A HYBRID KNOWLEDGE-BASED SYSTEM FOR COLLABORATIVE GREEN MANUFACTURING MANAGEMENT

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2014

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ACKNOWLEDGEMENT

The authors wish to express their gratitude to Ministry of Higher Education for the financial support under the Fundamental Grant Research Scheme and to Universiti Utara Malaysia for facilitating the management of the research.

ABSTRACT

This research is oriented towards the development of a new hybrid knowledge-based system for planning, design, and implementation of collaborative green manufacturing system (CGMM). We propose the development of a conceptual model of CGMM, and then translate it into a knowledge-based system, with the goal of investigating the recent state of green manufacturing philosophy practised in the automotive industry and its supply chain as compared to the ideal system. A prototype of reliable hybrid KBS is produced as a decision making tool to assist the management and policy makers in implementing the CGMM. The system captured the activities in the CGMM that have potential opportunity for collaborative development through the green value chain gap measurement in CGMM The results showed what the organizations' potential opportunity of their abilities compared to their partners' potential opportunity in the green supply chain.

Keywords: Green manufacturing, Knowledge based system, Automotive industry

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CHAPTER ONE

INTRODUCTION

Since 40 years ago, several highly visible environmental disasters, such as rising levels of greenhouse gas (GhG) emissions, global warming, and various types of pollution have demonstrated the importance of having a comprehensive environmental strategy in place (Desonie, 2008, Walton, Handfield, & Melnyk, 2008). This issue has raised the fundamental issue which involves green strategy to reduce and reverse the damage which already occurred. The concept of green is being the main priority today and started to being used everywhere starting from simple house chores until a larger scale of manufacturing and service industries.

Current manufacturing practice is being held accountable as one of the main influence to our environmental disaster (Dornfeld, 2013; UN, 2005). According to OCDE (2008), manufacturing energy usage has been increasing and used a third of global energy. From the perspective of carbon emission, the industry produces 9.17% of global carbon emission which is the 2nd highest industry after transportation (IEA, 2012). In response to this matter, manufacturing industries accompanied with various technologies have recently shown more interest in green manufacturing paradigm (Helu & Dornfeld, 2013).

Green manufacturing management (GMM) is a management system that contains only required resources and materials, manufactures only required quantity of quality products on time that meet customers' demands, and aims to reduce environmental impact (David Dornfeld, Yuan, Diaz, Zhang, & Athulan, 2013). The term "*green"* in this context referred to as (1) "*relating to or being an environmentalist political movement", (2) "concerned with or supporting environmentalism"* and (2) "*tending to preserve environmental quality (as by being recyclable, biodegradable, or nonpolluting*)" (Merriam-Webster, 2013).

The general idea of green manufacturing is a manufacturing system with the objective of the minimization of negative impact on the natural environment (David Dornfeld et al., 2013) GMM is manufacturing planning and control (MPC) system of the materials and information flow which involve initiatives of manufacturing resources planning (MRP II) and lean manufacturing (King & Lenox, 2003; S Rothenberg, Pil, & Maxwell, 2001). In addition, Total Quality Environmental Management (TQEM) is integrated to ensure the quality of the processes and products of the system which contribute the ecological sustainability. The capabilities of continuously improving the processes by identifying and eliminating manufacturing wastes are essential for effectiveness of GMM. The main benefit of effective GMM is high ratio of quality to cost of the products manufactured which finally contribute to high profitable organization with minimum pollution.

Green manufacturing has evolved from production shop floor to the whole organization and from the individual organization to all organizations in the supply chain (Womack, Jones, & Roos, 2007). The term itself is also extended to the terms such as green remanufacturing green operations, green design, and green supply chain (Srivastava, 2007). In this research, collaborative green manufacturing management (CGMM) is the term used for this enhanced GMM that covers all areas within and across the organization in the supply chain.

1.1 Automotive Industry in Malaysia

The automotive manufacturing facility is extremely complex and affecting the environment. Managing and understanding the dynamics of automotive manufacturing is a challenging endeavour. In the current era of dynamic global competition and environment has become a critical issue, a new concept such as collaborative green manufacturing management (CGMM) can be implemented as a better alternative for organizations to improve their manufacturing processes. All members in the CGMM and its value chain must work together towards common objectives in order to make the GMM achievable.

Automotive industry in Malaysia began in 1960s with the openings of several car assembly factories in Selangor with the first car, Volvo 144 rolled off the line in 1967 (Volvo Malaysia, 2005). The incorporation of PROTON (Perusahaan Otomobil Nasional) on 7 May 1983 and the introduction of Proton Saga model in 1985 proved that Malaysian government is committed to involve seriously in car manufacturing and heavy industry. Now, after more than 20 years, there are four national-status car companies, i.e. PROTON, PERODUA (Perusahaan Otomobil Kedua), INOKOM (Industri Otomotif Komersial) and NAZA (Naza Automotive Manufacturing). In addition to this, there are a number of foreign companies that assemble imported vehicles such as Ford, BMW, Mercedes-Benz, Volvo, Toyota, Honda, and Nissan.

Automotive industry is considered as one of highly profitable sector of the Malaysia's economy. Since its establishment in 1985, PROTON has proved to be a success project to the Malaysian government where it once controlled more than 60% of the car market in Malaysia (Ahmad, 2003a). With this good achievement, the second national car company, PERODUA was incorporated in 1995, which focusing on the manufacturing of small and compact cars. It is also a successful project when PERODUA cars dominate the small car segment market. The success of both companies is however contributed by the protection by the government, which introduces and imposes various taxes to the imported cars (Ahmad, 2003b).

1.2 Problem Statement

In the light of globalisation and current competitive business environment, management should not only focus on the Green Manufacturing within organizations, but also the Green Manufacturing between the organizations in the supply chain. All members in the GMM chain from suppliers to customers must work together towards common objectives in order to make the Green Manufacturing work effectively in the collaborative environment.

Although GMM is a system that improves competitiveness of the organizations, there are still problems related to it. The problems include suppliers' perception of being exploited, coping with product variability, and high pressure to shop floor workers (Dornfield, 2013; Hines, Holweg, & Rich, 2004)

With the realization that the green manufacturing concept is not fully understood and adopted due to its business dynamic in nature, a frame work of CGMM is needed to investigate the gap between the practice and ideal system (Dornfeld, 2010; King & Lenox, 2003). Furthermore, people factors such as culture, openness, trust, willingness to change and commitment also play significant roles in the CGMM development.

1.3 Research Objectives

The problems stated in the previous section have motivated this research. The main objective of this research is to investigate the recent state of Green Manufacturing philosophy practised in automotive industry and its supply chain, particularly in Malaysia. This research is also designed to capture the knowledge, understanding and culture within this industry community and to recommend the necessary actions which can be taken by the industry in developing and improving the CGMM. This main objective has led to the following systematically listed research objectives:

1) To investigate the recent state of green manufacturing philosophy practiced in the automotive industry and its supply chain.
2) To design a conceptual model of collaborative green manufacturing management (CGMM)

3) To develop a knowledge-based system of collaborative green manufacturing management (CGMM) that can be used to analyze the CGMM implementation in the automotive industry and its supply chain.
4) To recommend the necessary actions which can be taken by the industries in developing and improving the CGMM.

1.4 Significance of the Study

The novel research approach emphasises the use of Knowledge-Based (KB) approach in such activities as planning, designing, assessing and providing recommendations of CGMM implementation, through: a) developing the conceptual CGMM model; b) designing the KB system structure based on the conceptual model; and c) implementing gap analysis and other approaches in the hybrid KBS for CGMM.

The development of theoretical framework and conceptual model is the most detailed part in the research process and consists of five major components in two stages. Stage 1 (Planning stage) consists of Organization Environment, Collaborative Business and Green Manufacturing components. Stage 2 (Design stage) consists of Organization CGMM Capability and Organization CGMM Alignment components. Each of these components consists of sub-components and activities that represent particular issues in the GMM development. From the conceptual model, all components were transformed into the KB system structure, which is embedded with the relevant techniques, and thus, key areas of potential improvement in the GMM are identified for each activity along with the identification of both qualitative and quantitative aspects for GMM implementation.

This research will provide the opportunity for experts from the fields of operations research, information technology, and social science to exchange ideas and working methodologies. Such synergy-oriented activities will guarantee a free flow of technology transfer and the diffusion of working methodologies across multiple disciplines.

1.5 Report Organization

This report consists of five chapters. The introduction to the research, its background, problem statements, research objectives, methodology, and significance of the research are included in this chapter, Chapter 1.

Chapter 2 presents the literature review in the area of Collaborative Green Manufacturing Management (CGMM). This chapter also review the Knowledge-Based System (KBS) literature and its application in manufacturing management.

Chapter 3 presents the research methodology and basic framework of CGMM, including brief description of every component in the planning, design, and implementation stages, followed by the description of the KBCGMM System structure.

Chapter 4 describes the details of the verification, validation, and analysis of the KBCGMM System. It covers the data analysis through the published case studies and the industrial case studies.

In Chapter 5, overall conclusion of this research, achievement of the research objectives, and recommendation for the future research are presented.

CHAPTER TWO

LITERATURE REVIEW

2.1 Environmental Management System

Perhaps the most important element for a company to practice GMM is to execute Environmental Management System (EMS) into their business operations. The United States Environmental Protection Agency defines EMS as “a set/system of processes and practices that enable an organization to reduce its environmental impacts and increase its operating efficiency” (Rendell & McGinty, 2004). An EMS integrates environmental management into the organization’s overall management system by identifying the policies, environmental targets, measurements, authority structures and resources necessary to produce both regulatory compliance as well as environmental performance "beyond compliance" (EPA, 2003). A continual improvement cycle is established through this process.

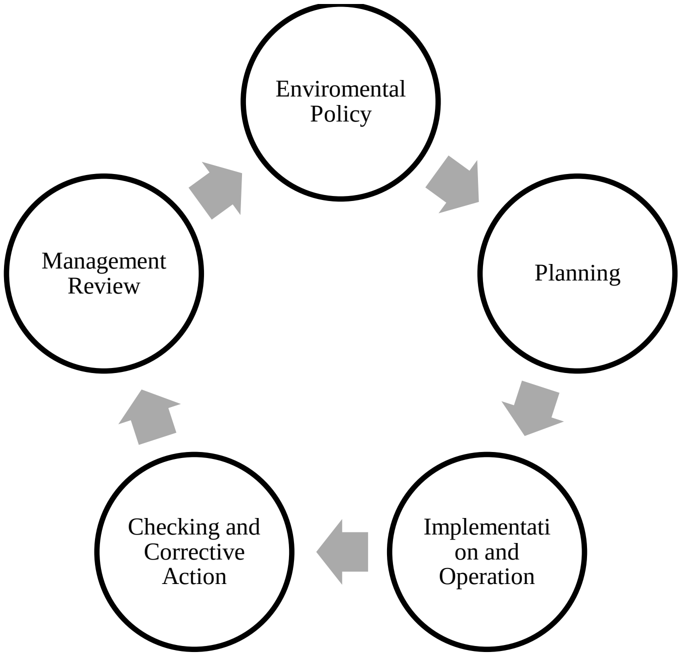


Figure 2.1: EMS Continual Improvement Cycle

There are plenty model or conceptual framework for EMS such as European Eco-Management and Audit Scheme (EMAS), Responsible Care model developed by the American Chemical Council (ACC), US Department of Justice (DOJ) "Seven Key Compliance Program Elements" and EPA National Enforcement Investigation Center (NEIC) "Compliance Focused" EMS but the most famous and well accepted model is ISO 14001 standards. ISO 14001 is indeed an ideal measure for EMS in such that it is general enough to apply to any business environment, yet specific enough to assure that the right set of policies and procedures are in place to drive green waste reducing activity.

2.2 Green Manufacturing Frameworks

Based on EMS concept, we review several well-known framework/models introduced in GMM field. Russo (2001) conducted a study to determine the influence of EMS using ISO140001 standards towards the electronic industries' environmental performance which was measured in terms of toxic emissions. His main finding shows that there is significant correlation between the electronic manufacturing plant/facilities that applies ISO140001 and increased environmental performance. Meanwhile, Melnyk, Sroufe, and Calantone (2003) explored the effect of EMS have on the implementation of environmental options on operations performance. They found out that the presence of certified EMS significantly reduced overall cost and lead time, and therefore increased quality. Based on these two studies, we conclude that EMS and ISO14001 is crucially essential for company to practice GMM. Notice that these studies exclude the essence of Green Manufacturing Management (LMM) practiced by most of the companies today. Realizing that GMM is fundamental importance as well as LMM, we go through the studies which linked these two approaches in the next section.

Lean manufacturing is a philosophy of manufacturing that focuses on delivering the highest quality product at the lowest cost on time. It is a systematic approach to identifying and eliminating waste (all non-value-added activities) through continuous improvement (often know as Kaizen) by flowing the product at the pull of the customer in pursuit of perfection (Schroer, 2004). Majority of the study conducted shows that the 'waste elimination' thinking of LMM is consistent with the philosophy of 'pollution reduction' in GMM. The definition of waste in LMM can be suited with the inclusion of environment waste in GMM.

Table 2.1: Wastes of Lean Manufacturing. Adopted from "A Study of Toyota Production System from and Industrial Engineering Viewpoint," by Shingo, S. (1989), Productivity Press.

Types of waste	**Description**
Overproduction	Producing more than is required which leads to excess inventory
Transportation	Moving tools or materials to another location than is needed.
Waiting	Delays of time for people, process, information etc.
Motions	People moved or worked unnecessarily
Defects	Defect products force reworks which can leads to delays.
Inventory	Excess inventory of the raw materials, work-in-progress (WIP), or finished goods, represents a capital that has bring any income yet either by the producer or for the consumer.
Over-processing	Doing extra work which is not needed.

Table 2.2: Wastes of Green Manufacturing. Adopted from "Lean Manufacturing and the Environment," by EPA (2003), *United States Environmental Protection Agency*

Types of wastes	**Description**
Permit Compliance	Compliance with applicable permits.
Toxic Release Inventory (TRI)	Over 300 chemicals subject to release.
33/50 Chemicals	A subset of TRI chemicals identified by the EPA as priority candidates for voluntary reductions by industry.
Clean Air Act Toxics	189 chemicals listed in the Clean Air Act as air toxics.
Risk-Weighted Releases	Toxic chemicals weighted by their relative toxicity.
Waste Per Unit of Production	Percentage of production lost as waste, generally measured by weight.
Energy Use	Total energy use by all aspects of corporate operations; also expressed as carbon dioxide.
Solid Waste Generations	Total solid waste going to landfills or other disposal facilities.
Product Life Cycle	The total impact of a product on the environment from raw materials sourcing to ultimate disposal.

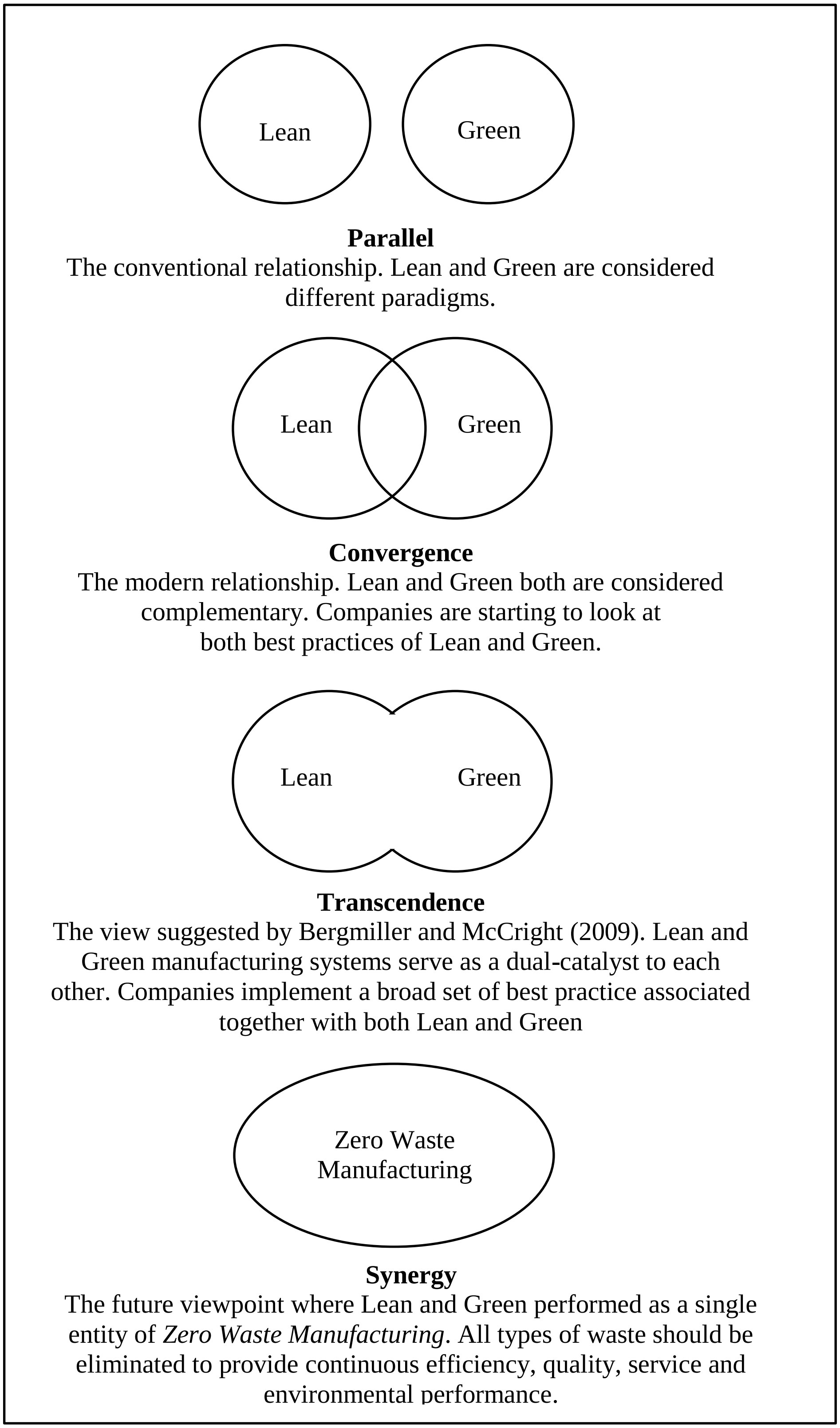
This is supported with the studies of Bergmiller, Mccright, and Florida (2009), Florida (1996), King and Lenox (2003), Sandra Rothenberg, Pil, and Maxwell (2001) which proved that the company which practices Lean are more likely to exhibits better enviromental performance. Hence, we conclude that it is pretty irrelevant to exclude LMM philosophy in order to develop a better GMM framework.

2.3 Lean and Green Manufacturing Frameworks

Here, we review the studies shown at the previous section to exhibit the importance of LMM to GMM. Florida (1996) investigated the connection between advanced manufacturing practices which includes LMM and environmental performance. He concluded that company which applied advanced management techniques (e.g. the use of teams, technology investment, process improvement, involvement of suppliers and customers, pursuit of zero waste, involvement of all types of employees) are heading towards minimizing environmental waste. This study indicated that these techniques are associated with both LMM and GMM.

Rothenberg (2001) focused on the case of the automotive industry where the study illustrated that lean manufacturers are proven to more energy efficient than non-lean manufacturers thus making them ‘greener’. King and Lenox (2001) demonstrated that ISO 9000 (International certification for Total Quality Management Systems) certified manufacturers with low inventories of hazardous materials have lower emissions of toxic chemicals. However, this study assumed that ISO 9000 standards are equivalent with LMM concepts where this assumption may not be true. In addition, EPA (2003) showed that the Boeing’s LMM program reduced environmental waste as a byproduct of process efficiency and quality improvements.

More recently, Bergmiller and McCright (2009) concerns on the relationship between lean and green where they believed that lean manufacturers transcend to GMM. They proposed a comprehensive Lean and Green framework which fills the gap of all previous LMM model and GMM model. The study developed an improved framework of LMM namely, Advance Lean System Model and GMM framework namely, Advance Green System Model before combining it into their Lean and Green framework. These three frameworks were developed and classified under three main categories which are Management Systems, Waste Reducing Techniques, and Business Results. In spite of this, the current unresolved debate in the body of knowledge is the true nature of association between LMM and GMM. The major question still exist whether Lean and Green should be addressed as parallel, complementary, transcendence or synergy elements (Bergmiller & McRight, 2009).



Parallel
The conventional relationship. Lean and Green are considered different paradigms.

Convergence
The modern relationship. Lean and Green both are considered complementary. Companies are starting to look at both best practices of Lean and Green.

Transcendence
The view suggested by Bergmiller and McCright (2009). Lean and Green manufacturing systems serve as a dual-catalyst to each other. Companies implement a broad set of best practice associated together with both Lean and Green

Synergy
The future viewpoint where Lean and Green performed as a single entity of *Zero Waste Manufacturing*. All types of waste should be eliminated to provide continuous efficiency, quality, service and environmental performance.

Figure 2.2: Relationship among Lean and Green. Adapted from "*Lean Manufacturers Transcendence to Green Manufacturing: Correlating the Diffusion of Lean and Green Manufacturing Systems*," by Bergmiller, G., 2006, PhD Thesis, University of South Florida

Based on Bergmiller et al.(2009) study, Dues, Tan, and Lim (2013) extended lean and green beyond the waste reduction objective. They suggested that lean practices can be used as catalyst to greening the supply chain. Their finding supported the transcendence relationship of lean and green as in Figure 2.2

Every literature mentioned in this section managed to prove to us the significant inter-relationship between LMM and GMM. Based on our analysis, all of them were conducted empirically and only use quantitative techniques as their main approach. The frameworks proposed by them are general and not case specific into the characteristics of any manufacturing industry and environment. This shows that the frameworks proposed are flexible and can be implemented in any business settings. All of the studies validates their frameworks via analyzing literature, developing hypothesis and test their hypothesis with the real world implementation. However, none of them validate their frameworks with the actual real world perspectives. Nevertheless, in our opinion, we also need to look from the viewpoint of the real world industrial players.

Based on Womack et al. (2007), Jayal, Badurdeen, Dillon, and Jawahir (2010) and Dues et al. (2012), the difference and the similarities of lean and green manufacturing has been summarized and compiled in Table 2.3. Other conspicuous studies in this area can be found in Aminuddin (2013), Carvalho, Duarte, and Machado (2011), Franchetti, Bedal, Ulloa, & Grodek (2009), Parveen, Kumar, and Rao (2011), Ross (2003), Simons, Mason, and Cardiff (2003) and Venkat and Wakeland (2006).

Table 2.3: Comparison of Lean and Green Manufacturing Paradigms

<table>
<tr><th>Lean</th><th>Criteria</th><th>Green</th></tr>
<tr><td>Cost minimization and flexibility</td><td>Focus</td><td>Sustainable development and ecological impact</td></tr>
<tr><td>Driven by cost, quality and time efficiency</td><td>Customer</td><td>Driven by environmental friendly conscious</td></tr>
<tr><td>7 waste of lean</td><td>Definition of Waste</td><td>Inefficient use of resource, non-product output (scrap and polluted emissions)</td></tr>
<tr><td>Performance maximization and cost minimization</td><td>Product design</td><td>Life-cycle assessment</td></tr>
<tr><td>Increase replenishment frequency</td><td>Practice</td><td>Reduce replenishment frequency</td></tr>
<tr><td>High utilization, Just in Time (JIT)</td><td>Manufacturing</td><td>Remanufacturing</td></tr>
<tr><td>No concern for impact of product use or end-of-life recovery</td><td>End-of-life</td><td>Consideration of impact of product use and end-of-life recovery in form of re-use or recycling</td></tr>
<tr><td>Cost</td><td>Key Performance Index (KPI)</td><td>Greenhouse gas (GhG) emission</td></tr>
<tr><td>Physical cost (Monetary and resource)</td><td>Dominant cost</td><td>Cost for future generation (Quality of life)</td></tr>
<tr><td>Lean Value Stream Mapping (VSM)</td><td>Principal tool</td><td>Life-Cycle-Assessment (LCA)</td></tr>
<tr><td colspan="3">Lean and Green
Objective of waste reduction
Waste reduction technique
People and organization
Lead time reduction
Supply chain relationship
KPI: Quality of service
Tools/Practice</td></tr>
</table>

2.4 Green Manufacturing Management Application In Industries

Emmet and Sood (2010) highlighted 6 main industries which have significant impacts from Green manufacturing. It includes logistic, automobile, Fast Moving Consumer Goods (FMCG), chemical, construction and electronics where these industries are synonym with their direct and indirect negative effects to environmental sustainability. The major myth to GMM concept is it always involves additional cost to the company. However, the study from Emmet and Sood (2010) proved it conversely and the results are shown in Figure 2.3.

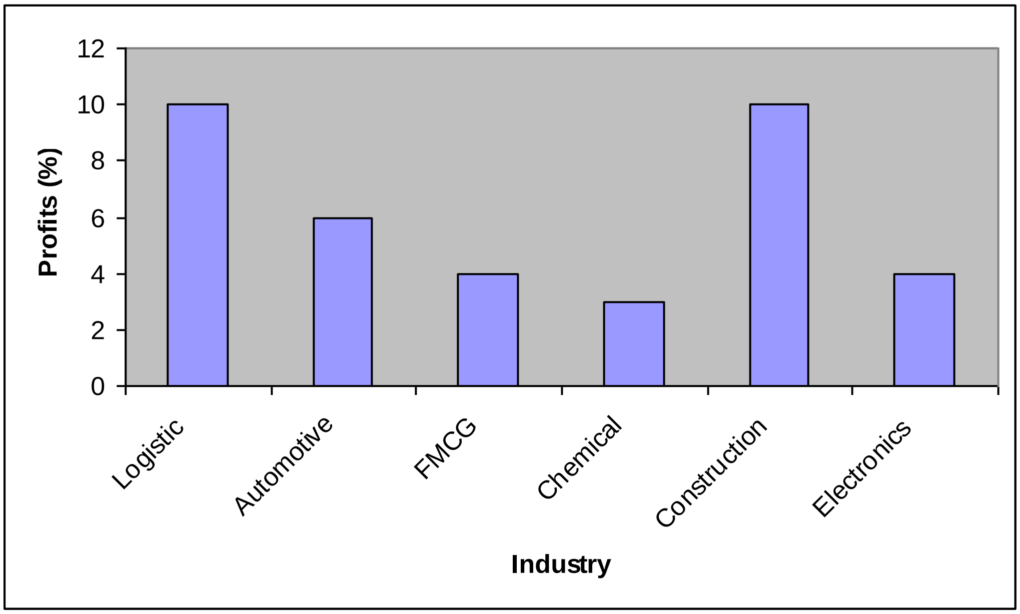


Figure 2.3: Industry-Wise Average Profitability Gains from GMM

2.5 Automotive Industry

The global automobile industry has emerged for over a period of more than 100 years and still growing. The industry surpassed three business revolutions. Starting with standard mass assembling industry of Fordism, continued with a customized, vertically integrated mass production industry of GM's productive model, and went through into a lean manufacturing system which also can be known as Toyotism. In present, it faces its fourth generation which is ‘Green’ revolution (Wad, 2009).

As we can see in Figure 2, the GMM can contribute up to 6% increment in profit into the automotive industry. The key contributor to this includes design for disassembly, reduced procurement costs and increased recycling of materials, reduced costs of disposal of unrecyclable waste due to minimal or no use of hazardous material and effective maintenance of vehicle which require lower maintenance cost (Emmet & Sood, 2010). To put in a whole, the basic 3R rule remains: (1) Reduce – waste, raw material dependency, fossil fuel dependency, hazardous emissions and substance. (2) Reuse – Energy (3) Recycle – Scrap, by-product (Ing, 2007; Tiwari, 2010; Sinha, 2010).

Pioneered by Toyota, hybrid automotive technology was embarked by combining combustion engine with an electric engine. Toyota launched its ‘Prius’ as the first commercial hybrid electrical vehicle (HEV) ever in 1997. Honda followed Toyota by launching their HEV in 1999. As the fuel prices shot up during the 2000s, the other group of automakers began trying to catch-up with Toyota and Honda. In addition to the hybrid electrical vehicles (HEVs), new technologies included plug-in hybrid electrical vehicles (PHEVs), electrical vehicles (EVs) with battery-based electrical propulsion (BEVs) and with plug-in mechanism (PEVs), and finally fuel cell electrical vehicles (FCEVs) based on hydrogen.

The first group of followers producing HEVs or EVs includes among US automakers; Ford, GM, Chrysler (with GEM) and Tesla (allied with Daimler) and Japanese Nissan. The second group of followers that does not yet produce environmental- friendly vehicles includes VW, Audi, Porsche, BMW (including Mini), Miles Electric Vehicles, Daimler, Smart, French PSA and Renault, and Japanese Mitsubishi and Subaru (Chanaron 2009). The technological revolution is evolving from hybrid electrical vehicles to electrical vehicles and eventual hydrogen fuel cell technology. However, it was estimated that it will take 20 years to have an invulnerable EV technology. Thus, many automakers still continue improving the fuel efficiency and reducing hazardous emission (Just-auto, 2009).

In the case of Malaysia, total vehicle sales in Malaysia grew 13% to hit an all-time high of 605,156 units in 2010, surpassing the previous record of 552,316 units achieved in 2005, with the trend expected to continue in 2011. According to the Malaysian Automotive Association (MAA), the local automotive industry is expected to hit another all-time total industry volume (TIV) high of 618,000 units in 2011 as the positive trends continue this year. Although, the environmental-friendly hybrid car were only sold for 120 units in 2010, the fact that the Malaysian Government recently announced the exemption of excise duties of hybrid car and the rising fuel price, have become push factors for the rapid increasing demand of hybrid car in 2011 (Mahalingam, 2011). The fact clearly shows that Malaysia is also moving towards environmental sustainability, specifically via automotive sustainability itself.

2.6 Knowledge Based Systems (KBS)

Knowledge-Based System (KBS) can be comprehend as the representation tool of any types of knowledge element in a form of computer system to solve specific tasks and is one of the major techniques in the field of Artificial Intelligence. From a formal viewpoint, KBS is defined as "*a computer program for extending and/or querying a knowledge base which is a collection of knowledge expressed using some formal knowledge representation language. A knowledge base forms part of a knowledge-based system*" (FODOC, 2000) or "*A computer system that is programmed to imitate human problem-solving by means of artificial intelligence and reference to a database of knowledge on a particular subject*" (Computer User High-Tech Dictionary). The best definition of KBS due to its thorough explanations of the system's elements together with its potential functionality is suggested by the Elsevier Knowledge-Based Systems Journal which entitles as below:

"*Knowledge-Based Systems focuses on systems that use knowledge-based techniques to support human decision making, learning and action. Such systems are capable of cooperating with human users and so the quality of support given and the manner of its presentation are important issue*" (Knowledge-Based System, 2004).

The knowledge can be classified into more types of explicit, tacit, common sense, heuristic, meta and domain as shown in Table 2.5 and the description of knowledge can best be shown in form DIKW components as in Table 2.4 (Sajja & Akerkar, 2010).

Table 2.4: DIKW Components

Major Elements	**Description**	**Example**	**Volume**	**Complexity**
Data	Symbols that represent objects, events, and their properties	Percentage of carbon dioxide (CO2)	Highest	Lowest
Information	Refined processed data which has been made useful	20% of CO2 is considered high	High	Low
Knowledge	Synthetized and analyzed information such that it can provide meaningful function and outcome which consists of instructions and explanations	How to measure the percentage level of CO2	Low	High
Wisdom	Knowledge which comes from experience, judgment, values and laws and it is usually developed in a period of certain times	The level of CO2 should be constantly monitored to maintain the safety level for the staff in the manufacturing facility	Lowest	Highest

Table 2.5: Types of Knowledge

Types of Knowledge	**Description**
Explicit	Shown on the form of words or numbers in the form of data. Instructions, guidelines etc. It is can be easily understood because it is more structured, systematic and organized.
Tacit	Knowledge in the form of unstructured, informal and non-systematic in the mind of an individual. It is highly unique and it is hard to understand.
Common sense	Knowledge which is generally known and present in most normal people.
Heuristic	A specific rule-of-thumb which utilize unsupported/incomplete evidence of rule which is usually derived from experiences.
Meta	Knowledge which provide descriptions of the other knowledge
Domain	Valid and trusted source of knowledge which gained from the experts/specialist on certain matter/problem setting.

With regards to the availability of advanced computing technologies, KBS is being pushed to response to more demanding tasks which at some point may require higher level of intelligence. In that sense, KBS can also be classified under the field of computational intelligence (CI) or Intelligent System (IS). Those two fields is the extension of AI field with the addition of human involvement of in the decision making process, a more responsive, faster and more efficient implementation techniques (Kordon, 2010).

2.6.1 Structure of KBS

Figure 2.4 shows a typical KBS structure, where each of these components is described in the following sub-sections.

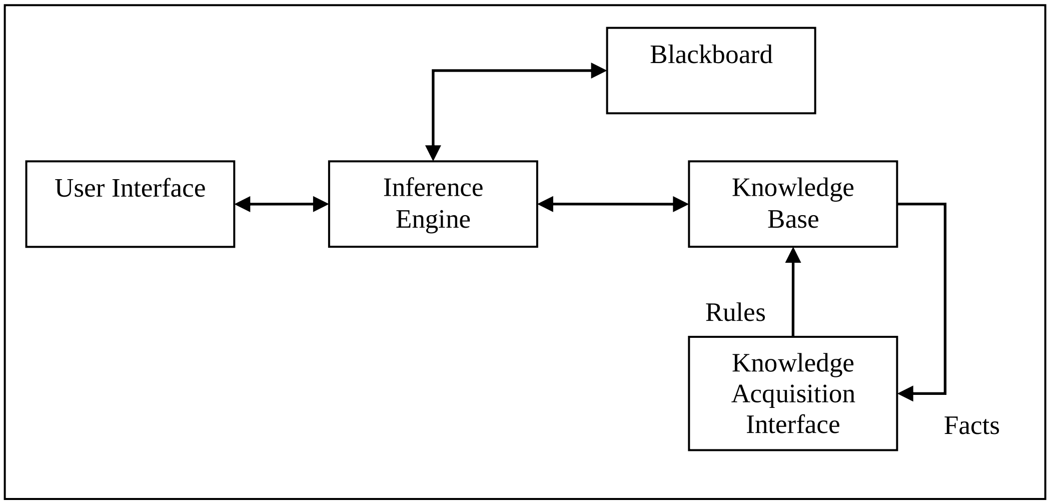


Figure 2.4: Structure of a typical KBS (adapted from Udin (2004))

2.6.1.1 Knowledge Base (KB)

The KB is the main component of KBS where rules, facts, and knowledge acquired from human expert are stored. The knowledge contained in the knowledge base is needed to understand, formulate and solve specific problem of particular domain (Turban, Aronson, & Liang, 2005). There are various approaches including production rules, logic representation, semantic networks, and frames to represent the knowledge (Pigford & Baur, 1990; Turban et al., 2005). As most of KBSs use production rules, KBSs are also known as rule-based systems (Awad, 1996; Giarratano & Riley, 2005)

2.6.1.2 Production Rules

Production rules are the most common approach of representing knowledge (Hussain, 1998; Wibisono & Khan, 2003). In this approach, premise-action or IF ... THEN is the basic structure of representing knowledge (Awad, 1996). Other structures in production rules include *connectors* (AND and OR), and *alternative action* (ELSE). An example of production rules is:

IF *the number of full time employee is more than 150*
OR *the company annual sales turnover is more than £3.68 million*
THEN *the company is classified as a large company*
ELSE
IF *the number of full time employee is between 51 and 150*
AND *the company annual sales turnover is between £1.47 million and £3.68 million*
THEN *the company is classified as a medium company*
ELSE *the company is classified as a small or micro company*

The statements of “*the number of full time employee is more than 150*” and “*the company annual sales turnover is more than £3.68 million*” are known as *procedural* parts. Since OR represents *connector* to these statements, if at least one of these statements is true, then the action will result the statement of “*the company is classified as a large company*”, which is called *consequence* or conclusion.

If both statements are false, the next statements of “*the number of full time employee is between 51 and 150*” and “*the company annual sales turnover is between £1.47 million and £3.68 million”* will be tested. Since AND represents *connector*, both statements need to be true to result the statement of “*the company is classified as a medium company*”. Otherwise, the action will result the statement of “*the company is classified as a small or micro company*”. The explanations of other components of KBS in the subsequent sections refer specifically to this type of production rule-based system.

2.6.1.3 Inference Engine

The inference engine is the brain of the KBS and refers to the control program or rule interpreter (Turban et al., 2005). It decides how and when facts and rules in the knowledge base are to be used in making decisions. In making inferences to the knowledge base, the inference engine utilises reasoning techniques before the conclusion and suggestion can be obtained (Udin, 2004). In controlling the mechanism of inferencing, backward chaining and forward chaining approaches are used. These approaches are illustrated in Figure 2.5

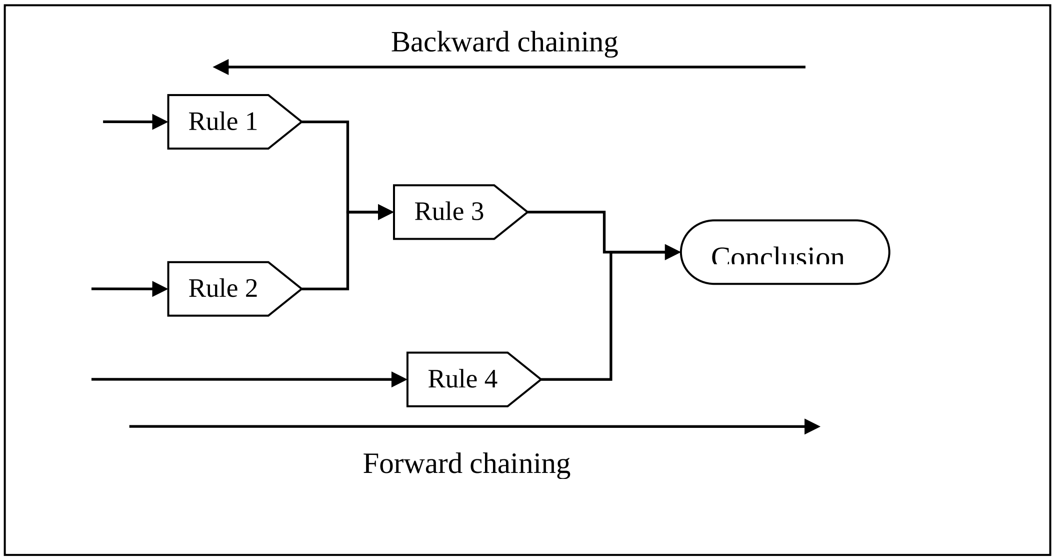


Figure 2.5: Forward Chaining and Backward Chaining Approaches (adapted from Udin (2004))

In the backward chaining approach, the chaining checks the premise or consequence of every rule in the KB based on existing assertions. Also known as goal-driven approach, it works backward from the goal to find supporting data (Awad, 1996). This backtracking process tests every rule and fact that leads to the conclusion. On the other hand, in the forward chaining approach, the basic data are tested against the rules in the KB until a conclusion is drawn (Udin, 2004). This approach is also known as data-driven approach.

2.6.1.4 Blackboard

The blackboard or working memory is an area for the description of a current problem according to the user-input data. According to Turban et al. (2005), the blackboard records an immediate hypothesis and three types of decisions: plan, agenda and solution. The Blackboard is different from database, in that it is similar to the concept of Random Access Memory (RAM) in computer systems. The contents of the blackboard are changed according to the problem situation.

2.6.1.5 Knowledge Acquisition Interface

In KBS, human participation is divided into two categories. The first category is where the end user of the KBS is a non-expert user who uses the system in seeking expert advice relating to a particular domain of problem. The second category of human participation in the KBS is in the knowledge acquisition process (Awad, 1996).

There are many sources of knowledge acquisition which include knowledge from the published materials, interview with the experts, observations of experts at work, and induction of rules from examples. The most common way identified is the comprehensive interview with the experts (Hussain, 1998; Wibisono & Khan, 2003) . In this process, specific steps used are listed in Table 2.6

Table 2.6: Steps of Knowledge Acquisition (adapted from Wibisono & Khan (2003))

Step	**Description**
Problem discussion	The knowledge engineer and domain expert(s) explore the kind of data, knowledge and procedures needed to solve specific problems.
Problem description	The expert describes a prototype problem for each category of answer in the domain.
Problem analysis	The knowledge engineer asks a series questions from the expert to solve the problem while looking for the rationale behind the reasoning steps.
Refinement	The knowledge engineer solves a series of problems using the rules and procedures acquired during the interview with experts.
Verification	The expert examines and criticise the prototype rules and evaluates the control strategies used to select the rules.
Validation	The knowledge engineer presents the cases solved by the expert and prototype system to other experts to compare their strategies and problem solving approaches

The knowledge acquisition process involves the knowledge engineer and the expert. The knowledge engineer, normally the system developer, is the person who interviews and listens to the human expert and is able to interpret and structure the knowledge into the language that is understood by the KBS in a particular problem domain (Wibisono & Khan, 2003)

2.6.1.6 Domain Expert

The domain expert is the person who possesses the special knowledge, experience, skills and judgement in solving problems in a particular problem domain. The expert knows the importance and relationship of the facts and provides this to the knowledge engineer or directly to the knowledge base. In addition, the expert also provides the skill on how to solve the problem that the KBS will perform. Apart from the expert, the knowledge engineer also extracts the knowledge from written documents and translates it into the system. The extracted knowledge should be consistent, accurate and complete in order to make the KBS work effectively (Udin, 2004).

2.6.1.7 End User

The user interface is the location where the end user communicates with the system by providing all the inputs, conditions and other relevant information to the problem being tackled. In designing the user interface, there are two important components that should be considered: firstly, the screen display and secondly, the user interaction through input devices. The effectiveness of these components can contribute in enhancing the performance of the system (Giarratano & Riley, 2005)

2.6.2 Advantages and Disadvantages of KBS

KBS have the capabilities in providing solutions and justifications for the given solutions. Furthermore, KBS also play a significant role in transferring and reproducing expertise. According to Mallach (2000), there are some advantages and disadvantages of KBS when compared to human experts and these are listed in Table 2.7

Table 2.7: Advantages and Disadvantages for Human Experts and KBS (Source: Udin (2004))

Dimensions	**KBS**		**Human Expert**	
	Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Speed	Faster			Variable
Cost	No cost while not use	High initial cost	No development cost	Regular payment
Performance	Consistent	Knowledge updated periodically	Knowledge updated constantly	Variable
Availability	Normally weekdays		Always available	
Sustainable	Yes			No
Emotion	No	No common sense	Able to use common sense	Yes

The development of KBS is not to replace the human in the decision-making, but is used as a supportive tool in order to assist in providing guidance for the decision-making process. In addition, KBS is limited to a narrow domain of expertise and in certain cases there is a difficulty in knowledge acquisition when the knowledge is limited or cannot be accessed.

2.6.3 Tools for KB System Development

There are many tools that have been used for building KB Systems (KBS). The tools vary from general programming languages, such as *C* and *Pascal* to special purpose AI languages such as *PROLOG* and *LISP*. However, using these kinds of languages requires the developer to build the KB system’s user interface from beginning and implement appropriate inference engine (Darlington, 1997). To avoid this time-consuming process, software programs known as “shells" are mostly used nowadays.

Shells offer an easy starting point for KBS building because they are KB systems which have been emptied of their knowledge. This means that developers can concentrate on entering the KB without having to build everything including the inference engine and user interface. Even non-programming experts can familiarise themselves with shells fairly rapidly. Also, many ES shells contain tools which can simplify the knowledge acquisition process. There are several shells commercially available. These include: XPERT RULE, AM for Windows, and Leonardo (Darlington, 1997).

In this research, the KBS shell known as *Application Manager for Windows* (AM) is used in developing the KBS, due to its availability, ease of use, and previous successful researches (A. Khan & Day, 2002; M. K. Khan & Hafiz, 1999; Udin, 2004; Wibisono & Khan, 2003). AM is designed and developed by Intelligent Environments Inc. as an upgraded version of *Crystal* which was based on the DOS environment. AM uses a highly interactive interface and includes a wealth of database access with remote system connectivity. This enables users or developers to develop a powerful stand alone or client/server applications easily and quickly. AM uses production rules techniques in representing knowledge that is stored in the application. The base component available in AM software is called modules which consists of *procedures*, *commands*, *variables*, *windows*, *functions* and *menus* (AM, 2002). Appendix A explains in detail each of these elements.

2.7 Review of Gauging Absences of Pre-requisites (GAP)

Gauging Absences of Pre-requisites (GAP) analysis is a technique that is used to measure the performance disparity between the organization's actual environment and an ideal one, resulting in knowledge of the desirable prerequisites for an effective implementation (Udin, 2004; Wibisono & Khan, 2003).

According to the scope of this research, GAP analysis has three objectives. The first objective is to identify the main elements for initiatives implementation from the proposed KBS. The second objective is to provide a quantitative basis for comparing the status in the present condition with the future requirement for the effective functioning of the initiatives. Finally, the third objective is to identify the strengths and weaknesses of current practices in manufacturers, suppliers, and customers so that some practices can be aligned or amended for suitability in the new collaborative environment (Udin, 2004).

The GAP analysis in the proposed KBS is conducted through the responses of the user to the questions provided. The problems highlighted for each negative reply are classified into five categories, which are structured in descending order of importance (Udin, 2004; Wibisono & Khan, 2003) and shown in Table 2.8

The code is used to identify whether the response given by users is in the Good Point (GP) Category or Bad Point (BP) Problem Category (PC). The PCs is ranked from 1 to 5 (PC1 to PC5), as shown in Table 2.8, with PC1 being the most critical condition. Due to the aim of the system to identify the missing pre-requisites that are needed in order to make the implementation of improvement initiatives a success, only the BPs are categorised into PCs.

Table 2.8: Problem Categories and Description of GAP Analysis Technique (Source: Kochhar et. al. (1991), Wibisono (2003), Udin (2004))

Problem Category	**Code**	**Description**
1	PC1	This indicates a serious problem, which should and can be resolved in the short term and the result of the problem is quite likely to provide a real short-term benefits.
2	PC2	This indicates a serious problem, which is likely to have pre-requisites and is better dealt with as part of an appropriate and logical improvement and implementation plan.
3	PC3	This is not a serious problem and can be dealt with now. If resolved, it is likely to produce short-term benefits.
4	PC4	This is not a serious problem. Although it could be dealt with now, it is unlikely to produce short-term benefits. Therefore, it should only be dealt with if it is a pre-requisite for other things.
5	PC5	This is not really a Good or Bad point it self. The questions associated with this category are primarily asked to identify certain situations in the environment, which upon subsequent probing by succeeding questions may well reveal problems.

From this result, the missing pre-requisites of the current position of manufacturers, suppliers, and customers can be identified through the number of PCs.

2.8 Review of Analytic Hierarchy Process (AHP)

Decision-making is a process of selecting the best alternative from the various alternatives to achieve a specific goal or objective. Based on the literature, there are several techniques of decision-making that are used in organizations. Apart from utilising the application in IS, one technique that is currently accepted in supporting the decision-making process is Analytic Hierarchy Process (AHP). AHP was first developed and introduced by Saaty in 1970s (Saaty, 2001), and is a decision making tool that supports in dealing with complex, unstructured and multi-attribute problems.

The application of AHP is widely accepted in various areas such as operation management, manufacturing, economics, business, and information technology (Render, Ralph M. Stair, & Hanna, 2006). With its ability to mimic human opinions in structuring a complex and multi-attribute problem, AHP has significantly improved the performance of the decision-making process in organizations. Razmi, Rahnejat, and Khan (2000) stressed that the AHP is a powerful tool, which can be used to deal with multi-attribute and complex problems particularly in selecting and prioritising an alternative for improvement purposes. AHP has the capability to compare the alternatives and make a comparison amongst the alternatives before the optimum solution can be suggested.

2.8.1 Application of AHP in Production and Operations Management (POM)

AHP has been applied to several decision problems related to POM. Some of the recent areas of research are shown in Table 2.9.

Table 2.9: Application of AHP in POM

Authors	Area of Application	Description
(Sharma & Agrawal, 2008)	Production control	AHP is used to analyse production policies of Kanban, CONWIP and Hybrid Push-Pull as alternatives for controlling the engineering manufacture
(Aguilar-Lasserre, Bautista Bautista, Ponsich, & Gonzalez Huerta, 2008)	Design	Integrating AHP with AI techniques to design batch plants with imprecise demands in product amounts.
(Rabelo, Eskandari, Shaalan, & Helal, 2007)	Supply Chain	Analysis the service and manufacturing activities of the global supply chain of a multinational construction equipment corporation using hybrid AHP/simulation.

2.8.2 AHP Development Process

There are three basic steps or principles in AHP, which are structuring hierarchies, setting priorities and logical consistency (Saaty, 2001). Each of these steps is described in the following sections.

2.8.2.1 Structuring Hierarchies

AHP divides the complex multiple criteria of problems into a hierarchy, where each layer consists of specific elements. The structure of this hierarchy is shown in Figure 2.6.

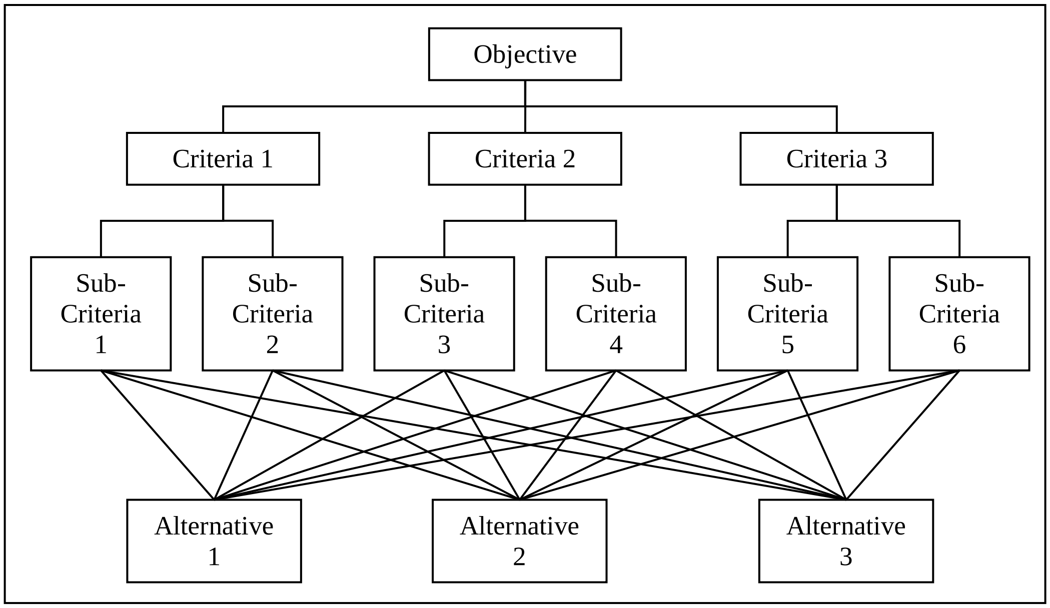


Figure 2.6: Structure of Hierarchy within AHP

The top layer of the hierarchy, referred to as a goal or objective, is the focus of the analysis. The lowest level of the hierarchy is called alternatives, which contribute positively or negatively towards the main objective through their impact on the criteria in the intermediate level. The intermediate level consists of criteria or attributes that may have several elements that affect the decision.

2.8.2.2 Setting Priorities

Once the problem is constructed into a hierarchy, the pair-wise judgement is conducted, which starts at the second level and finishes in the lowest level. This pair-wise judgement is done in order to prioritise each of the elements to determine their importance. Each pair-wise comparison is quantified accordingly to Saaty (2001), by assigning it a number from 1 to 9. The scale for the comparison is shown in Table 2.10

Table 2.10: Scale for Pair-Wise Comparisons

Intensity of Importance	Definition
1	Equal importance
2	Very Weak importance
3	Weak importance
4	Moderate importance
5	Importance
6	Strong importance
7	Very strong importance
8	Almost absolute importance
9	Absolute importance

For pair-wise comparison, these elements are structured into the form of a matrix. The matrix is a simple tool that provides a framework for consistency testing. Following Saaty (2001), to begin the comparison process, the property or basis (C) is selected from the top of hierarchy, while elements in the next level of hierarchy are selected for comparison. Figure 2.7 below illustrates the sample of a matrix for the pair-wise comparison.

C	A1	A2	A3
A1	1	A1/A2	A1/A3
A2	A2/A1	1	A2/A3
A3	A3/A1	A3/A2	1

Figure 2.7: Matrix for Pair-Wise Comparison

Based on the normalised matrix, the test of consistency is done in order to make sure the judgement made by the decision-maker is good. The AHP measures the judgement presented in the matrix by using Consistency Ratio (CR) (Saaty, 2001)).

2.8.2.3 Logical Consistency

The consistency of the matrix is important to maintain, since it reflects the decision made by the decision–maker (Saaty, 2001). Since the judgement made by users cannot be so certain, consistency could be forced into the matrix. On this principle, the AHP process determines the consistency of the matrix based on the Consistency Ratio (CR). The value of CR should be 10% or less, and if it is more than 10%, the decision-maker should review the judgement. The mathematical process integrates the weights to develop overall evaluation of the decision alternatives. The example of the mathematical process for performing the calculation in the AHP is explained in Appendix B.

2.8.3 Hybrid System

Based on algorithm developed by Wibisono and Khan (2003), supported by Udin (2004), the utilisation of this hybrid approach (the combination between the GAP analysis and the AHP approach) required specific algorithms in the process to match the five-point scales of Problem Categories (PC) in the GAP analysis and the nine-point scales of Intensity of Importance in the AHP technique. Since these nine-point scales are used in the prioritisation process of AHP, there is a need to transfer all five-point scales of PC into AHP point scales. The detail explanations of the transfer algorithm and the performance score are discussed in Appendix C. Table 2.11 shows the guide for transferring performance scores in GAP in intensity of importance in AHP.

Table 2.11: Guide for Transferring Performance Scores into Intensity of Importance

Intensity of importance in AHP	**Definition**	**Explanation**	**Performance Score (S) in GAP**
1	(A) is equal importance with (B) in improvement priority	Two activities contribute equally to the objective	S = 0
2	(A) is very weak importance with (B) in improvement priority	Experience and judgement very slightly favour one activity over another	0 < S ≤ 50
3	(A) is weak importance of (B) in improvement priority	Experience and judgement slightly favour one activity over another	50 < S ≤ 100
4	(A) is moderate importance of (B) in improvement priority	Experience and judgement moderately favour one activity over another	100 < S ≤ 150
5	(A) is importance than (B) in improvement priority	Experience and judgement favour one activity over another	150 < S ≤ 200
6	(A) is strong importance than (B) in improvement priority	An activity is favoured strongly over another	200 < S ≤ 250
7	(A) is very strong importance than (B) in improvement priority	An activity is favoured very strongly over another; its dominance is demonstrated in practice	250 < S ≤ 300
8	(A) is almost absolute importance than (B) in improvement priority	The evidence favouring one activity over another is almost of the highest possible order of affirmation	300 < S ≤ 350
9	(A) is absolute importance than (B) in improvement priority	The evidence favouring one activity over another is of the highest possible order of affirmation	350 < S ≤ 400

Based on Table 2.11, each component is assigned with the Intensity of Importance scale in the form of matrices, where the mathematical process starts, in order to normalise and find the priority weights for each matrix. Since the consistency of the pair-wise comparison is important to confirm the result validity, the Consistency Ratio (CR) for each matrix is measured and if the CR is bigger than 0.10, it implies that there is a 10% chance that the elements have not been compared well and the decision-maker must review the comparison again.

The utilisation of AHP and GAP analysis in the KBS makes it more manageable and the possibility of accurate calculation is higher. In essence, the AHP analysis determines the priority of importance between the main modules (criteria) whereas the GAP analysis determines the priority of improvement internally to each module (criteria).

2.9 Summary

This chapter has provided review of Knowledge Based Systems (KBS), and the proposed embedded techniques, GAP and AHP. In the business and manufacturing environments, the applications of KBS are widely used for supporting management in decision making, planning and designing processes. In the manufacturing environment, the application of KBS can be classified into five main areas, which are design, process planning, quality, scheduling, planning and control activities. In manufacturing system, KBS is used in the area of procurement or purchasing, and relates to issues such as planning, production, and quality management. This application provides some advantages to organizations in managing the collaborative green manufacturing, and helps organizations in satisfying customer through quality improvement and cost reduction.

In this research, the *AM for Windows* (AM) software is used as a development tool for KBS system in developing a CGMM along with Analytic Hierarchy Process (AHP) which is embedded in the system. Basically, the AHP is a tool that is used to support management in problem-solving processes that relate to multi-attribute problems that occur in day-to-day (but complex) operations. In developing CGMM, the AHP is used to prioritise the factors that are needed for improvement, and based on a series of questions that have been analysed by the GAP analysis technique. Furthermore, the description on how transferring, calculating and displaying the AHP prioritisation result has been discussed.

CHAPTER THREE
FRAMEWORK AND METHODOLOGY

This chapter presents the framework and methodology for this research. The main activities of the research are presented in Section 3.1. Section 3.2 describes the methodology and the chapter summary is presented in the last section.

3.1 Research Framework

The framework is developed as a roadmap that intends to provide guidelines in doing the research as shown in Figure 3.1. The research framework starts with the design of the conceptual model. The second stage is the development of the KBCGMM model which also covers the verification, validation and analysis of the model. This is followed by the investigation on real industry cases.

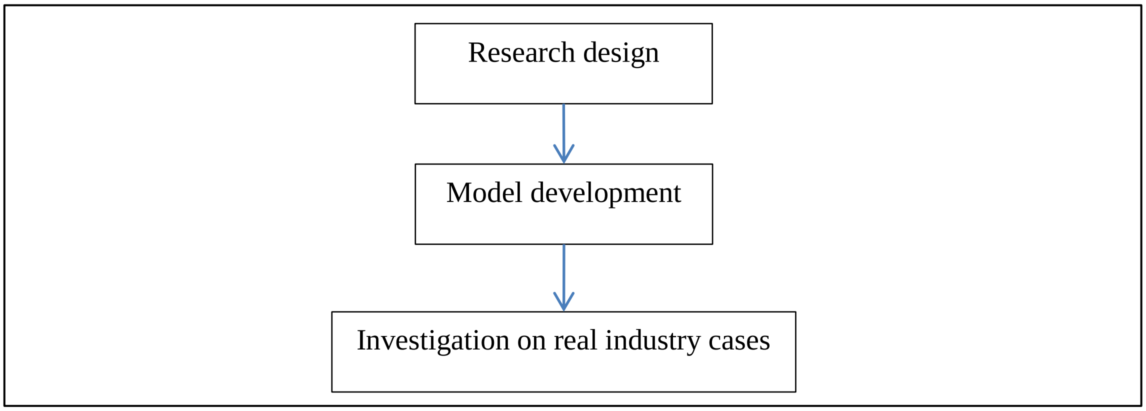


Figure 3.1: Research framework

3.2 Research Methodology

This research starts with extensive literature survey on green technology and manufacturing management practices. Investigation to determine the recent status and development on green technology and manufacturing management practices in the automotive industry have been carried out. Knowledge, understanding and culture of green manufacturing philosophy within this industry community were captured, in order to develop the theoretical framework and design for CGMM (Phase 1).

Then based on the outcome of Phase 1, a conceptual model of CGMM has been developed. The model will was translated into an expert system (Phase 2). For the verification purpose, we demonstrated the system to the domain experts of both green manufacturing and supply chain. We present it to relevant stakeholders in order to gain feedback and improve the reliability and validity of the system.

The system developed then has been validated further using some real industry cases to determine the suitability and practicality of the developed model (Phase 3). Using the developed system, we investigate some related problems in some automotive and automotive related manufacturers to formulate policies and recommendations for green manufacturing management.

3.3 Framework of KBCGMM Model

Chapter 2 has surveyed essential elements of CGMM, which covered green and lean management. The information gathered from the literature review was interpreted and "translated" into a KB. This KB will be used as the main foundation of the conceptual model framework. Concurrently, other general elements of any manufacturers, such as organization environment, market, finance, and supply chain will also be reviewed in this section as part of the conceptual model development.

In order to develop the conceptual model, some of general approaches of IDEFØ modelling technique were adapted. IDEFØ is a systematic method used to model the actions, activities, and decisions of an organization or system (IDEF0, 1993). The conceptual model emphasizes three stages: Planning, Design and Implementation.

In Stage 1 (Planning Stage), there are two major sets of information that need to be considered: *Collaborative Business* and *Green Manufacturing* perspectives. Profile of organization is the first component needed in the *Collaborative Business* perspective. This component is used to gather the general information of the organization environment, and much related to the organization's financial status and market share (Udin, Khan, & Zairi, 2006). These financial and market components need to be analysed to evaluate the strength of the organization in planning the strategy for CGMM achievement. For that reason, the inter-related elements of *Organization Environment*, *Financial Analysis* and *Market Analysis* are identified to be assessed in the *Collaborative Business* perspective of the model.

As operations are the heart of any manufacturing organization, a component to gather the strategy of the organization towards CGMM is needed. This component, *Green Manufacturing* perspective is needed to gather the information on how green the organization in term of product design, production, internal relationship, and external relationships with suppliers and customers (Nawawi, Khan, & Hussain, 2007). For that reason, three elements are identified to be assessed: *Product Design for Manufacture*, *Internal Green Chain*, and *External Green Chain* which is linked to *Collaborative Business* perspective. It can be seen that the Stage 1 involves planning elements of the organization’s strategy. This strategy then needs to be designed accordingly to successfully achieve CGMM, and contained in Stage 2.

In Stage 2 (Design Stage), there are two major sets of information that need to be considered. The capability of the organization to compete in the business is the first component that needs to be evaluated. This element, *Organization CGMM Capability* is assessed based on the organization capabilities in terms of quality, time, flexibility, value (cost), and supply chain (Nawawi, Khan, & Hussain, 2008). At the same time, the organization’s resource capabilities of human, technology, and finance which play important roles to achieve CGMM need to be identified.

Since business success mainly depends on customers, the organization’s efforts on the operational processes need to be aligned to acquire and satisfy the customers. The involvement of all employees, identifying and elimination non-value adding activities, and continuously improve the manufacturing process are the elements identified to ensure the customers loyal to the organization.

In essence, all elements in Stage 1 and Stage 2 are inter-related and can be integrated as shown in Figure 3.2.

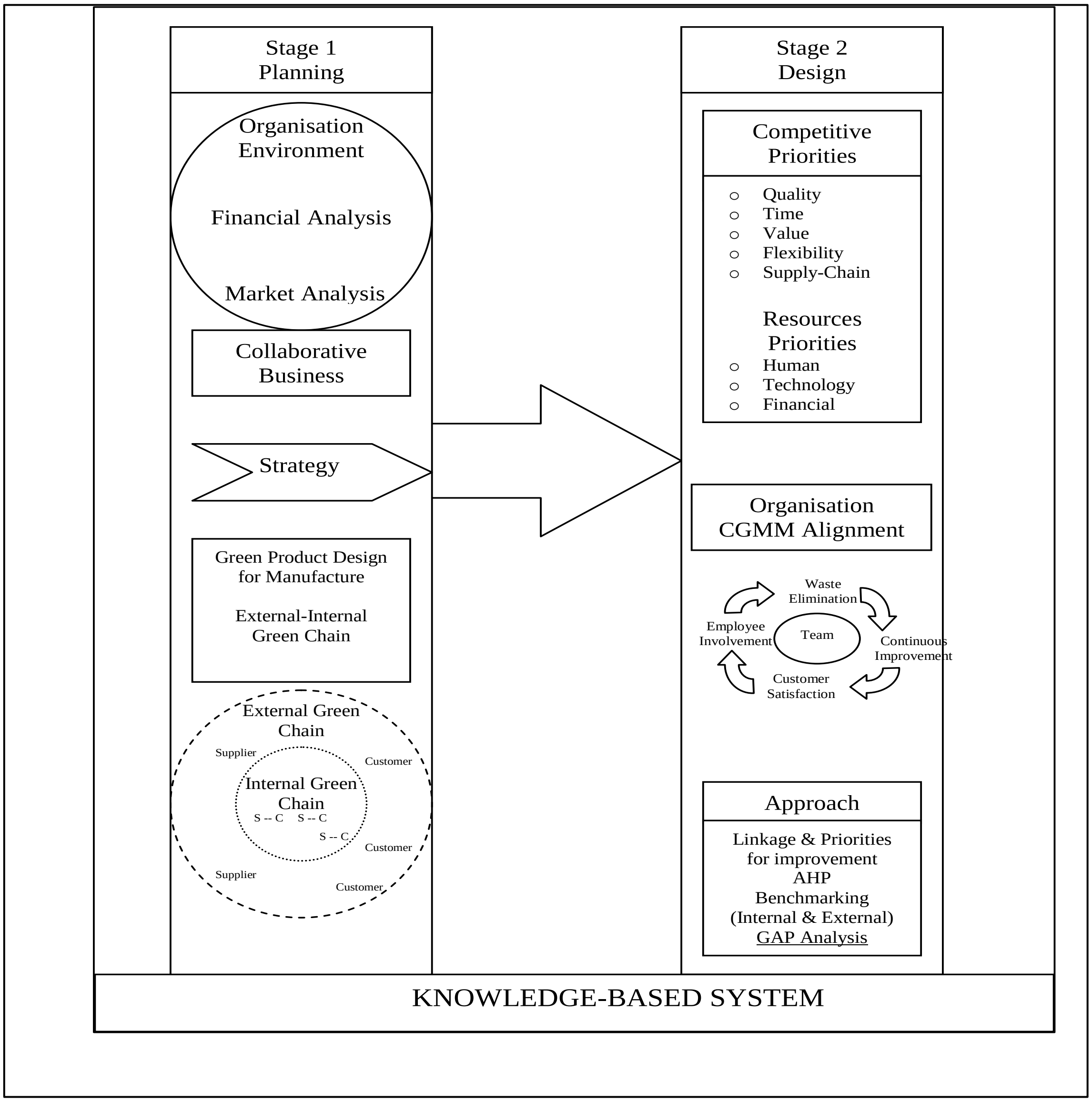


Figure 3.2: Conceptual Model for KBCGMM

CHAPTER FOUR

KNOWLEDGE-BASED COLLABORATIVE GREEN MANUFACTURING MANAGEMENT (KBCGMM) MODEL AND ANALYSIS

4.1 Structure of KBCGMM System

As clearly stated in the second objective of this research, the need to develop a knowledge-based (KB) system requires the conceptual model shown in Figure 3.2 to be converted into a structured model. Strategic issues in the conceptual model are contained in the planning stage (Stage 1) of the model, while tactical and operational issues are more relevant to the design stage (Stage 2) of the model.

To enable the conceptual model to be developed into KB system, clear KBCGMM Model needs to be clearly structured in hierarchical levels from most strategic issue to the most operational issues as shown Figure 4.1, reflecting in a way, the hierarchical strategic and operational issues of the organization. The KBCGMM Structure reflects the potential of detailed KBCGMM System which will be developed and discussed in the following two chapters.

For this reason, Stage 1 is divided into three levels (Level 0 to Level 2). *Organization Environment* is identified as the most strategic issue and placed in Level 0 to gather the basic profile of the organization for the purpose of identification and reference. As market and financial status are much related to the strength of the organization business, Level 1 contains *Market Analysis* and *Financial Analysis*. Other strategic issues which related to the organization operations are placed in Level 2, which includes *Product Design for Manufacture*, *Internal Green Chain*, and *External Green Chain*.

For the tactical and operational issues, five competitive priorities of *Quality*, *Time*, *Flexibility, Value* and *Supply Chain* are transferred to Level 3. While Level 3 contains the competitive priorities capability, Level 4 consists of the capabilities of the organization's resources: *Human*, *Technology* and *Financial*. The most operational issues, i.e. the identified processes to align the CGMM to achieve customer satisfaction are located in Level 5, which includes *Employee Involvement*, *Waste Elimination* and *Continuous Improvement*. Finally, the mechanism steps of implementation in Stage 3 are linked to each of the process in Level 5. These steps are *Performance Measurement*, *Benchmarking*, *Evaluation*, *Diagnosis* and *Action Plan*.

Based on this structure, a clear relationship is shown between conceptual components in the Stages 1, 2 and 3 of the model by dividing them into six CGMM perspectives. These perspectives were developed according to their relevance to the CGMM development, based on the elements or variables that were derived from the previous green manufacturing management literature discussed in Chapter 2. The KBCGMM Model is developed in the Knowledge-Based environment, based on the capability of the *AM for Windows* expert system shell.

In Figure 4.1, it is clearly shown that the KBCGMM System is developed on six interrelated levels (Level 0 down to Level 5). The core of the KBCGMM System extends from Level 1 to Level 5. From a strategic management point of view, both Levels 1 and 2 could be considered as corporate or strategic decision levels while the remaining Levels 3 to 5 are considered as functional or operational decision levels. This six-level structure of the KBCGMM System also reflects a typical functional hierarchy of most companies, leading to a very practical KB model. Each of these components (or modules, as viewed in the *AM for Windows* software) in every perspective will be discussed.

Since the KBCGMM Model is embedded with GAP analysis and AHP technique for improvement prioritization, the assessment and evaluation of the organization’s current situation will be conducted through a series of questions that are contained in every module from Levels 0 to 5 in the System. These modules are considered as criteria, and based on the points gathered from these questions, the AHP technique will be used to prioritize every criterion.

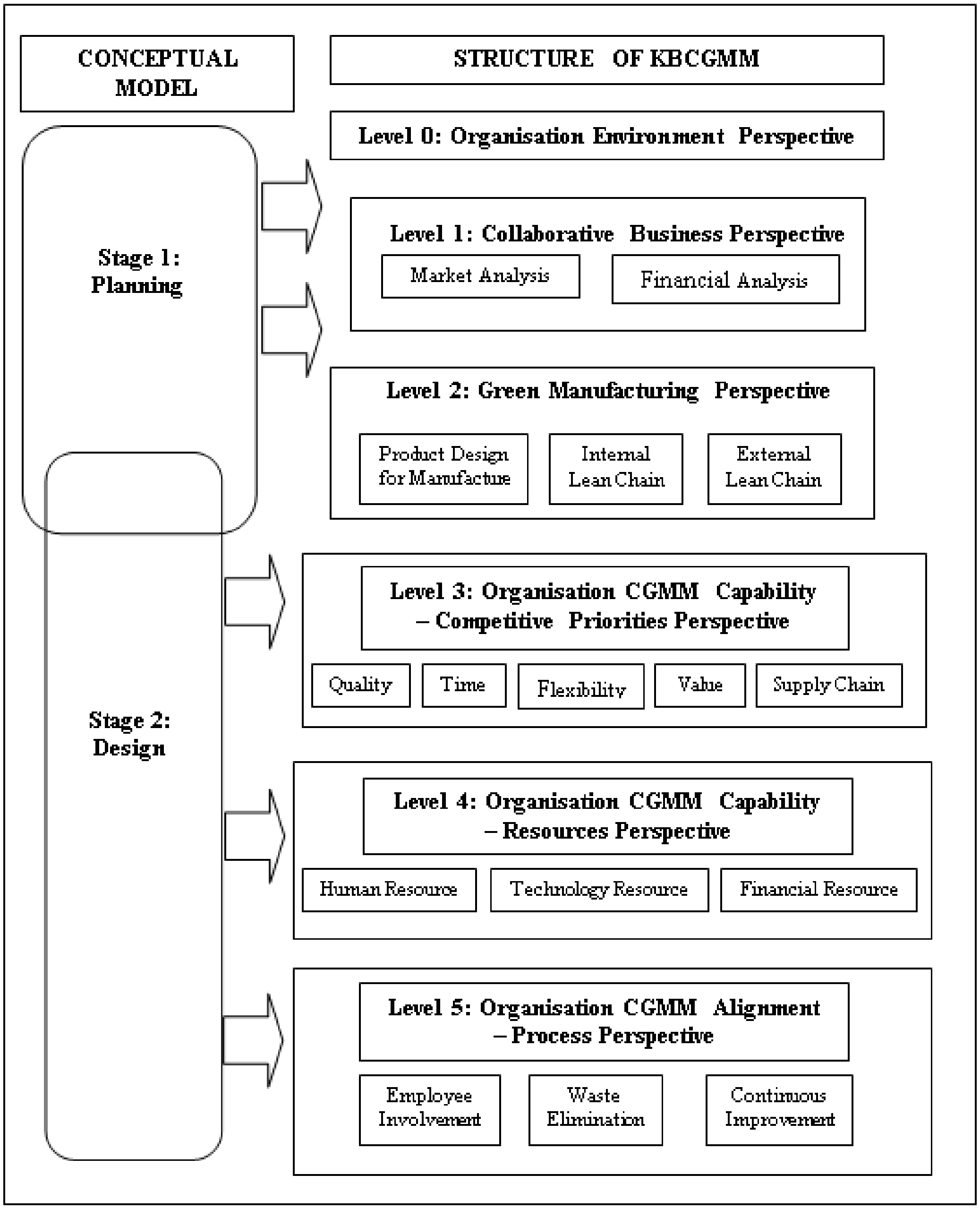


Figure 4.1: Conversion of Conceptual Model to Structure of KBCGMM System

4.2 Industrial Case Validation and Analysis

The previous discussion has focused on a detailed validation of the KBCGMM within Company A. The following sections summarize the results analysis for Company A as well as the other company.

4.2.1 Analysis for Company A

Table 4.1 shows the summary results of KBCGMM Model verification and validation in terms of GAP Analysis for Company A. Out of a total of 472 KB rules that were responded, 388 were *Good Points* and 84 were *Bad Points* (representing 18.6%). The number of *Bad Points* indicates the present performance gap of the organization relative to the best practice standard contained in the model.

Table 4.1: Summarized GAP Analysis Results for Company A

Perspective	**Module**	**No of Questions**	**GAP Analysis**						
			GP	BP	Problem Category				
					1	2	3	4	5
Level 2: Green Manufacturing	Product Design for Manufacture	84	75	9	2	0	0	7	0
	Internal Green Chain	49	41	8	6	0	0	2	0
	External Green Chain	32	24	8	5	1	1	0	1
	Total	**165**	**140**	**25**	**13**	**1**	**1**	**9**	**1**
Level 3: Competitive Priorities	Quality	52	42	10	3	3	1	0	3
	Time	33	17	16	4	0	6	0	6
	Flexibility	29	26	3	3	0	0	0	0
	Value	25	17	8	5	0	3	0	0
	Supply Chain	15	15	0	0	0	0	0	0
	Total	**154**	**117**	**37**	**15**	**3**	**10**	**0**	**9**
Level 4: Resources	Human	51	48	3	0	2	1	0	0
	Technology	34	28	6	5	1	0	0	0
	Financial	21	14	7	0	0	0	7	0
	Total	**106**	**90**	**16**	**5**	**3**	**1**	**7**	**0**
Level 5: Process	Employee Involvement	21	18	3	0	0	3	0	0
	Waste Elimination	11	9	2	0	2	0	0	0
	Continuous Improvement	15	14	1	0	1	0	0	0
	Total	**47**	**41**	**6**	**0**	**3**	**3**	**0**	**0**
	Grand Total	**472**	**388**	**84**	**33**	**10**	**15**	**16**	**10**

It can be seen that in the Level 2: *Green Manufacturing* Perspective, 15.2% (25 out of 165) of the responses was *Bad Points*. In the other levels, the percentages of *Bad Points* are: 24.0% (37 out of 154) in the Level 3: *Competitive Priorities* Perspective, 15.1% (16 out of 106) in the Level 4: *Resources* Perspective, and 12.8% (6 out of 47) in the Level 5: *Process* Perspective.

Table 4.2 shows the summary results for the AHP Analysis in terms of *Priority Vector* values. From the results, KBCGMM acts as a decision support system to the organization by showing the actions needed to be tackled in a prioritized order. It needs to be reiterated that if GAP Analysis provides the performance gaps of the organizations relative to the best practice for each activities within a module and a sub-module, then AHP provides the improvement initiative priorities across the modules and sub-modules. The bold figures show the priorities for each perspective. For example in the Level 2: *Green Manufacturing* Perspective, Company A needs to focus first on improving the *External Green Chain* activities, and within this module it needs to focus on *Integration with Suppliers* sub-module. Furthermore, the GAP Analysis discussed earlier for this *Integration with Suppliers* sub-module has identified the key aspects which need to be overcome to achieve the duly best practice.

Table 4.2: Summary of AHP Priority Vector Values for Company A

Perspective	**Module**	**Priority Vector**	**Sub-Module (with Priority Vector)**		
Level 2: Green Manufacturing	Product Design for Manufacture	0.1638	Conceptual Design 0.2680	Design Tools for Analysis 0.1946	Product Development **0.5374**
	Internal Green Chain	0.2973	Internal Continuous Improvement 0.2500	Internal Process Control **0.7500**	
	External Green Chain	**0.5390**	**Integration with Suppliers** **0.6667**	Integration with Customers 0.3333	
Level 3: Competitive Priorities	Quality	0.1246	Quality in Supply 0.2000	Quality in Production **0.6000**	Quality in Delivery 0.2000
	Time	0.2519	Time in Supply 0.2014	Time in Production 0.1179	Time in Delivery **0.6806**
	Flexibility	0.1773	Flexibility in Supply 0.2000	Flexibility in Production **0.6000**	Flexibility in Delivery 0.2000
	Value	**0.3591**	Material Cost 0.2500	Production Cost 0.2500	**Resource Cost** **0.5000**
	Supply Chain	0.0870	Location 0.5000	Logistics 0.5000	
Level 4: Resources	Human	0.1593	Development **0.5000**	Support 0.2500	Values 0.2500
	Technology	**0.5889**	Technology Management 0.1111	Process Technology 0.1111	**Information Technology** **0.7778**
	Financial	0.2519	Financial for Human **0.4905**	Financial for Technology 0.1976	Financial for Implementation 0.3119
Level 5: Process	Employee Involvement	0.1976	Measurement & Benchmark **0.6667**	Evaluation, Diagnosis & Action 0.3333	
	Waste Elimination	**0.4905**	Measurement & Benchmark 0.3333	**Evaluation, Diagnosis & Action** **0.6667**	
	Continuous Improvement	0.3119	Measurement & Benchmark 0.3333	Evaluation, Diagnosis & Action **0.6667**	

Based on both AHP and GAP Analysis results provided by the KBCGMM, Figure 4.2 shows the summary of identified areas or activities that need priority improvement for Company A. In Level 2, *External Green Chain* is the module needs to be in the first priority for immediate improvement mainly *Integration with Suppliers* activity. For Level 3, Company A needs to prioritize first on *Value* especially on *Resources Cost*.

In Level 4, Company A needs to focus first on *Technology Resource* with special attention to *Information Technology*. Finally in Level 5, *Waste Elimination* module needs attention with priority on *Evaluation, Diagnosis & Action Plan* activity. Thus all the high level, mid-level and low level modules can be analysed in a step-by-step, prioritized manner to improve the CGMM.

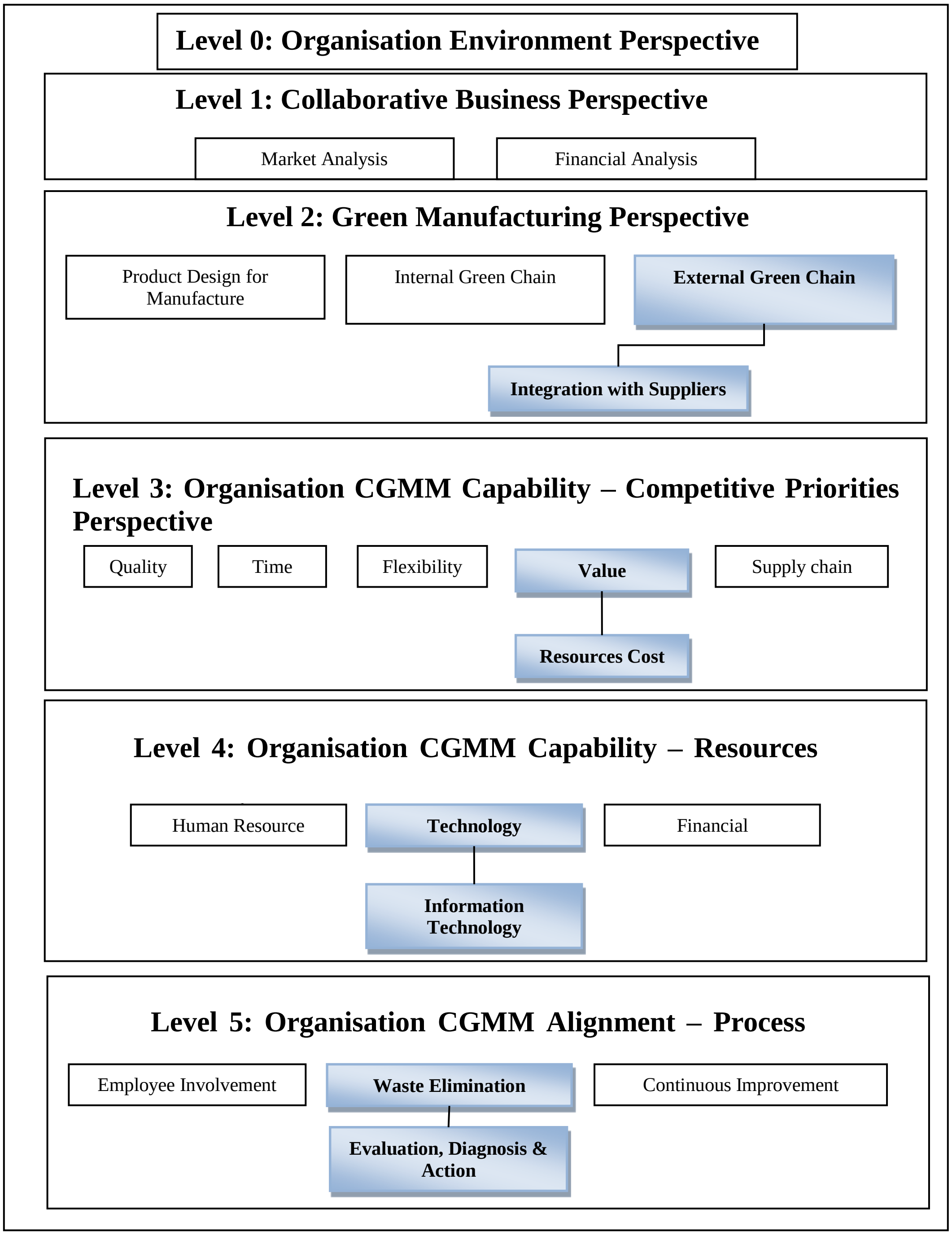


Figure 4.2: The Immediate Improvement Areas or Activities for Company A Based on AHP/GAP Analysis Embedded in KBCGMM

4.2.2 Analysis for Company B

Table 4.3 shows the summary results of KBCGMM Model verification and validation in terms of GAP Analysis for Company B (supplier to Company A). There were 368 *Good Points* and 96 *Bad Points* (representing 20.7%) out of 464 KB rules that were responded. The number of *Bad Points* indicates the present performance gap of the organization relative to the best practice standard contained in the model.

Table 4.3: Summarized GAP Analysis Results for Company B

Perspective	**Module**	**No of Questions**	**GAP Analysis**						
			GP	BP	Problem Category				
					1	2	3	4	5
Level 2: Green Manufacturing	Product Design for Manufacture	76	68	8	2	0	0	6	0
	Internal Green Chain	49	40	9	7	0	0	2	0
	External Green Chain	32	24	8	4	4	0	0	0
	Total	**157**	**132**	**25**	**13**	**4**	**0**	**8**	**0**
Level 3: Competitive Priorities	Quality	52	42	10	4	3	1	0	2
	Time	33	17	16	1	0	3	3	9
	Flexibility	29	22	7	5	0	2	0	0
	Value	25	21	4	1	0	3	0	0
	Supply Chain	15	15	0	0	0	0	0	0
	Total	**154**	**117**	**37**	**11**	**3**	**9**	**3**	**11**
Level 4: Resources	Human	51	43	8	1	5	2	0	0
	Technology	34	28	6	5	1	0	0	0
	Financial	21	9	12	0	0	8	4	0
	Total	**106**	**80**	**26**	**6**	**6**	**10**	**4**	**0**
Level 5: Process	Employee Involvement	21	17	4	0	0	4	0	0
	Waste Elimination	11	8	3	0	2	1	0	0
	Continuous Improvement	15	14	1	0	1	0	0	0
	Total	47	**39**	**8**	**0**	**3**	**5**	**0**	**0**
	Grand Total	**464**	**368**	**96**	**30**	**16**	**24**	**15**	**11**

Based on the results in the above table, for the Level 2: *Green Manufacturing* Perspective, 15.9% (25 out of 157) of the responses were *Bad Points*, with most of them are categorized as serious problems (13 PC1 and 4 PC2) compared to only 8 PC4 (not serious problems). In the Level 3: *Competitive Priorities* Perspective, 24.0% (37 out of 154) of the responses were *Bad Points*, with 11 of them were PC1. The *Quality* and *Flexibility* Modules found to be in serious problems with 4 and 5 PC1 respectively.

It can also be seen in Table 4.3 that 26 out of 106 (representing 24.5%) responses in Level 4: *Resources* Perspective were *Bad Points*, with all 5 out of 6 PC1 were contained in *Technology* Module. Lastly in Level 5: *Process* Perspective, 17.0% (8 out of 47) of the responses were *Bad Points*, most of them contained in *Employee Involvement* Module. However, the problems were not as serious as problems found in the other two modules, *Waste Elimination* and *Continuous Improvement* Modules.

Table 4.4: Summary of AHP Priority Vector Values for Company B

Perspective	**Module**	**Priority Vector**	**Sub-Module (with Priority Vector)**		
Level 2: Green Manufacturing	Product Design for Manufacture	0.1638	Conceptual Design 0.3119	Design Tools for Analysis 0.1976	Product Development **0.4905**
	Internal Green Chain	0.2973	Internal Continuous Improvement 0.3333	Internal Process Control **0.6667**	
	External Green Chain	**0.5390**	**Integration with Suppliers** **0.7500**	Integration with Customers 0.2500	
Level 3: Competitive Priorities	Quality	0.2357	Quality in Supply 0.2000	Quality in Production **0.6000**	Quality in Delivery 0.2000
	Time	0.1274	Time in Supply 0.3119	Time in Production 0.1976	Time in Delivery **0.4905**
	Flexibility	**0.3611**	**Flexibility in Supply** **0.5571**	Flexibility in Production 0.3202	Flexibility in Delivery 0.1226
	Value	0.1801	Material Cost 0.1976	Production Cost **0.4905**	Resource Cost 0.3119
	Supply Chain	0.0957	Location 0.5000	Logistics 0.5000	
Level 4: Resources	Human	0.1976	Development 0.2973	Support 0.1638	Values **0.5390**

	Technology	**0.4905**	Technology Management 0.1111	Process Technology 0.1111	**Information Technology** **0.7778**
	Financial	0.3119	Financial for Human 0.3119	Financial for Technology 0.1976	Financial for Implementation **0.4905**
Level 5: Process	Employee Involvement	0.3119	Measurement & Benchmark **0.6667**	Evaluation, Diagnosis & Action 0.3333	
	Waste Elimination	**0.4905**	Measurement & Benchmark 0.3333	**Evaluation, Diagnosis & Action** **0.6667**	
	Continuous Improvement	0.1976	Measurement & Benchmark 0.3333	Evaluation, Diagnosis & Action **0.6667**	

Table 4.4 shows the summary results for the AHP Analysis in terms of *Priority Vector* values. The bold figures show the priorities for each perspective. For example in the Level 3: *Competitive Priorities* Perspective, Company B needs to focus first on improving the *Flexibility* activities (0.3611), and within this module it needs to focus on *Flexibility in Supply* sub-module (0.5571). For the other levels, key results with first priority module and sub-module are: Level 2: *External Green Chain* Module (0.5390) with *Integration with Suppliers* sub-module (0.7500), Level 4: *Technology Resource* Module (0.4905) with *Information Technology* sub-module (0.7778), and Level 5: *Waste Elimination* Module (0.4905) with *Evaluation, Diagnosis & Action* sub-module (0.6667).

Based on both AHP and GAP Analysis results provided by the KBCGMM, Figure 4.3 shows the summary of identified areas or activities that need priority improvement for Company B. In Level 2, *External Green Chain* is the module needs to be in the first priority for immediate improvement mainly *Integration with Suppliers* activity. For Level 3, Company B needs to prioritise first on *Flexibility* especially on *Flexibility in Supply*. In Level 4, Company B needs to focus first on *Technology Resource* with special attention to *Information Technology*. Finally in Level 5, *Waste Elimination* module needs attention with priority on *Evaluation, Diagnosis & Action Plan* activity.

As the case of Company A, all the high level, mid-level and low level modules can be analysed in a step-by-step, prioritized manner to improve the CGMM of Company B.

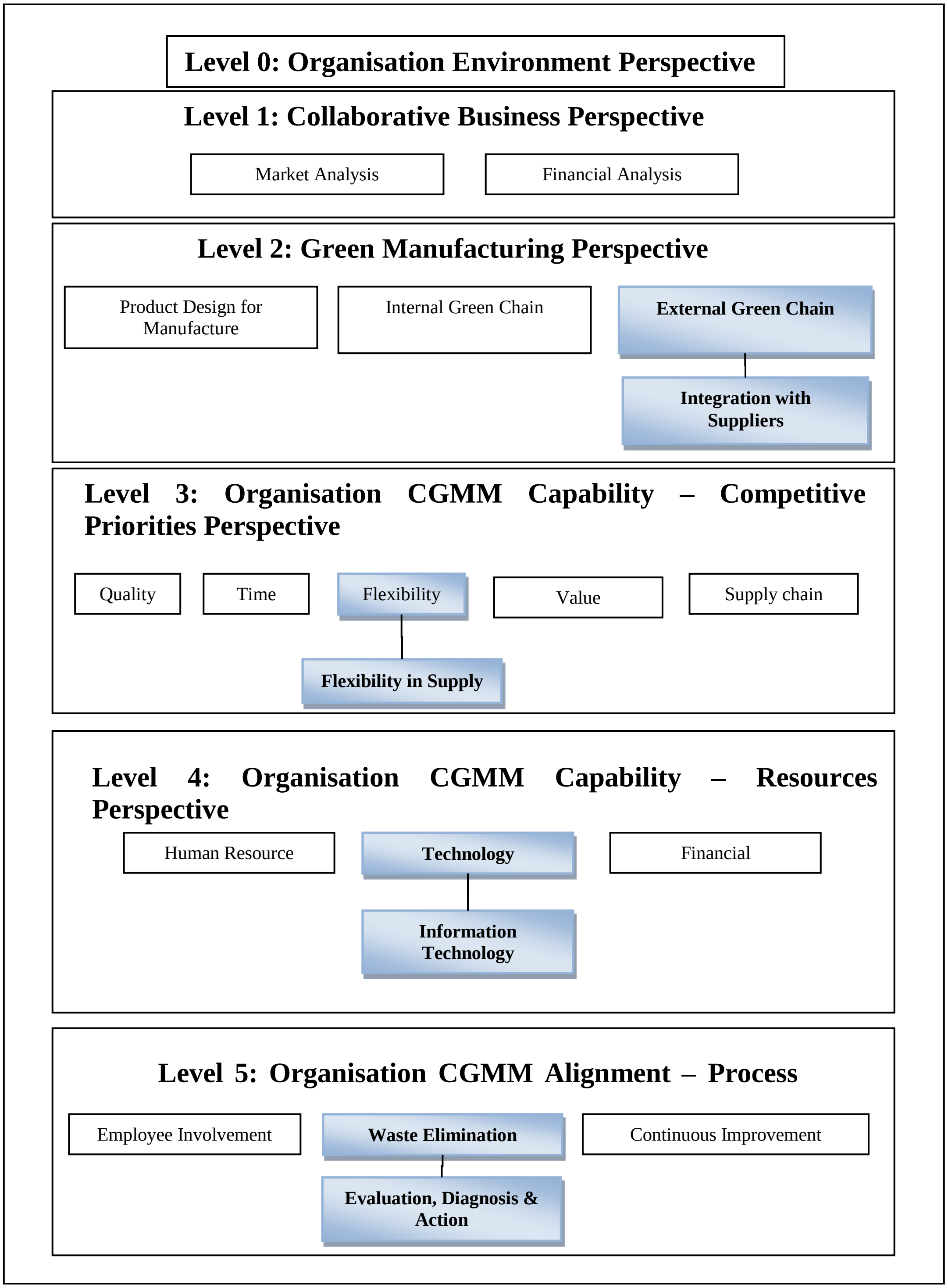


Figure 4.3: The Immediate Improvement Areas or Activities for Company B Based on AHP/GAP Analysis Embedded in KBCGMM

4.3 Green Value Chain Gap in CGMM Identified by KBCGMM

In addition to the verification and validation through individual assessment for each of the organisations, green value chain gap measurement in CGMM chain is also conducted. This assessment is important to identify activities in the CGMM that have potential opportunity for collaborative development. By performing this assessment, the results will show what the organisations' potential opportunity of their abilities compared to their partners' potential opportunity in the green chain. In the KBCGMM, the questions and rules were designed in such a way that able to assess the gap between the organisation and its suppliers and customers.

From the summary of GAP Analysis, Table 4.5 provides the AHP results for the all four organizations involved. It can be seen that in the Level 2: *Green Manufacturing* Perspective, the KBCGMM System suggests that both companies need to focus on *External Green Chain* for improvement, and within this module they need to give more attention on the *Integration with Suppliers* activities.

Table 4.5: Summary of KBCGMM AHP Analysis for both companies

	Company A		**Company B (Supplier)**	
	Module (PV)	**Sub-module (PV)**	**Module (PV)**	**Sub-module (PV)**
Green Manufacturing	External Green Chain (0.5390)	Integration with Suppliers (0.6667)	External Green Chain (0.5390)	Integration with Suppliers (0.7500)
Competitive Priorities	Value (0.3591)	Resource Cost (0.5000)	Flexibility (0.3611)	Flexibility in Supply (0.5571)
Resources	Technology (0.5889)	Information Technology (0.7778)	Technology (0.4905)	Information Technology (0.7778)
Process	Waste Elimination (0.4905)	Evaluation, Diagnosis & Action (0.6667)	Waste Elimination (0.4905)	Evaluation, Diagnosis & Action (0.6667)

In the Level 3: *Competitive Priorities* Perspective, the System suggests that Company A needs to focus on *Value* Module, with attention on *Resource Cost* aspects whilst Company B to focus on *Flexibility* Module, with more consideration in *Flexibility in Supply* activities.

It can also be seen in Table 4.5, in the Level 4: *Resource* Perspective, it was realized that the KBCGMM System found that both companies shared the same highest Priority Vector for the *Technology* Module, and within this module they need to focus on the *Information Technology* sub-module. This means that both companies should work collaboratively with minimum obstruction to improve their information technology aspects. Finally, in the Level 5: *Process* Perspective, the KBCGMM System suggests that both companies to focus first on improving the *Waste Elimination* Module, and within this module they need to focus on *Evaluation, Diagnosis & Action* activities. In summary, the KBCGMM provides the suggestions for the organizations involved in this study to choose the area which need to be prioritized in the improvement programs.

CHAPTER FIVE
CONCLUSION

5.1 Introduction

This chapter highlights the summary of information presented in this research that includes discussions of research achievements, main findings, advantages and limitation of the developed system, and recommendations for future work that can be undertaken. The general goal of this research was to develop a Knowledge-Based (KB) approach model for planning and designing a Collaborative Green Manufacturing Management (CGMM), by embedding Gauging Absences of Pre-Requisites (GAP) Analysis and Analytic Hierarchy Process (AHP) technique in the KB system. The achievement of research objectives and overall conclusions are presented, along with advantages and limitations of the proposed model. Finally, the contributions of this research, together with recommendations, are offered.

5.2 Achievement of Research Objectives

The objectives of this research listed in Chapter 1 have been achieved. This research provides a model for planning and designing a CGMM for a given automotive manufacturing environment. It offers a technique to assess organization current situation through the GAP Analysis. In addition, it also provides an analytical tool in prioritising factors that need improvement through the AHP technique.

As the Objective 1 of the research was to design a conceptual model of CGMM, extensive literatures of the subject of Green Manufacturing Management (GMM) has been reviewed in Chapter 2. It was found that the GMM, which evolved from the Just-in-Time (JIT), Manufacturing Resources Planning (MRP II), and Total Quality Management (TQM) concepts, plays significant roles in capturing, maintaining and sustaining the competitive advantage of organizations. Based on the literatures, the KBCGMM Conceptual Model was developed and presented in Chapter 3, by describing each component in the model and its relationship.

Once the Objective 1 has been achieved as presented in Chapter 3, the conceptual model was then converted into a hybrid KB/GAP/AHP System (Objective 2). In order to 'translate' the KB approach used to support the CGMM development, the KBCGMM Conceptual Model was transformed into the KBCGMM System Structure, consisting of six levels. The system was developed using the *AM for Windows* shell and through the production rules methods. Additional KB was contained in the detailed explanations for each of the rules developed, with the specific aim of reducing the uncertainty within the developed KB system. The development of the KBCGMM through the integration of the KB methodology, GAP Analysis and AHP technique is a novel approach for planning and designing a CGMM, especially for the automotive manufacturing environment.

To achieve the Objective 3 of the research, the KBCGMM System was then validated through the industrial and published case data to ensure its validity, reliability, and applicability, as presented in Chapters 4. There were two industrial cases involved in the verification process. Based on the information retrieved from the organizations' data and knowledge gained from the interview with the experts, the verifications results were used to improve the KBCGMM System (Objective 3). The System found to be work as planned, valid, reliable, consistent, and has the capability in identifying and suggesting the areas that need improvement.

Finally, thorough the process of development, application and validation of KBCGMM System, the advantages and limitations of the System has been discovered (discussed in Section 5.4 and 5.5). Based on these advantages and limitations, the Objective 4 of recommendation for future work has been suggested (discussed in Section 5.6).

5.3 Summary of Results Findings for KBCGMM

For this study, two industrial verification and validation results were completed, which involved two automotive manufacturing organizations, an automotive assembler and its vendor. The results from the KBCGMM System performance during the verification and validation process showed that the System successfully captured the reality of what existing in these two organizations towards CGMM implementation.

The System also captured the activities in the CGMM that have potential opportunity for collaborative development through the Green value chain gap measurement in CGMM The results showed what the organizations' potential opportunity of their abilities compared to their partners' potential opportunity in the green chain. In this research, the green value chain gaps between Original Equipment Manufacturers (OEM) and their supplier were evaluated. From the results, there were some gaps between customer and supplier which could obstruct the CGMM achievement. In this case, the KBCGMM System showed its capability as a Decision Support System to assist both customer and supplier to work collaboratively to improve their activities.

5.4 Advantages of KBCGMM System

The KBCGMM System has a number of benefits, noted during its development and application, which can be outlined as follows:

1. The KBCGMM System acts as a decision support system which can advise the management on a particular activity that need to prioritise on the development of CGMM based on the current situation assessment. The system also offers an integrated approach that can be used as guidance to the management in planning and designing the CGMM. The System successfully showed these advantages in the verification and validation process as discussed in Chapter 4.
2. The development of the System is in a modular approach, but integrated as a whole. Information and production rules in the system can be modified and amended easily by the developer.
3. The KBCGMM System was found to be user-friendly by the participants, combining the enhanced GUI with supplementary information during the interactive sessions.

5.5 Limitations of KBCGMM System

This research has successfully achieved its objectives and has generated important and interesting findings. However, some limitations of the KBCGMM System still need to be addressed. The identified limitations are described below.

1. The KBCGMM System is developed using AM for Windows software, an expert system shell. AM for Windows has its own limitations, in terms of memory, allocating the control of program during execution, illegal functions being performed and lack of flexibility to amend information that had been input in the earlier procedure.
2. The uncertainty factor (fuzzy logic) has not been used with the rule-base, and is an area for future work. However, in the current research, this problem was tackled by providing detailed explanations for every rule.
3. The rule-based approach in the system also has limitations. Since AM for Windows does not have its own inference engine that could support deducing the rules, the KBCGMM System consisted of a huge number of lines (syntax) which affected the effectiveness of the system during execution.
4. Since there is no available system designed for CGMM development, it is hard to benchmark the effectiveness of KBCGMM in terms of its functionality and acceptability.

5.6 Recommendations for Future Work

Despite the novelty of approaches in planning and design of the CGMM as presented in this thesis and based on the findings and the limitations of this research, there are still areas of further improvements. The following recommendations are listed for the future work.

1. The System should also utilise the web-based technology, which could be reached by multiple organizations in multiple tiers in the KBCGMM web.
2. In order to maximise the capability of the KBCGMM System, the confidence level of the user should be added while answering the question, due to the subjectivity of the question, which requires only a Yes/No/Do not know answer. By including the user confidence level, for example, through fuzzy logic application, it could improve the user judgement and could influence the calculation of the improvement priorities.
3. The process of entering the data in the KBCGMM System is based on an interactive mode, which can take a considerable time to accomplish, due to the user having to answer all the questions in a serial way. It is possible to design a database, which can store all the information and connect it to the KBCGMM System.
4. The statistical tests necessary to gauge the reliability and consistency of the KBCGMM System has not been done. It is recommended that statistical tests should be done to the assessment results in order to justify the particular hypothesis in the KBCGMM System. This would require repeated verification and validations.
5. A simulation model should be developed to complement the KBCGMM System. This stochastic modelling will assist the managers and developer to understand

the manufacturing system at a deeper level. Once a simulation model is established, the bottlenecks or the stages where process is most time consuming, can be found. The simulation model then should be developed, verified, validated, simulated, and analysed to complement the System.

6. In this research, the focus is on the basic CGMM, involving the OEMs and their first and second tier suppliers. It would be possible to expand the organizational involvement by considering upstream and downstream organizations, as well as government agencies. The upstream organizations might include third tier suppliers up to raw material suppliers, and downstream organizations include distributors down to end users.
7. The verification and validation process is done in the Malaysian setting, which is totally different in terms of policy, culture and practice. It is recommended that the KBCGMM System should be validated in other environments, which can provide further opportunities for its improvement.
8. The verification and validation process is done in the automotive manufacturer environment, which is slightly different to other manufacturing environments. It is recommended that the KBCGMM System should be validated in the other manufacturing environments or settings, which can also provide further opportunities for its improvement.

5.7 Conclusion

The research objectives were to develop a hybrid KB system by embedding GAP Analysis and AHP Approach for the planning and design of the CGMM. This chapter has consolidated the discussions made regarding the planning and design of the CGMM, has reviewed the achievement of the objectives of the research, and has summarised the overall conclusions about the KBCGMM System. Finally, the advantages, limitations of the system and recommendations for future research work have been outlined. It can be concluded that the KBCGMM System provides a sound and reliable prototype for organizations to use in planning and designing of the CGMM for capturing, maintaining and sustaining the organization competitive advantage through the power of Green Manufacturing Management collaboration.

REFERENCES

Aguilar-Lasserre, A. A., Bautista Bautista, M. A., Ponsich, A., & Gonzalez Huerta, M. A. (2008). An AHP-based decision-making tool for the solution of multiproduct batch plant design problem under imprecise demand. *Computers & Operations Research*, *In Press*, . Retrieved from http://www.sciencedirect.com/science/article/B6VC5-4R335HG-1/2/b4e81ed4d9550a505e414af31a00f232

Ahmad, A. (2003a). Sekilas fakta mengenai industri kereta dunia. *Massa*.

Ahmad, A. (2003b). Langkah kontigensi industri kereta. *Massa*.

AM. (2002). AM for Windows. Intelligent Environments Inc.

Aminuddin, A. S. A., & Nawawi, M. K. M. (2013). Investigation of the Philosophy Practised in Green and Green Manufacturing Management. *International Journal of Customer Relationship Marketing and Management*, *4*(1). doi:10.4018/jcrmm.2013010101

Awad, E. M. (1996). *Building expert systems: principles, procedures, and applications*. St. Paul, Minn.: West Pub. Company.

Bergmiller, G., Mccright, P., & Florida, S. (2009). Green Manufacturers Transcendence to Green Manufacturing. In *Industrial Engineering Research Conference* (pp. 1144–1148).

Carvalho, H., Duarte, S., & Machado, V. C. (2011). Green, agile, resilient and green: divergencies and synergies. *International Journal of Green Six Sigma*. doi:10.1108/20401461111135037

Darlington, K. (1997). Expert systems in nursing. Retrieved from http://www.bcs.org/upload/pdf/nsg-itin-vol9-darlington1.pdf

Desonie, D. (2008). *Humans and the Natural Environment: The Future of Our Planet*. Facts On File, Incorporated.

Dornfeld, D. (2010). Green Issues in Manufacturing - Greening Processes, Systems and Products.

Dornfeld, David. (2013). *Green Manufacturing: Fundamentals and Applications*. (D. A. Dornfeld, Ed.). New York: Springer. doi:10.1007/978-1-4419-6016-0

Dornfeld, David, Yuan, C., Diaz, N., Zhang, T., & Athulan, V. (2013). Introduction to Green Manufacturing. In D. Dornfield (Ed.), *Green Manufacturing: Fundamentals and Applications* (pp. 1 – 23). New York: Springer.

Dornfield, D. (2013). Concluding Remarks and Observations About the Future. In *Green Manufacturing: Fundamentals and Applications* (pp. 269 – 286). New York: Springer.

Dues, M. T., Tan, K. H., & Lim, M. (2013). Green as the New Green: How to Use Green Practices as a Catalyst to Greening Your Supply Chain. *Journal of CGreener Production*, *40*, 93–100.

Emmet, S., & Sood, V. (2010). *Green Supply Chains: An Action Manifesto*. John Wiley & Sons.

EPA. (2003). *Green Manufacturing and the Environment*. Washington DC.

Florida, R. (1996). Green and green: The move to environmentally conscious manufacturing. *California Management Review*, *39*, 80–105. doi:10.2307/41165877

FRANCHETTI, M., BEDAL, K., ULLOA, J., & GRODEK, S. (2009). GREEN and GREEN. *Industrial Engineer: IE*, *41*, 24–29. doi:10.1016/j.eururo.2010.02.033

Giarratano, J. C., & Riley, G. (2005). *Expert systems: principles and programming*. Boston: Course Technology.

Helu, M., & Dornfeld, D. (2013). Principles of Green Manufacturing. In David Dornfeld (Ed.), *Green Manufacturing: Fundamentals and Applications*. Springer.

Hines, P., Holweg, M., & Rich, N. (2004). Learning to evolve: A review of contemporary Green thinking. *International Journal of Operations & Production Management*, *24*(10), 994–1011.

Hussain, I. (1998). *A knowledge-based approach for the planning and design of flexible manufacturing systems: development and implementation of an integrated hybrid (knowledge-base and analytical) planning and design model for the flexible manufacturing system and an explora*. *Department of Mechanical Engineering*. University of Bradford, Bradford.

IDEF0. (1993). INTEGRATION DEFINITION FOR FUNCTION MODELING (IDEF0). Gaithersburg: National Institute of Standards and Technology .

IEA. (2012). *CO2 Emissions from Fuel Combustion*. Retrieved from http://www.iea.org/co2highlights/co2highlights.pdf

Ing (2007). *Porche and the environment*. Porche AG.

Jayal, A. D., Badurdeen, F., Dillon, O. W., & Jawahir, I. S. (2010). Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels. *CIRP Journal of Manufacturing Science and Technology*, *2*, 144–152. doi:10.1016/j.cirpj.2010.03.006

Just-auto (2009) Green regulation of auto sector spreads and deepens worldwide. *Management briefing*, October 2009. Bromsgrove: Just-auto.

Khan, A., & Day, A. J. (2002). A Knowledge Based Design Methodology for manufacturing assembly lines. *Computers & Industrial Engineering*, *41*(4), 441–467. Retrieved from http://www.sciencedirect.com/science/article/B6V27-44VVVGM-6/2/faa93aa05a9340c31225cf5fb6facc26

Khan, M. K., & Hafiz, N. (1999). Development of an Expert System for implementation of ISO 9000 quality systems. *Total Quality Management*, *10*(1), 47–59. Retrieved from http://docserver.ingentaconnect.com/deliver/connect/routledg/09544127/v10n1/s4.pdf?expires=1187978818&id=39163179&titleid=12&accname=University+of+Bradford&checksum=16F6DA94935C85BF33850FC468EBC5F9

King, A. a., & Lenox, M. J. (2003). Green and Green? an Empirical Examination of the Relationship Between Green Production and Environmental Performance. *Production and Operations Management*, *10*, 244–256. doi:10.1111/j.1937-5956.2001.tb00373.x

Kordon, A. (2010). *Applying Computational Intelligence: How to Create Value*. Springer.

Mahalingam, E. (2011). *"Record number of vehicles sold last year".* Star, *January 20.*

Mallach, E. G. (2000). *Decision Support and Data Warehouse Systems*. London: McGraw-Hill.

Melnyk, S. A., Sroufe, R. P., & Calantone, R. (2003). Assessing the impact of environmental management systems on corporate and environmental performance. *Journal of Operations Management*, *21*, 329–351. doi:http://dx.doi.org/10.1016/S0272-6963(02)00109-2

Merriam-Webster. (2013). Define: Indicator. *Merriam-Webster Dictionary*. Retrieved October 20, 2013, from http://www.merriam-webster.com/dictionary/green

Nawawi, M. K. M., Khan, M., & Hussain, K. (2007). Conceptual Model of Collaborative Green Manufacturing Management System: Planning Stage. In D. J. Stockton, R. A. Khalil, & R. W. Baines (Eds.), *The 5th International Conference* *on Manufacturing Research (ICMR07)* (pp. 148–152). De Montfort University, UK.

Nawawi, M. K. M., Khan, M. K., & Hussain, K. (2008). Paper 1: Colllaborative Green Manufacturing Management - The Framework and Hybrid Knowledge-Based System. *24th International Conference on CARS & FOF'08*.

Parveen, C. M., Kumar, A. R. P., & Rao, T. V. V. L. N. (2011). Integration of Green and green supply chain - Impact on manufacturing firms in improving environmental efficiencies. *International Conference on Green technology and environmental Conservation (GTEC-2011)*, 143–147. doi:10.1109/GTEC.2011.6167659

Pigford, D., & Baur, G. R. (1990). *Expert systems for business: concepts and applications: featuring VP-Expert*. Boston: Boyd & Fraser.

Rabelo, L., Eskandari, H., Shaalan, T., & Helal, M. (2007). Value chain analysis using hybrid simulation and AHP. *International Journal of Production Economics*, *105*(2), 536–547. Retrieved from http://www.sciencedirect.com/science/article/B6VF8-4KTMTT0-1/2/b77d85fcca4f348f4156931aa3f794e5

Razmi, J., Rahnejat, H., & Khan, M. K. (2000). The new concept of manufacturing "DNA" within an analytic hierarchy process-driven expert system. *European Journal of Innovation Management*, *3*(4), 199–211. Retrieved from http://proquest.umi.com/pqdweb?did=115723718&Fmt=7&clientId=12449&RQT=309&VName=PQD

Rendell, E. G., & McGinty, K. A. (2004). *Environmental management systems: A guidebook for improving energy and environmental performance in local government*. Five Winds International.

Render, B., Ralph M. Stair, J., & Hanna, M. E. (2006). *Quantitative Analysis for Management* (9th ed.). Upper Saddle River, New Jersey: Pearson Prentice Hall.

Ross, A. (2003). Green is not enough [Green manufacturing]. *Manufacturing Engineer*. doi:10.1049/me:20030402

Rothenberg, S, Pil, F. K., & Maxwell, J. (2001). Green, Green and the Quest for Superior Environmental Performance. *Production and Operations Management*, *10*(3), 228–243.

Rothenberg, Sandra, Pil, F. K., & Maxwell, J. (2001). Green, Green, and the Quest for Superior Environmental Performance. *Production and Operations Management*, *10*, 228–243. doi:10.1111/j.1937-5956.2001.tb00372.x

Russo, M. (2001). *Institutional change and theories of organizational strategy: ISO14001 and toxic emissions in the electronics industry*.

Saaty, T. L. (2001). *Decision making for leaders: the analytical hierarchy process for decisions in a complex world* (New., Vol. 2, p. 315). Pittsburgh: RWM Publications.

Sajja, P. S., & Akerkar, R. (2010). Knowledge-Based Systems for Development. In *Advance Knowledge -Based System: Model Application & Research* (pp. 1–11).

Sharma, S., & Agrawal, N. (2008). Selection of a pull production control policy under different demand situations for a manufacturing system by AHP-algorithm. *Computers & Operations Research*, *In Press*, . Retrieved from http://www.sciencedirect.com/science/article/B6VC5-4S4JYVY-1/2/0b01781c79b988d9f2b0de8f0317561b

Shingo, S. (1989). *A Study of Toyota Production System from and Industrial Engineering Viewpoint*. Productivity Press.

Sinha, A. (2010). *Resource and energy conservation initiatives*. Hero Honda Motors.

Simons, D., Mason, R., & Cardiff, U. (2003). Green and green: doing more with less. *ECR Journal*, *3*, 84–91.

Srivastava, S. K. (2007). Green Supply Chain Management: A State of the Art Literature Review. *International Journal of Management Review*, *9*(1), 53–80.

Tiwari, A. (2010). Green product development – Key for the survival, current challenges. White Paper. HCL Technologies.

Turban, E., Aronson, J. E., & Liang, T.-P. (2005). *Decision support systems and intelligent systems* (7th ed.). London : Prentice-Hall.

Udin, Z. M. (2004). *A hybrid knowledge-based approach for planning and designing a collaborative supply chain management system*. *School of Engineering, Design and Technology*. PhD Thesis, University of Bradford.

Udin, Z. M., Khan, M. K., & Zairi, M. (2006). A collaborative supply chain management framework: Part 1 - planning stage. *Business Process Management Journal*, *12*(3).

UN. (2005). World Summit Outcome. In *United Nations General Assembly*. Retrieved from http://data.unaids.org/Topics/UniversalAccess/worldsummitoutcome_resolution_24oct2005_en.pdf

Venkat, K., & Wakeland, W. (2006). Is Green Necessarily Green ? *Carbon*, 1–16.

Volvo Malaysia. (2005). Volvo Malaysia 2005. Retrieved July 28, 2005, from http://www.volvocars.com.my/Tier3/AboutUs/VolvoMalaysia.htm.

Wad, P. (2009). Impact of the global economic and financial crisis over the automotive industry in developing countries. Research and Statistics Branch Working Paper 16/2009.

Wibisono, D., & Khan, D. M. (2003). *A knowledge based approach to assist in the design of a performance measurement system for a manufacturing environment*. *School of Engineering, Design and Technology*. PhD Thesis, University of Bradford.

Womack, J. P., Jones, D. T., & Roos, D. (2007). *The Machine that Changed the World: How Green Production Revolutionized the Global Car Wars* (2nd ed., p. 336). Simon & Schuster.