on the environmental dimension alone. But for sustainability, there must be a balance among those three dimensions.

Hence, it is believed that there is a need to evaluate sustainable manufacturing performance for automotive companies, considering the triple bottom line of sustainability on an equal level. The focus of this research is to develop an evaluation tool to assess sustainable manufacturing performance in the automotive companies, which hopefully would help them to improve their sustainable manufacturing performance so as to become more competitive.

1.3 Research Questions

The research questions are as follows:

(i) What are the sustainable manufacturing performance measures that can be applied for automotive companies?

(ii) How are the automotive companies evaluating the sustainable manufacturing performance?

1.4 Research Objectives

The research objectives are as follows:

(i) To develop a set of sustainable manufacturing performance measures for the automotive companies.

(ii) To develop an evaluation tool of sustainable manufacturing performance for the automotive companies.

1.5 Research Hypotheses

The research hypotheses are as follows:

(i) The sustainable manufacturing performance measures differ between small, medium, and large companies.

(ii) The drivers of sustainable manufacturing initiatives differ between small, medium, and large companies.

(iii) The barriers of sustainable manufacturing initiatives differ between small, medium, and large companies.

(iv) The benefits of sustainable manufacturing initiatives differ between small, medium, and large companies.

1.6 Research Scopes

The research scopes of this study are as follows:

(i) This research focused only on the manufacturing processes of sustainability.

(ii) The population and sample of this research is the automotive companies, limited to automotive related manufacturing in Malaysia.

(iii) The sustainable manufacturing performance evaluation measures used in this research were derived and modified from the literature study

focused on the triple bottom line of sustainability consisting of environmental, economic, and social performance.

(iv) The sustainable manufacturing performance evaluation tool was developed using Interpretive Structural Modeling (ISM) and Analytic Network Process (ANP) methodology.

(v) A software-based tool was developed using PHP and MySQL programming languages.

1.7 Significance of the Research

This research developed an evaluation tool in assessing sustainable manufacturing performance for automotive companies. A set of sustainable manufacturing performance measures is proposed and believed to be suitable to the characteristics of automotive companies. The measures are then used in developing an evaluation tool to sustainable manufacturing performance for automotive companies. Subsequently, a software-based tool named SUSMAP is developed for the automation purpose.

The integration of Interpretive Structural Modeling (ISM) and Analytic Network Process (ANP) methodology can provide a better understanding of the interrelationship amongst the measures and help to solve a complex evaluation problem, so that it can enhance the quality of decision making. The evaluation tool enables and assists companies to know and understand their existing performance level on strengths and weaknesses. It provides suggestions and directions for the companies to take appropriate actions in improving their sustainable manufacturing performance level.

The SUSMAP evaluation tool enables automated quantification assessment and visual representation of the sustainable manufacturing performance for automotive companies. The tool aids the automotive managers to make decisions in an easier, faster, and accurate manner. SUSMAP can be used for self-assessment and benchmarking. It is hoped that SUSMAP would be of benefit to automotive

companies in their efforts to become more effective, competitive, and sustainable. Finally, this research is expected to be of beneficial for both researchers and practitioners.

1.8 Outline of the Thesis

This thesis is organized into seven chapters. The first chapter provides an introduction to the research. It describes the background of the research, problem statement, research questions, objectives, scopes, and significance of the research. Chapter 2 presents the literature study to understand the issues of the research. It included a review on manufacturing performance, previous manufacturing performance measures, sustainability, sustainable manufacturing, and a review on previous sustainable manufacturing performance measures, overview of automotive industry, automotive industry and sustainability, preliminary sustainable manufacturing performance measures for automotive companies, Interpretive Structural Modeling (ISM) methodology, Analytic Hierarchy Process (AHP) methodology, and Analytic Network Process (ANP) methodology.

The research methodology employed in conducting the study is described in Chapter 3. The research begins with a discussion on the overall structure of the research methodologies, survey methodology, developing a sustainable manufacturing performance evaluation tool for automotive companies, and finally, developing a software based-tool for sustainable manufacturing performance evaluation in automotive companies.

Chapter 4 presents the survey results and analysis. It discusses the general descriptive statistics of the respondents, results of sustainable manufacturing initiatives, reliability and validity test, and results of sustainable manufacturing performance measures. It also presents hypothesis test to examine the differences of results between small, medium, and large companies.

The development of a sustainable manufacturing performance evaluation tool for automotive companies is described in Chapter 5. The tool was developed using a hybrid Multi Criteria Decision Making (MCDM) technique which integrated the Interpretive Structural Modeling (ISM) and the Analytic Network Process (ANP) methodology. It involves determining the analytical structure, constructing the network relationship model using ISM methodology, calculating the importance weight using ANP methodology, and finally, evaluating the sustainable manufacturing performance.

Chapter 6 presents the development of a software-based tool named "**SUSMAP**" for automated assessment of sustainable manufacturing performance evaluation. It is a web based-software developed using PHP and MySQL. The software development process consists of software design, software coding, software testing, and finally, software validation. Finally, Chapter 7 presents the conclusions of the research, limitations of the study, and recommendations for further research.

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