THE DEVELOPMENT OF A HYBRID KNOWLEDGE-BASED SYSTEM FOR DESIGNING A LOW VOLUME AUTOMOTIVE MANUFACTURING ENVIRONMENT

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ABSTRACT

Keywords: Low Volume Automotive Manufacturing (LVAM), Lean Manufacturing, Knowledge Based (KB), Gauging Absences of Pre-requisites (GAP), Analytic Hierarchy Process (AHP)

The product development process for the automotive industry is normally complicated, lengthy, expensive, and risky. Hence, a study on a new concept for Low Volume Automotive Manufacturing (LVAM), used for niche car models manufacturing, is proposed to overcome this issue. The development of a hybrid Knowledge Based (KB) System, which is a blend of KB System, Gauging Absences of Pre-requisites (GAP), and Analytic Hierarchy Process (AHP) is proposed for LVAM research. The hybrid KB/GAP/AHP System identifies all potential elements of LVAM issues throughout the development of this system. The KB System used in the LVAM analyses the gap between the existing and the benchmark organisations for an effective implementation.

The novelty and differences in the current research approach emphasises the use of Knowledge Based (KB) System in the planning and designing stages by suggesting recommendations of LVAM implementation, through: a) developing the conceptual LVAM model; b) designing the KBLVAM System structure based on the conceptual LVAM model; and c) embedding Gauging Absences of Pre-requisites (GAP) analysis and Analytic Hierarchy Process (AHP) approach in the hybrid KBLVAM System.

The KBLVAM Model explores five major perspectives in two stages. Planning Stage (Stage 1) consists of *Manufacturer Environment* Perspective (Level 0), *LVAM Manufacturer Business* Perspective (Level 1), and *LVAM Manufacturer Resource* Perspective (Level 2). Design Stage (Stage 2) consists of *LVAM Manufacturer Capability – Car Body Part Manufacturing* Perspective (Level 3), *LVAM Manufacturer Capability – Competitive Priorities* Perspective (Level 4), and *LVAM Manufacturer Capability – Lean Process Optimisation* Perspective (Level 5). Each of these perspectives consists of modules and sub-modules that represent specific subjects in the LVAM development. Based on the conceptual LVAM model, all perspectives were transformed into the KBLVAM System structure, which is embedded with the GAP and AHP techniques, hence, key areas of potential improvement are recommended for each activity for LVAM implementation.

In order to be able to address the real situation of LVAM environment, the research verification was conducted for two automotive manufacturers in Malaysia. Some published case studies were also used to check several modules for their validity and reliability. This research concludes that the developed KBLVAM System provides valuable decision making information and knowledge to assist LVAM practitioners to plan, design and implement LVAM in terms of business organisation, manufacturing aspects and practices.

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GLOSSARY

AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AM	Application Manager
ANN	Artificial Neural Network
APQP	Advance Product Quality Planning
BIW	Body-In-White
BOM	Bill of Materials
BP	Bad Point
CAD	Computer Aided Design
CBR	Case Based Reasoning
CIM	Computer Integrated Manufacturing
CM	Cellular Manufacturing
CNC	Computer Numerical Control
CR	Consistency Ratio
DFM	Design for Manufacturing
DPD	Distributive Product Development
ERP	Enterprise Resource Planning
ES	Expert System
FBS	Frame Based System
FEM	Front End Module
FL	Fuzzy Logic
FMC	Full Model Casting
FMEA	Failure Mode and Effects Analysis
FMS	Flexible Manufacturing System
GA	Genetic Algorithms
GAP	Gauging Absences of Pre-requisites
GM	General Motors
GP	Good Point
HOQ	House of Quality
HRD	Human Resource Development
HVAM	High Volume Automotive Manufacturing
ICT	Information Communication Technology
IT	Inventory Turnover
JIT	Just in Time
KB	Knowledge Based
KBLVAM	Knowledge Based Low Volume Automotive Manufacturing
KBS	Knowledge Based System
KPI	Key Performance Indicator
LVAM	Low Volume Automotive Manufacturing
MHS	Material Handling Systems
MIYAZU	Miyazu Malaysia Sdn. Bhd
NVH	Noise, Vibration and Harshness
NDA	Non-Disclosure Agreement
OEM	Original Equipment Manufacturer
OICA	International Organization of Motor Vehicle Manufacturers
OOP	Object Oriented Programming
PC	Problem Category
PFMEA	Process Failure Mode and Effects Analysis
PME	Primary Manufacturing Enterprise
PMH	Polymer Metal Hybrid

PMS	Performance Management System
PROTON	Perusahaan Otomobil Nasional Sdn. Bhd
QCC	Quality Control Circle
QFD	Quality Function Deployment
RAM	Random Access Memory
ROE	Return on Equity
RTA	Return on Total Assets
SA	Simulated Annealing
SMC	System Manufacturing Company
SMC	Sheet Moulding Compound
SME	Small and Medium Enterprises
SMED	Single Minute Exchange of Dies
SPC	Statistical Process Control
SPIF	Single Point Incremental Forming
STA	Sales to Total Assets
TOYOTA	Toyota Motor Corporation
TPM	Total Productive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management
TWB	Tailor Welded Blanks
VW	Volkswagen
WCM	World Class Manufacturing
WIP	Work-In-Process
YTD	Year to Date

CHAPTER 1

INTRODUCTION

1.1 Background

Automotive manufacturing sector globally is increasingly becoming a competitive industry which requires new car models at a lower cost but at higher quality levels. In the global economic perspective, due to its magnitude and importance, the automotive sector remains a major international industry which attracts operation management researchers' continued attention (Taylor and Taylor, 2008). Therefore, car manufacturers should emphasise and focus on various strategies and concepts that can be accepted by local as well as overseas customers. Any new model development should consider various innovations to remain competitive (Okamuro, 2001). According to Hallgren and Olhager (2009), increased competition, global markets, and more challenging customers are all contributing factors that should be the main focus in today's business environment. In addition, Mohamed et al. (2005) suggested that fragmentation of markets and uses of new technology will be desirable options to overcome these challenges.

The aforementioned factors are particularly important in the automotive industry where radically shortened product development cycle time remains a crucial differentiating factor between the best performing companies and the remaining industry (Afonso et al., 2008). The focus of innovation must be on developing new-to-the-world products that provide consumers with totally new perceived benefits (Proff, 2000). To produce a new car model is not an easy task; taskforces from multi-functional discipline teams comprising of management staff, marketeers, designers, engineers and supporting staff ensure the smooth implementation of new model launches to tight deadlines. According to Yang et al. (2007), product development involves not only highly innovative and knowledge-driven processes but also requires collaborative efforts from multi-functional discipline teams. This is because the new model making process involves many stages including clay modelling, design drawings, prototypeing, production preparation and mass production, which include the procedures and requirements for testing, trials and final confirmation. Hence, to cope with these requirements, systematic approaches need to be implemented to drive the current business trend in automotive manufacturing.

In addition to the above product development factors, the manufacturing system itself also needs to be designed or improved. According to Matt (2008), *"the principles of lean production and agile manufacturing have become state-of-the-art in modern production system design"*. The lean concept itself was invented through a series of dynamic learning process from the automotive and textile sectors, particularly Toyota company's response to crisis in Japan after the World War II (Holweg, 2007). The application of Toyota Production System or Lean Manufacturing has become a competitive advantage to the automotive industry in facing global competition.

1.2 Problem Statement

High Volume Automotive Manufacturing (HVAM), used for mainstream automotive car models, involves complex phases of a development program and requires long lead times before the model is introduced. The product development process for the automotive industry is normally complicated, expensive, long and risky . However, different companies have various strategies to achieve their goal such as platform sharing (Kim, 2003), data base design (Cleveland, 2006b), lean manufacturing system (Flores, 2003) and common tooling (Brown, 2004). In some cases, low volume cars or niche products are required to sustain the market choices, such as luxury, sports and special purpose vehicles. If the normal route of car making processes from design, prototype, manufacture and trial is to be implemented, it is not feasible to build these low volume cars because of their inherent higher costs and longer delivery project timing. There must be a new approach to produce niche models without compromising on quality, cost and delivery of the low volume car.

Customers are demanding quality products, especially the unexpected quality which is the extra features that they never expected before. It is becoming difficult task for automotive manufacturers to meet not only the must-be-quality (the expected needs) but also to reach the level of attractive quality (Hassan et al., 2000). One way of manufacturing low volume cars is through the use of the platform sharing concept. According to Riesenbeck (2006), by applying this concept, not only the design time can be significantly reduced; but also the product quality, technology used, components, modules and system can be integrated. As a result, the manufacturer can adapt its total car manufacturing volume to the target or niche market with significantly reduced cost. The manufacturer who has the ability to produce this kind of product will have a major advantage over competitors.

Product design normally requires experts who know the entire automotive manufacturing system starting from design concept, tooling making and production requirements. To develop these experts requires time, resources and trainings that are normally the manufacturer's bottleneck. According to Khan et al. (2011), in coping with the competitive market, it is necessary to have a systematic tool for generic design such as Knowledge Based Methodology to achieve the production demands and the high standards of production quality. This concept was mutually agreed by Roy et al. (2008), as they suggested to use the expert based optimisation approach. According to them, this expert-based optimisation approach normally uses Knowledge Based or simulation techniques to optimize the product design by giving the incremental improvement to the design.

1.3 Research Project Aim

The current research aim is to use a hybrid Knowledge Based (KB) System for designing and implementing Low Volume Automotive Manufacturing (LVAM), used for niche car models manufacturing, with a view to optimise the LVAM system to achieve lean manufacturing. This hybrid KB approach is new and novel in the area of LVAM and will incorporate Gauging Absences of Pre-requisites (GAP) analysis and Analytic Hierarchy Process (AHP) methodology. By adding GAP and AHP in the KB System, the gap between the current LVAM environment and the ideal case (industry benchmark) will be thoroughly assessed, with the KB System assisting in achieving the benchmark. As a result, the KB System will assist the automotive manufacturers in their decision making process in order to design and implement a benchmark LVAM System. By having this KB system, the manufacturers will have the opportunity to optimise their costs and quality and minimise time to market for their niche models.

1.4 Research Objectives

The problems related to automotive manufacturing as discussed earlier have motivated this research to focus on Low Volume Automotive Manufacturing (LVAM). Throughout the literature review, it was found that there was no previous attempt to apply an integrated KB System which embedded the GAP and AHP in a single system for LVAM environment. The previous researchers had applied KB/GAP/AHP Systems for performance measurement system (Wibisono, 2003), collaborative supply chain management (Udin, 2004), and collaborative lean manufacturing management (Nawawi, 2009), but not for LVAM.

In order to achieve the research aim, this study focuses on the following specific objectives:

a) To ascertain the recent knowledge and information relating to automotive production from literature in order to find the current status of HVAM and LVAM, with the aim of acquiring knowledge in this area for designing a conceptual and actual KB System.

b) To design a conceptual model for KB/AHP/GAP System. This conceptual model will integrate the quality elements at different levels and modules of KBS that relate to the essential requirements for the new model development of automotive production. These factors will finally support the development of LVAM system.

c) To translate/convert the conceptual model into a hybrid KB/GAP/AHP System. At this stage, the conceptual model will be translated or converted into KBLVAM System, whereby KB rules will be developed and structured, using an Expert System shell. In order to make it an integrated system, the GAP analysis and AHP techniques will be embedded within the KB System.

d) To verify and validate the KB System by using actual industrial case studies and published case studies. Therefore, the system will be verified in a real automotive manufacturing environment.

e) To refine the KBLVAM System based on the verification and validation process results in order to improve the validity, reliability and consistency of the LVAM model.

f) To recommend future work based on the improved hybrid KB System.

1.5 Significance of Research

The significance of this research is to advance the knowledge of a hybrid KB/GAP/AHP System to design and implement a Low Volume Automotive Manufacturing (LVAM) system. The developed KB System is a new approach which identifies the problems related to LVAM and rectifies the problems by suggesting appropriate steps for improvements. Currently, the available systems are focusing on HVAM. GAP analysis and AHP techniques are embedded in the KB System, which makes it a comprehensive hybrid KB System. Hence, the developed KB System will be the advance system which navigates car maker to produce more niche car models with reduced timings and enable them to compete in the global market especially with all the new trade and environmental regulations.

In summary, the novelty and differences in the current research are listed as follows:

- The model develops a complete KB methodology for LVAM environment which has not been attempted previously.
- The integrated KB/GAP/AHP System implementation for planning and design is a new approach in the LVAM research area.
- The model analyses the current LVAM environment using the embedded system in order to reduce the gap against the benchmark standards. Hence the KB System assists the users in their decision-making process to achieve an ideal LVAM implementation.

1.6 Research Methodology

The methodology of this research is a combination of literature review, knowledge acquisition, development of research model and detailed development of strategic and operational of the overall KB System. The verification and validation processes will be conducted at the final stage of the overall system by using industrial and published cases.

1.6.1 Methodology Flow

The methodology flow of this research is shown in Figure 1.1, is structured from the understanding of the knowledge acquired from the literature review, development of a conceptual research model, detailed development of KBLVAM System, verification and validation process. It consists of two parts; the first part focuses on the detailed development of KBLVAM - strategic level and the second part is concentrated on KBLVAM - operational level of the KB System. The data for detailed development of KBLVAM System will be based on the primary data from car manufacturers in Malaysia. Proton and Miyazu Malaysia will be involved in the case study during the development stage and the validation of the model to reflect the actual car manufacturing process.

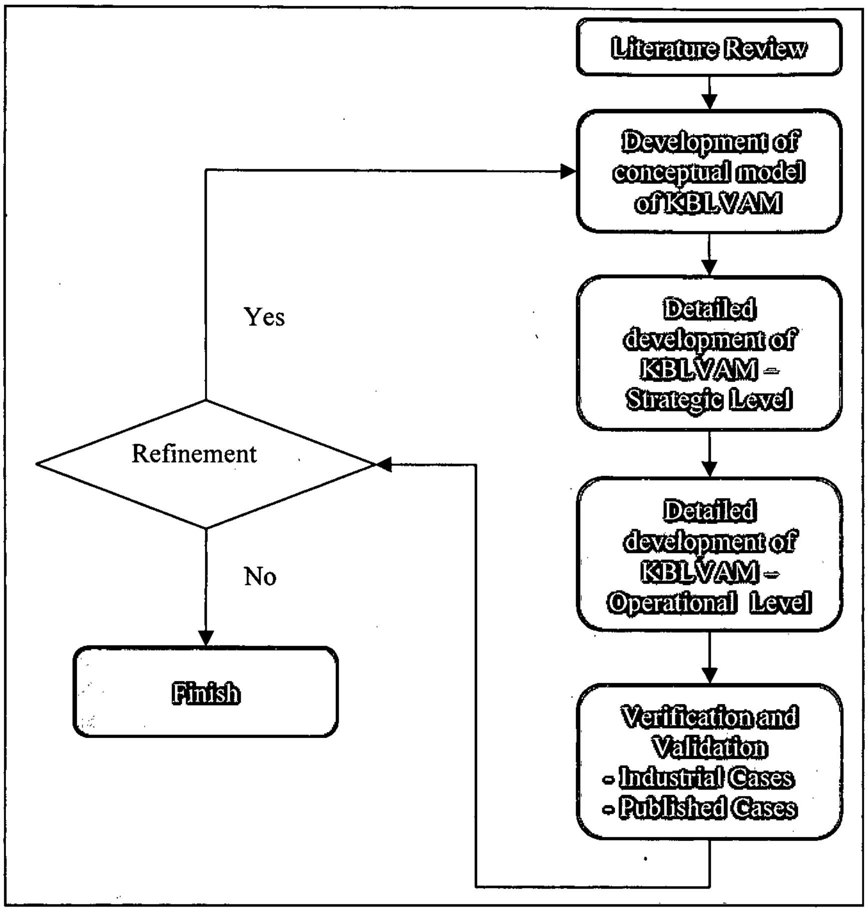

Figure 1.1: Methodology flow

1.6.2 Conceptual development

This research commences with the study of current methods of automotive making processes by carrying out a literature review on areas of manufacturing, HVAM, LVAM and Artificial Intelligence (AI). The design and development of KBLVAM will also involve GAP and AHP techniques that will be embedded in the

KB System. The published articles on KB, GAP, and AHP will be the basis for the development of a conceptual framework for KBLVAM. All factors that are essential requirements for the new model development of LVAM will be compiled, studied and analysed using GAP and AHP. There is no evidence in the literature that this approach to combine KB, GAP, and AHP has been used before in the context of this research. GAP analysis is a method to assess the gap between the necessary prerequisites for effective implementation compared to a benchmark (Nawawi, 2009). To achieve meaningful results, the GAP analysis should be in a structured and hierarchical format.

The GAP analysis has been designed to be in-line with the AHP methodology hierarchical structure. Yurdakul (2002) suggested that by using AHP, information is decomposed into hierarchical structure of criteria and sub-criteria. Then, pair-wise comparisons between criteria are made to establish their weight levels of each criterion. According to Abdul-Hamid et al. (1999), *"Inconsistency is a major bias in human judgement that accounts for a large portion of human deficiencies in planning and evaluation. The more alternatives and attributes or factors in the evaluation problem, the more significant the inconsistency becomes. This problem of inconsistency can be overcome by using the Analytical Hierarchy Process (AHP)."*

Once the conceptual framework is formed, the next stage is to develop this conceptual model into the hybrid KB System. This is the most detailed stage of the research process because it will focus on both the strategic and operational elements. During this stage, the Knowledge Base of the KBLVAM System will be designed and developed in a structured manner for the KB hybrid system implementation.

The next stage will be to verify and validate the KBLVAM System by using published case studies and actual industrial applications. The results from actual industrial case study applications are very important because they represent a real application of KBLVAM during the complete process of automotive production. This is an important aspect of this research because the analysed results will determine whether the hybrid KB System is practical and/or realistic decision – making tool for a low volume automotive production.

1.7 Thesis Outline

This thesis contains nine chapters. The introduction to the research, its background, problem statements, research project aim, research objectives, significance of the research, and research methodology are presented in this Chapter 1.

Chapter 2 presents the literature review in the area of Manufacturing, which includes High Volume Manufacturing, Medium Volume Manufacturing, Low Volume Manufacturing, and Lean Manufacturing. This chapter is important as it will form the foundation for knowledge acquisition for the LVAM environment.

Chapter 3 presents the literature review in the area of Automotive Manufacturing which covers High Volume Automotive Manufacturing (HVAM) and Low Volume Automotive Manufacturing (LVAM). Again, this chapter is crucial for knowledge acquisition in the specific area of LVAM.

Chapter 4 presents a review on Knowledge-Based System (KBS) literature and its application in manufacturing environment. Literature of Analytic Hierarchy Process (AHP) and Gauging Absences of Pre-requisites (GAP) Analysis, which are embedded in the KBVAM System, is also studied.

Chapter 5 presents the conceptual model of LVAM, containing brief description of every component in the planning, design, and implementation stages, followed by the description of the KBLVAM System structure.

Chapters 6 and 7 describe in detail the Planning Stage (Stage 1) and Design Stage (Stage 2) of the KBLVAM System. These two chapters contain the *Manufacturer Environment* Perspective (Level 0), *LVAM Manufacturer Business* Perspective (Level 1), *LVAM Manufacturer Resource* Perspective (Level 2), *LVAM Manufacturer Capability – Car Body Part Manufacturing* Perspective (Level 3), *LVAM Manufacturer Capability – Competitive Priorities* Perspective (Level 4), and *LVAM Manufacturer Capability – Lean Process Optimisation* Perspective (Level 5). These two chapters cover the key aspects of the KBLVAM development.

Chapter 8 presents the details of the verification and validation of the KBLVAM System. It covers the verification and validation through the published case studies and the industrial case study applications.

Finally, Chapter 9 presents the overall conclusion of this research, achievement of the research objectives, and recommendation for the future research.

1.8 Summary

This research chapter has proceeded from a background of automotive industry globally followed by an introduction to both HVAM and LVAM, in order to formulate the research project's aim and objectives. The research methodology to be adopted is then presented. As stated, the research will focus on the LVAM by using a hybrid KB System, which is a blend of KB System, GAP and AHP. Finally, the thesis outline is presented.

CHAPTER 2

LITERATURE REVIEW: MANUFACTURING

2.1 Introduction to manufacturing

Manufacturing is a global business that was started during the industrial revolution in the late 19th century to cater for the large scale production of products (Jovane et al., 2008). Since then, the manufacturing business has changed tremendously through the innovations of technology, processes, materials, communication and transportation. According to Chryssolouris et al. (2008), the major challenge of manufacturing is to produce more products with less material, less energy and less labour involvement.

In order to face these challenges, manufacturing companies must have strategy and competitive priority in order for them to compete in a dynamic market (Thun, 2008). According to Skinner (2007), *"a manufacturing strategy is a set of manufacturing policies designed to maximize performance among trade-offs among success criteria to meet the manufacturing task determined by a corporate strategy"*. It is the responsibility of the top management of the company to ensure that there is a coherent manufacturing strategy and policies derived from internal and external sources of information to support the whole company's mission (Paiva et al., 2008).

According to Miltenburg (2008), a competitive strength of a company is based on the structural and infrastructural readiness. There are four structural areas that are comprised of capacity, facilities, technology, and sourcing. The infrastructural areas are workforce, quality, production planning, and organisation. According to Swink et al. (2007), the company must have a specific and strategic goal based on the