CHAPTER 5

CONCEPTUAL MODEL FOR LOW VOLUME AUTOMOTIVE MANUFACTURING

5.1 Introduction

This chapter explains the development of the conceptual model of Knowledge Based Low Volume Automotive Manufacturing (KBLVAM). Since presently there is no solid framework for developing LVAM, this research focuses on the problem by proposing a generic framework for KBLVAM. This chapter details a proposed conceptual model with the aim of tackling the LVAM problems with the support of Knowledge Based (KB) capability. This chapter also describes the KBLVAM structure and types of assessment that can be conducted during the validation process.

The implementation of Knowledge Based Systems (KBS) in manufacturing management has become a field of research since 1980s, along with the introduction of the intelligent manufacturing system concepts (Nawawi, 2009). By using this KB methodology, organisations have made improvements in their operations, ranging from the decision making process (Khan and Wibisono, 2008), manufacturing process (Abburi and Dixit, 2006) and product design planning (Hung et al., 2008). KBS also evaluates the overall manufacturing performance based on Analytical Hierarchy Process (AHP) in identifying opportunities for improvements, comparing internal performance and comparing external competitors (Yang et al., 2009). The acquired knowledge of the KBS is the input from various sources such as human expert, research papers, and books (Benavides and Prado, 2002).

In the current era of dynamic and global competition, the need for a new approach in LVAM will offer a detailed guideline to organisations in order to tackle the issues of quality, cost, delivery, production, customers and eliminate wastes that can be achieved through a low volume automotive manufacturing system. The literature review of manufacturing, HVAM, LVAM and AI (described in Chapters 2, 3, and 4), has inspired and assisted the development of a conceptual model which integrates these approaches.

There are many previous relevant KBS systems which have been developed for the planning and design manufacturing improvement initiatives which include Pull and Push Manufacturing Planning and Control (Razmi, 1998), Performance Measurement System (Wibisono, 2003), Collaborative Supply Chain Management (Udin, 2004) and Collaborative Lean Manufacturing Management (Nawawi, 2009). However, the need for KBS with special attention to LVAM has not been developed before which has motivated the development of KBLVAM to meet this need. The detail of this framework is discussed in the following section.

5.2 Conceptual design of KBLVAM Model

The applications of KB in manufacturing have been widely used, as mentioned in Chapter 4, to improve the organisation's competitiveness in the era of a dynamic market. Automotive manufacturing is a very important industry that creates a business opportunity to the manufacturers. Due to the global competition, LVAM is one of the strategies to sustain the automotive market share by producing niche models (Meichsner, 2009). Chapters 2, and 3 have reviewed various aspects of manufacturing being practised by the automotive manufacturers globally. The key elements from the reviews will be the basis for the development of the conceptual design of KBLVAM model. Based on the gathered information, the literature review was interpreted and "translated" into a KB which proposed a conceptual model to be developed in two stages of planning and design. The Planning Stage will represent the strategic components of an actual organisation's environment, whereas the Design Stage will represent the operational components of an actual organisation, both with respect to the LVAM environment.

The Planning Stage is to focus on the strategic level of the organisations (Thun, 2008). For this reason, two major sets of information need to be considered: *LVAM Business* and *LVAM Resource* perspectives as the strategic input to the KB System. The first stage of the proposed KBLVAM conceptual model development is shown in Figure 5.1, which involves planning elements of the manufacturer's strategy.

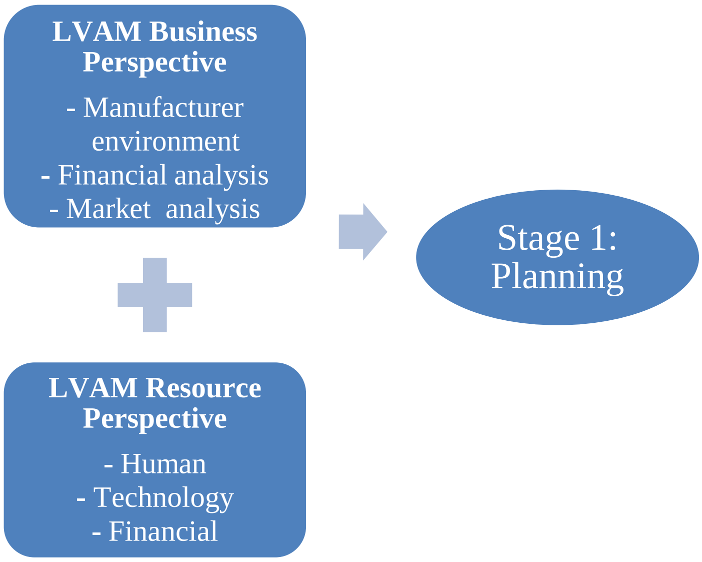

Figure 5.1: Stage 1 of the conceptual design of the KBLVAM model

As the business perspective is important in the global economic environment, thus the main task for the *LVAM Business* is to obtain information about the manufacturer's environment, financial status and market analysis (Taylor and Taylor, 2008). Therefore, the designed *LVAM Business* perspective as shown in Figure 5.1, will be able to gather the general information of the manufacturer environment as well as the manufacturer's financial status and market share (Udin, 2004). These inter-related components need to be analysed by the KBLVAM Model in order to gauge the strength of the manufacturer in planning the strategy for LVAM achievement (Nawawi, 2009).

The second element of the planning stage in the conceptual model development is the *LVAM Resource* perspective. Resource plays a very important role in the manufacturing's strategic planning (Paiva et al., 2008). Thus, in *LVAM Resource* perspective, as shown in Figure 5.1, the resource capabilities are focused and assessed in term of *Human*, *Technology* and *Finance* that play very important parts in order to achieve LVAM (Miltenburg, 2008). Once the elements of *LVAM Business* and *LVAM Resource* perspectives are developed in the strategic level of the conceptual model of KBLVAM, the next task is to proceed with the Design stage of the conceptual model development, which is also the operational element of the LVAM manufacturer (Meichsner, 2009). The detailed explanation of each of the elements in the Planning Stage will be discussed in Section 5.2.1.

The second stage (Stage 2: Design) of the conceptual design of the KBLVAM Model, is designed based on the LVAM requirements as mentioned in Chapter 2 and Chapter 3. This operational stage requires data and information on the manufacturer's capability in the LVAM environment so that it can be captured in the system, as shown in Figure 5.2; the *LVAM Manufacturer Capability*. According to Miguel (2006), and Nagahanumaiah et al. (2008), the manufacturer capability in LVAM environment is important in order for the manufacturer to become competitive by offering faster car model development, lower cost and high quality product.

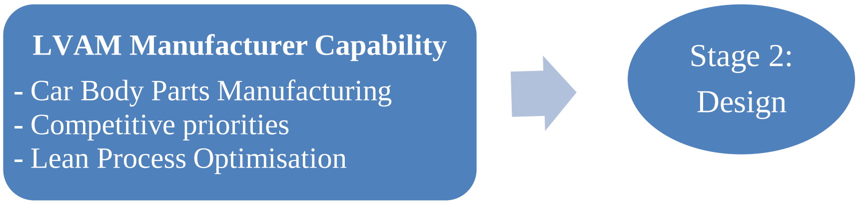

Figure 5.2: Stage 2 of the conceptual design of the KBLVAM model

As the manufacturing operations are the focus of any LVAM organisation, a conceptual LVAM model to gather the strategy of the organisation towards LVAM development is needed (Skinner, 2007). It is important for the LVAM manufacturer to have a proper strategy in order to compete in this low quantity of specialised, complex and customised products (Bellgran and Aresu, 2003). Therefore, the perspectives that need to be evaluated in the *LVAM Manufacturer Capability* are the capability of the LVAM manufacturers to compete in the automotive business in terms of *Car Body Parts Manufacturing* (Shafia et al., 2009), *Competitive Priorities* (Trappey and Hsiao, 2008), and *Lean Process Optimisation* (Cagliano et al., 2004).

There are three elements identified based on the LVAM *Car Body Parts Manufacturing* requirements that include *Car Body Design Development* (Qiu and Chen, 2007), *Car Body Parts Manufacturing Process* (Shivpuri and Zhang, 2009), and *Car Body Assembly Process* (Mondragon et al., 2009). These three elements need to be considered during the conceptual development in order to achieve the LVAM environment standard practice.

The second perspective in the Design Stage that needs to be evaluated is the *Competitive Priorities*. In this component, the organisational capabilities are assessed in term of *Quality* (Yadav and Goel, 2008), *Cost* (Riesenbeck et al., 2006), *Delivery* (Uffmann et al., 2006), *Flexibility* (Seidel et al., 2005) and *Supply-chain* (Harmancioglu, 2009). Thus, these competitive priorities are included in the conceptual model so that the assessment will determine the competitive level of the LVAM manufacturer compared to the benchmark standard.

Finally, the third perspective of the Design Stage that needs to be considered is the *Lean Process Optimisation.* In this perspective, it is very important to assess the manufacturer's efforts on the operational processes in term of lean environment (Shah and Ward, 2007). Lean process optimisation is a thorough assessment of each activity of a LVAM manufacturer in reducing waste at all levels of the manufacturing process. Thus, the involvement of all employees, identifying and elimination of waste and continuously improve the manufacturing process are the elements identified to ensure the customer satisfaction (Herron and Hicks, 2008). The detailed explanation of each of the elements in the Design Stage will be discussed in Section 5.2.2.

On the *LVAM* approach to the conceptual design of the KBLVAM development model, it will integrate the implementation of GAP and AHP techniques in the KBLVAM system (Nawawi, 2009). As mentioned in Chapter 4, GAP analysis is a method to assess the gap between the manufacturer's necessary pre-requisites for effective (benchmark) implementation compared to its status quo, while the AHP is one of the decision making process tools in selecting the best alternatives for a specific aim (Aguilar-Lasserre et al., 2009). In this conceptual development, the GAP analysis will benchmark the internal and external information on both HVAM and LVAM that will be used in the system. AHP will then link the priorities for improvement and in the decision making process.

These two stages (Planning and Design) are designed with the aim to structure the manufacturer towards the implementation of LVAM environment. Therefore, the components of Planning (Stage 1) and Design (Stage 2) are inter-related and can be merged to become an integrated system, as shown in Figure 5.3. Once the two stages (Planning and Design) are formed in a single conceptual model, the KBS now can be used as the foundation of the model. The conceptual model only provides ideas and key components which will then be translated into a much more detailed and specific KB rule structure. The following sections will describe each of the inter-related elements in detail.

5.2.1 Stage 1: Planning

As mentioned in the conceptual development (Section 5.2), there are two major components in this stage, namely *LVAM Manufacturer Business* Perspective and *LVAM Manufacturer Resource* Perspective. The Planning Stage is the strategic level in the development of KBLVAM System because it can be considered as the corporate or strategic decision levels of a company (Nawawi, 2009).

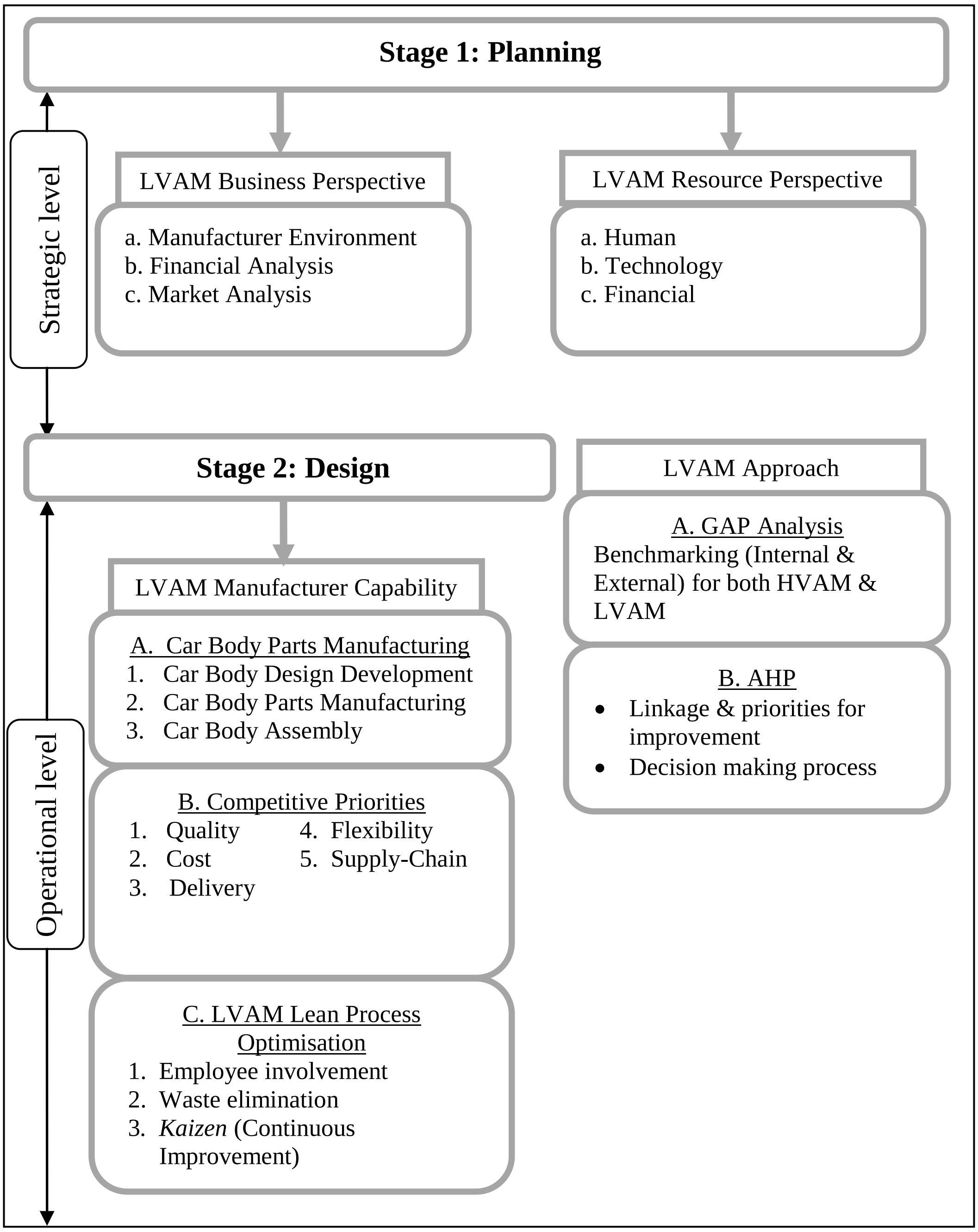

Figure 5.3: Conceptual design of KBLVAM model

5.2.1.1 *LVAM Business* Perspective

In order to compete in the dynamic global market, it is important for the LVAM manufacturer to have an organised business perspective (Balakrishnan et al., 2007). A proper business perspective will help the LVAM manufacturers to secure their customers (Kost and Zdanowicz, 2005). Therefore, there are three main items that need to be assessed at this strategic level in order to gauge the status of the low volume automotive manufacturer; *Manufacturer environment, Market Analysis,* and *Financial Analysis*.

Manufacturer Environment:

The *Manufacturer Environment* component is used to study how the particular company operates the business based on general information and background of the company. As different manufacturer environments need different performance standards and different improvement strategies, thus this stage is important to identify and map the manufacturer's environment to ensure the performance diagnosis is valid, reliable and factual (Wibisono, 2003). The information and data required for this module is; type of automotive product, size of manufacturer, number of employees, age of manufacturer, number of suppliers, number of customers, number of competitors and LVAM investment activities.

The manufacturer annual sales turnover and the number of employee information determine the size of manufacturing and manufacturing related services. For example, in Malaysia, the manufacturers are classified into four categories; micro, small, medium and large, as shown in Table 5.1. This is due to the reason that different sizes of manufacturers have different environment and capabilities, which influence the strategy in developing and implementing LVAM. The classification also helps the manufacturer to formulate effective development policies, support programmes as well as provision of technical and financial assistance (Chang et al., 2003).

Table 5.1: Categories of organisation size in Malaysia (Smecorp, 2011)

Size	Description
Micro Enterprise	Sales turnover of less than RM250,000 (approx. £50,000) OR full time employees less than 5
Small Enterprise	Sales turnover between RM250,000 (approx. £50,000) and less than RM10 million (approx. £2 million) OR full time employees between 5 and 50
Medium Enterprise	Sales turnover between RM10 million (approx. £2 million) and RM25 million (approx. £5 million) OR full time employees between 51 and 150
Large Enterprise	Sales turnover more than RM25 million (approx. £5 million) OR full time employees more than 150

The number of employee data determines various important measures that can be calculated and reveals the competitive level of the manufacturer. Those measures consist of labour productivity (sales/employee), financial performance (profit/employee), labour turnover, and labour qualification which reflect the manufacturer performance (Nawawi, 2009).

In LVAM environment, the position of the manufacturer in the automotive industry is required to determine its role and relationship with its suppliers, customers and competitors. This is due to LVAM aspect that stresses the relationship among the LVAM teams internally as well as between other manufacturers (Herron and Hicks, 2008).

The age of organisation, calculated from the established year is important to position the manufacturer compared to the competitors, so that the improvement measures can be strategised. Thus, the manufacturer can be classified as growth, sustain, or harvest stage [(Nawawi, 2009), and (Wibisono, 2003)]. In this study, a LVAM manufacturer with less than 5 years in business is categorised as in the stage of growth, 5-15 years is in the stage of sustain, and more than 15 years is in the harvest stage.

Financial Analysis:

Financial performance is the key indicator for the management of the company to make decisions on the overall business of the organisation (Sueyoshi and Goto, 2007). *Financial Analysis* is very important in this module because it relates to the manufacturer's financial information. It indicates how the organisation is presently being run in terms of efficiency and effectiveness (Emin Öcal et al., 2007). The *Financial Analysis* is based on the *Income Statements*, *Balance Sheet* and *Cash Flow Statement* of the manufacturer. Based on *Income Statements* input, *Gross Profit* and *Net Profit are assessed*.

Gross Profit is the profit remaining after deducting the *Cost of Goods Sold* (CGOS) from the sales turnover whereas *Net Profit* is the profit related to operating activities after deducting operating expenses, tax and any financial items. Based on the *Balance Sheet*, three financial performance criteria of the manufacturer could be analysed which includes *Leverage*, *Liquidity*, and *Profitability*. Based on the *Cash Flow Statement*, net increase (or decrease) in cash of the manufacturer could be assessed from operating, investing and financing activities of the manufacturer.

Market Analysis:

The manufacturers' strength is very important to survive in the competition and it could be identified through their market share status. *Market Analysis* assesses how the manufacturers are positioning their products and attracting customers in the market. This assessment also will reveal how competitive the price and products offered by the manufacturer in the market (Tavcar and Duhovnik, 2005). Thus, it is important to measure a manufacturer's market share compared to its competitors (Wibisono, 2003). The market analysis also helps LVAM manufacturer to structure the company in order to improve the manufacturer's competitiveness to win bigger market share.

5.2.1.2 *LVAM Resource* Perspective

LVAM Resource includes all of those resources which could stimulate the capability of a manufacturer's LVAM integration. The evaluation of resource priorities will concentrate on three elements; *Human*, *Technology* and *Financial* (Mital and Pennathur, 2004). These elements are important to the manufacturer in terms of processes and operations of the entire business (Chryssolouris et al., 2008). These three resources are dependent on each other and must exist in parallel in the whole operations and activities in the LVAM environment. Hence, *LVAM Resource* evaluates the capability of the manufacturer in dealing with the automotive manufacturing environment.

Human:

Human resource focus such as the mechanism of motivation, organisation structure and characteristics of management personnel are among the most important criteria for an organisation (Chen et al., 2008). Thus, human resource is a critical point to be assessed in the LVAM development. The basis of this is to develop a good teamwork culture which will benefit the company's productivity, reliability, economy and flexibility (Mital and Pennathur, 2004). The impact of human resource factors, such as proper training programme and management commitment support, and benefits help the success of the organisation (Celano et al., 2004).

Technology:

Technology resource is one of the important manufacturing criteria in order to compete in the global competition (Wiendahl et al., 2007). The manufacturer's ability to compete is vital for contemporary manufacturing, such as LVAM, depending on its awareness and speed of adopting the technological influence (Mital and Pennathur, 2004). The technology management factors, such as unique, reputation, experiences, and future technological capability are important to be considered for the LVAM environment (Chen et al., 2008). Therefore, the use of technology resource is supposed to encourage the effectiveness of the LVAM process (Peças et al., 2009). According to Miltenburg (2008), one of the strengths of a manufacturing company is measured based on its manufacturing technology readiness. Furthermore, Information, and Communication Technologies (ICT) play an enormous role in manufacturing technology over the past few decades. The ICT applications ranges from simple machining applications to manufacturing planning and control support, have made the manufacturing systems become much more effective and efficient (Chryssolouris et al., 2008).

Financial:

Financial resource capability is another important factor that needs to be considered in any implementation programmes such as LVAM. Financial resource provides investment to the manufacturer especially in funding the employment, training and consultancy (Ester, 2007). Strong financial resource is important in funding the required technology to any manufacturer, especially for those who are new in the business. Normally, the small, new, and risky firms are more considerably affected by strict monetary conditions than large, established and secure firms (Bougheas et al., 2006). Many studies have discussed that many companies especially in the Small and Medium Enterprises (SMEs), are financially more constrained than large companies and are less likely to have access to finance resource, thus a major limitation to the successful LVAM development (Beck and Demirguc-Kunt, 2006).

5.2.2 Stage 2: Design

The design stage is the operational level in the development of KBLVAM System because it can be considered as the tactical or operational decision levels of a company (Nawawi, 2009). This operational level, consists of three main *Manufacturer Capability* components; *Car Body Parts Manufacturing* (Fuchs et al., 2008), *Competitive Priorities* (Nobelius, 2004), and *Lean Process Optimisation* (Mohamed and Khan, 2011). These components are used to evaluate the various aspects of capabilities of the manufacturer in dealing with LVAM environment that will be elaborated below.

5.2.2.1 *LVAM Car Body Parts Manufacturing* Perspective

LVAM Car Body Parts Manufacturing perspective component gathers and assesses all the data related to the manufacturer's manufacturing perspective for LVAM such as *Car Body Design Development* (Borsellino and Bella, 2009), *Car Body Parts Manufacturing Process* (Jeswiet et al., 2008), and *Car Body Assembly Process* (Mondragon et al., 2009). This assessment will determine the current level of manufacturer's achievement compared to the benchmark level.

Car Body Design Development:

In the car body design development stage, KBLVAM considers multifunctional teams from marketing, engineering, manufacturing, and quality staffs to be involved as early as possible (Mohamed et al., 2005). The areas that need to be considered at the car body design development stage are the design concepts, design analysis and design assessment. The design concept stage visualises the current LVAM requirements and global business perspective into a car concept sketch (Kumar et al., 2006). It is the work of the design team which can be done either internally or outsourced to suppliers. Next, the design analysis stage assesses the LVAM manufacturers on how it analyses the design concept. This sub-module assesses on the application of design tools such as Failure Mode and Effect Analysis (FMEA) in the car body design development activities (Johnson and Khan, 2003). Finally, in the design assessment sub-module, it assesses the manufacturer's capability in developing a new automobile model. The assessment evaluates the performance of the manufacturer in producing new car models which include how many numbers of new products, total development time, and what types of activities involved in the development process (Hallgren and Olhager, 2009). This information is important to determine the level of manufacturer's capability in the area of car body design.

Car Body Parts Manufacturing Process:

Types of car body parts manufacturing process are important to this type of manufacturing in order to maximise profit by having the most economical means of tools (Nobelius, 2004). In the car body parts manufacturing process, there are two important stages involved, the design of dies and checking fixtures, and design of manufacturing process. Dies transform the material into the car body parts, whereas the checking fixtures check the accuracy of the produced parts against the car body parts data. These designs are based on the automotive manufacturer's own specifications, systems and requirements (Park et al., 2001). In LVAM environment, the tools may use various techniques such as stamping (Sweeney and Grunewald, 2003), laser forming (Jeswiet et al., 2008), spray forming (Yang and Hannula, 2008), incremental forming (Jeswiet et al., 2008), hydro-forming (Yuan et al., 2006), and roll forming (Thuillier et al., 2008). LVAM manufacturers can take advantage of these car body parts forming options in order to minimize the process (Nakagawa, 2000). This will avoid the fabrication of dies for the normal sequential stamping processes. The additional processes can be done manually as well as flexible automation of laser cutter (Qiu and Chen, 2007) and bending machine (Nakagawa, 2000).

Car Body Assembly Process:

The car body assembly process combines individual parts or components to become a complete body in white which required synchronisation and interaction of many components (Mondragon et al., 2009). In LVAM environment, the car body assembly process joins the individual panels and components and assembled them through a variety of processes, such as welding, riveting, and bonding (Chen et al., 2006). Normally, these processes are only suitable for non-closure parts. Another type of parts is known as closure parts, which always refer to automotive body-in-white opening parts, such as doors, deck lids and hoods (Thuillier et al., 2008). Closure parts require a hemming process to assemble the outer skin and the inner reinforcing parts. LVAM is suitable to use roll hemming process, instead of the die hemming process. This process, in which a roller is guided by a robot along the hemming edge, bends the flange height along the line until a complete join is finished. According to Thuillier et al. (2008), this roller hemming process is suitable for LVAM due to low cost, versatile tool from prototype to production and helps reduce the body assembly tooling development time.

5.2.2.2 Competitive Priorities

The capability of any organisation is largely based on the speed of delivery, flexibility and quality, which can be achieved through dynamic partnerships, rich information sharing and the coordination of physical flows (Cagliano et al., 2004). Furthermore, current market trends require faster product development, lower cost and high quality products (Nagahanumaiah et al., 2008). The competitiveness of the manufacturer also depends on the relationship of the suppliers and manufacturers which play an important role in delivering products to customers (Shafia et al., 2009). These competitive priorities are used by manufacturers to handle operations within and between their organisations in order to be competitive among the manufacturers (Udin, 2004).

Quality:

The quality of car models is extremely important for all automotive manufacturers and has become a key area of competition (Miguel, 2006), Quality is always associated with a higher return on investment for almost all kinds of products and market situations (Khan and Wibisono, 2008). Therefore, it is very important to consider all aspects related to the LVAM thoroughly during the development stage and it is obvious that quality conformance is very important in the automotive competitive environment (Park et al., 2001). According to Flynn et al. (1994), a quality car model design involves concurrent engineering, reliability engineering and design for manufacturability. The early involvement among representatives from manufacturing, purchasing, quality assurance and suppliers that meet and discuss the details with the designers, helps to achieve the ultimate quality goal by having all the inputs from all related parties.

Cost:

The development costs for automotive models have increased over the years mainly due to supplier, production, and resource costs. According to

Balakrishnan et al. (2007), the global competitiveness in the manufacturing sector, especially in the automotive environment requires high quality products and low prices. Hence, the automotive manufacturers are considering new ways on how to reduce these costs (Kim, 2003). One area of concern is the supplier cost, which requires the manufacturers to have a supplier management plan in order to have a strong relationship between suppliers and manufacturers in controlling the supply cost (Shafia et al., 2009). Production cost also needs to be focused by the LVAM manufacturers by minimising the processes from the initial stage of the production until the delivery to the customers by applying various techniques and production system (Alford et al., 2000). Furthermore, resource cost (which includes the material, energy and labour involvement) is a major challenge to the manufacturing environment for it to produce high quality products, but with low cost (Chryssolouris et al., 2008).

Delivery:

Delivery timing has become a competitive factor in the manufacturing environment which is also the key performance indicator for the manufacturer (Kost and Zdanowicz, 2005). This is due to the dynamic competition among the manufacturers to secure their customers by offering shorter delivery timing. In the automotive industry particularly, Just-In Time (JIT) delivery has become the world standard. As for the Toyota case, by implementing JIT, the goal of having quality car, lower cost and speed to market (delivery timing) can be achieved (Liker and Hoseus, 2008). Therefore, companies are likely to apply innovative features to avoid the delays of the manufacturing implementation programme within a stream of new products and platforms (Beaume et al., 2008), as well as the efficient material handling systems (Raman et al., 2009).

Flexibility:

Flexibility in manufacturing environment refers to the tactical ability of the entire manufacturing processes and logistics area to adapt with reasonably little time and effort to new set of products, by changing manufacturing processes, material flows and logistical functions (Wiendahl et al., 2007). Flexibility in manufacturing is being used in a range of industries and it improves the productivity to cope with the changes in the global demand (Özcan and Toklu, 2009). The versatility of the manufacturing system with the application of flexible workers and machinery, can make the set-up times between product models could be reduced significantly (Boysen et al., 2008). Flexibility in manufacturing is also one of the main goals of the lean manufacturing process. Lean manufacturing seeks to achieve speed of delivery, flexibility and quality. The manufacturing flexibility can be achieved through dynamic partnerships, rich information sharing and the coordination of physical flows, in order to allow quick manufacturing system reconfiguration (Cagliano et al., 2004). According to Riesenbeck (2006), flexibility helps to reduce significantly the product design lead time. In addition, flexibility can enhance product quality, it can be achieved through technology, it can reduce number of components and module, and it can improve the performance of the total manufacturing system. For example the function of the inner reinforcements for the Door Inner is replaced by a typical application of Tailor welded Blanks (TWB). The technology used in TWB combines two blank pieces with different thicknesses into a single Door Inner blank. Then, the combined part is transformed to become a formed panel in stamping process. According to Qiu and Chen (2007), TWB technique reduces 66% of the total number of body and chassis parts which also can significantly reduce weight, process and cost besides create the opportunity to maximise the consumption of material and quality of the parts. This is a good example of how flexibility can be achieved through technology, reduce number of components, and in the end reduce the product design and manufacturing lead time..

Supply-chain:

Efficient and effective supply-chain system for the automotive industry creates the opportunity to improve the competitiveness of the automotive manufacturers (Tang and Qian, 2008). González-Benito and Dale (2001) suggested that potential suppliers need to be involved in the early design stage of the car model with the Original Equipment Manufacturer (OEM), in order to share ideas, improve quality and innovation. The performance of suppliers is important to the automotive quality and it is directly related to the supplier quality management (Park et al., 2001). In order to maximise profit, the supply-chain management for LVAM manufacturers should consider the locations and logistics of their suppliers to cope with the low volume flexibility requirements. Hence, the flexible processes by using "Distributive Product Development" (DPD) should be considered. This concept applies a methodology of designing a product development process by sharing the portion of the process by suppliers which are in different geographical locations (Cleveland, 2006). The potential suppliers are selected based on their expertise, track records and lower cost due to their geographic locations and labour cost (Sturgeon et al., 2008). Logistically, another flexible supply-chain approach, known as supplier park, whereby groups of suppliers are gathered together near to the automotive manufacturers' production site (Howard et al., 2006). The main objective of a supplier park is to easily integrate orders made by the OEM based on production schedules and requirements.

5.2.2.3 *LVAM Lean Process Optimisation*

Lean Process Optimisation is the component that relates to processes in the functional areas of the organisations. The Toyota Production System (TPS) forms the basis of lean manufacturing (Liker, 2004). It evaluates *Employee Involvement*, *Waste Elimination* and *Kaizen* (continuous improvement) as the main priorities in lean concept in order to improve the overall manufacturer performance (Mohamed and Khan, 2011). According Melton (2005), lean environment analyses cost of all activities comprehensively and defined as activities in a process which does not add value to customers in order to eliminate waste.

Employee Involvement:

Employee Involvement is considered as one of the important components in any manufacturing improvement initiatives (Nawawi, 2009). As the employee is the asset of any manufacturer, therefore, it is crucial to develop a programme which benchmarks, assesses, measures, analyses, and plans an action to improve the employee involvement process in the organisation. The programme requires employee involvement and company culture change support (Herron and Hicks, 2008). The employee involvement programme may include job specialisation, job enrichment, job enlargement, job rotation, employee empowerment, organisational cultural change and teamwork encouragement (Chase et al., 2006). The level of employee involvement can be evaluated based on three levels (see Table 5.2) of authority empowerment (Slack et al., 2007).

Table 5.2: Level of employee empowerment

Suggestion involvement	- Lowest level of empowerment - Staff to contribute through suggestions for the operation might be improved - No autonomy for staff to implement changes to their jobs - To prevent dilution of organisations standardised task methods, especially for high-volume operations
Job involvement	- Empower staff to redesign their jobs - There must be some limits to the way each individual makes changes which could impact on other staff and on performance of the operations as a whole
High involvement	- Includes all staff in the strategic direction and performance of the whole organisation

Waste Elimination:

Lean manufacturing process optimisation is a thorough assessment of each activity of a company with the aim of reducing waste at all levels, which is important for LVAM environment and pioneered by Toyota (Liker, 2004). Through the lean manufacturing process, the efficiency and effectiveness of each operation are studied including machines, equipment, layouts and personnel. Lean manufacturing analyses the non-value adding activities (value chain) comprehensively in order to eliminate waste. According to Hicks et al. (2004), there are seven types of waste, namely, over production, waiting, transport, inventory, over processing, motion and defects. To facilitate waste identification and elimination, 5S is a methodology that has been used by many lean manufacturing practices (Nawawi, 2009). The five Ss are summarised as follows:

- Sort (Seiri) : Employee keeps items that are needed. Unwanted items are eliminated.
- Set in order (Seiton) : Items are positioned in such a way that they can be easily reached whenever they are needed.
- Shine (Seiso) : Everything is kept clean and tidy.
- Standardise (Seiketsu) : Operation is in a consistent and standardised fashion.
- Sustain (Shitsuke) : Commitment and pride in keeping to standards are developed.

***Kaizen* (Continuous Improvement):**

In the LVAM philosophy, improvement is considered as a never-ending process. *Kaizen* or Continuous Improvement, which is part of the Toyota Production System (TPS), is a continuing effort to identify and remove wasteful elements in the manufacturing process (Liker, 2004). *Kaizen* requires employee involvement and company culture change by having a clear internal and external communication strategy, and a system of improvement suggestions should also be in place (Nawawi, 2009). *Kaizen* helps to improve the manufacturing process, delivery performance, better space, enhanced productivity and quality (Herron and Hicks, 2008).

At this point, all the elements of the Planning Stage and Design Stage have been incorporated into the conceptual design of KBLVAM model, as in Figure 5.3. The next step is to convert it into a more detailed and specific KB structure model which represents the strategic and operational levels of an actual organisation. The conversion from the conceptual model into a structured model is according to the third objective of the research in order to develop a hybrid KB/GAP/AHP system.

5.3 Framework of KBLVAM Model

The need to convert the conceptual model into a structured KBLVAM model is that reflects an actual hierarchical (strategic and operational) structure of an organisation is important, as it facilitates the subsequent implementation of the KBLVAM recommendations. The Planning Stage, which represents the strategic component of a manufacturer, is converted into the Strategic Level; whereas the Design Stage, which represents the tactical component of a manufacturer, is turned into the Operational Level of the KBLVAM system for the manufacturer in which it will be applied, as shown in Figure 5.4. The conversion clearly shows the relationship between the two conceptual model stages and the six structured model perspectives.

The Strategic Level is divided into three sub-levels; Level 0, Level 1 and Level 2. Level 0, *Manufacturer Environment* Perspective, is acknowledged as the most strategic issue to gather the basic profile of the organisation for the purpose of identification and reference (Khan and Wibisono, 2008). Level 1, *Business* Perspective, contains *Financial Analysis* and *Market Analysis*, are much related to the strength of the manufacturer. Level 2, consists of the strategic issues of the manufacturer’s resources: *Human*, *Technology* and *Financial*.

The Operational Level is also divided into three sub-levels to represent the tactical issues of a LVAM manufacturer; Level 3, Level 4 and Level 5. At this point, the main focus of the second part (tactical) of the KBLVAM is to assess the capabilities of the manufacturers in LVAM environment. Level 3, *Car Body*

Parts Manufacturing, is to access the manufacturer's capability in term of car body parts manufacturing processes from initial design stage to the parts manufacturing. Level 4, *Competitive Priorities*, which relates to five competitive priorities of *Quality*, *Cost*, *Delivery*, *Flexibility*, and *Supply Chain.* Level 5, *Lean Process Optimisation*, assess the LVAM manufacturer's capability to achieve customer satisfaction, which includes *Employee Involvement*, *Waste Elimination* and *Kaizen* (continuous improvement).

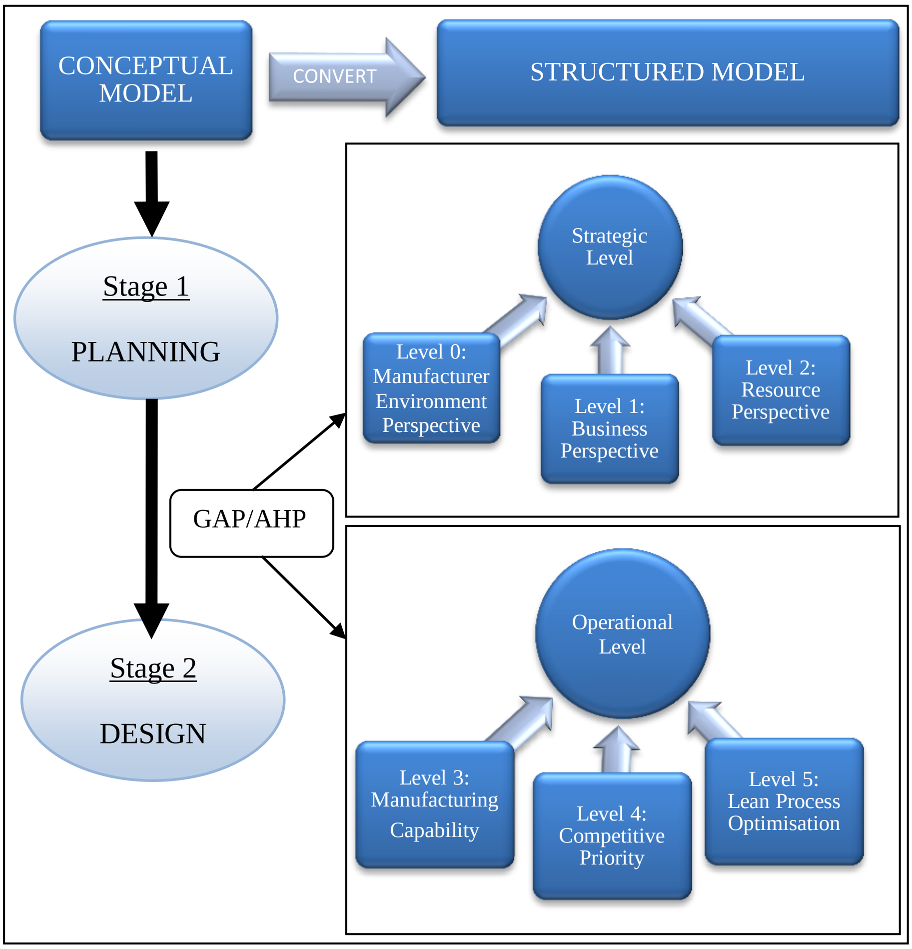

Figure 5.4: Conversion of conceptual model to a hierarchical structure of KBLVAM model

Finally, a framework or structured model of KBLVAM, as illustrated in Figure 5.5, shows a clear relationship between the conceptual components in the Stage 1 (Planning) and Stage 2 (Design) of the model by converting them into six

LVAM perspectives. The development of these perspectives was based on their relevance to the LVAM development, according to the elements or variables that were derived from the literature discussed in Chapter 2, Chapter 3, and Chapter 4. This six-level structure of the KBLVAM System also replicates a typical functional hierarchy of most manufacturers, leading to a very practical KB model.

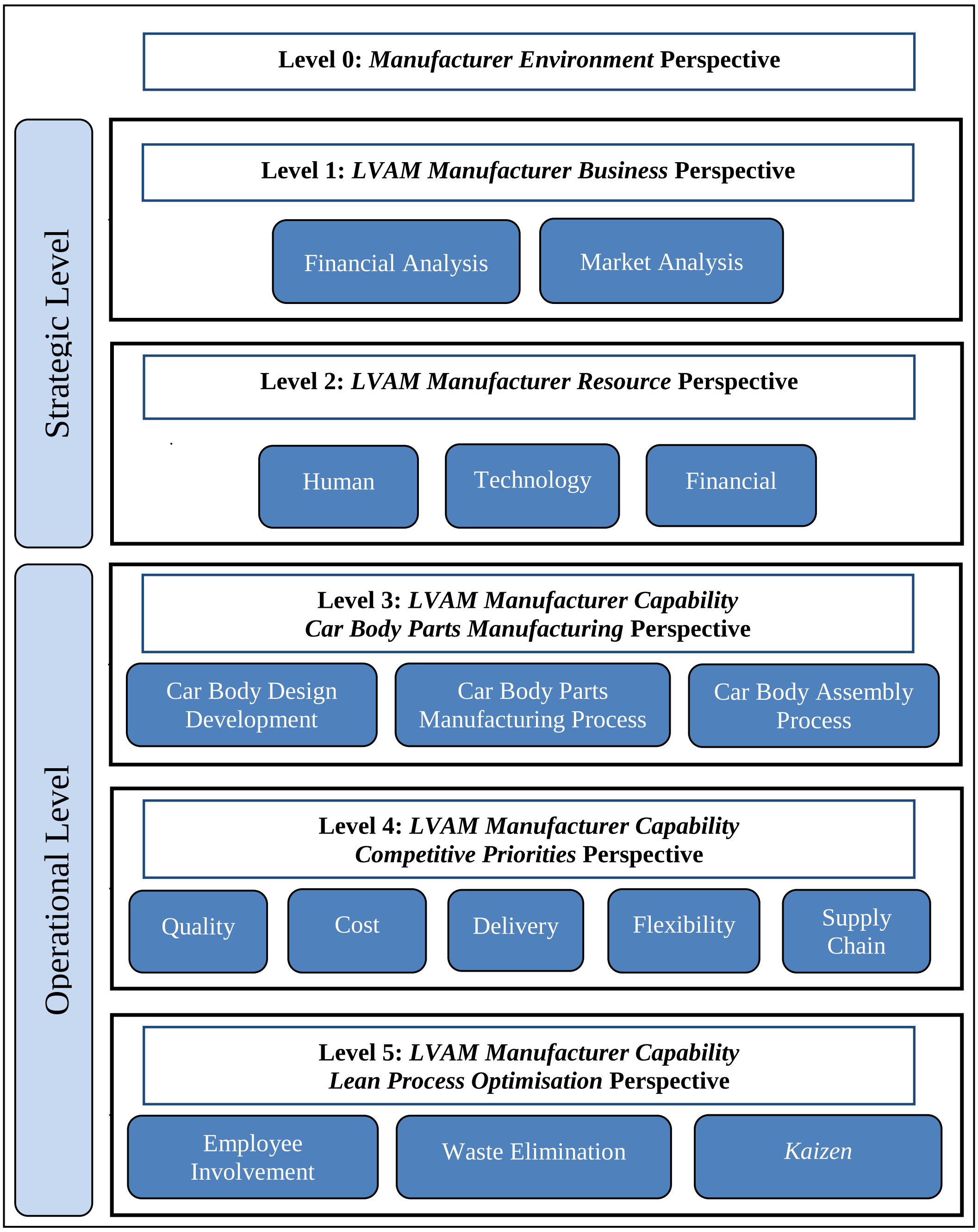

Figure 5.5: Framework of KBLVAM model

The KBLVAM Model details out the development of the system which also considers the capability of the *AM Enterprise* knowledge based software. The developed hybrid KBLVAM System is embedded with GAP analysis and AHP technique for the purpose of improvement prioritisation. The details of the hybrid KBLVAM KB/GAP/AHP System will be explained in section 5.3.2. Hence, the system assesses and evaluates the manufacturer's current condition by conducting a series of KB questions that are built-in in every module. Each of these modules from Level 0 to Level 5 will be discussed in detail in Chapter 6 and Chapter 7.

5.3.1 Development Tools for Knowledge Based Low Volume Automotive Manufacturing (KBLVAM) System

In developing the KBLVAM system, the KBS Shell known as *Application Manager* (AM) is used throughout the research. The software was designed and developed by Intelligent Environments Inc in two versions; *AM Builder*, which is intended for a single developer, while *AM Enterprise* for use by a group of developers. The software uses a highly interactive interface that enables users to develop powerful stand-alone system applications easily and quickly. In representing knowledge, AM uses production rules techniques that are stored in the system applications. *Modules* are the base components in AM software which consists of *procedures, commands, variables, windows, functions* and *menus*. Each of these elements is explained in Appendix A.

5.3.2 Hybrid Knowledge Based/GAP/AHP System

Hybrid Knowledge Based/GAP/AHP System is the integration of both GAP and AHP in a system. This hybrid system requires a specific algorithm that combines the nine-point scales of *Problem Categories* (PC) in the GAP analysis and the nine-point scales of *Intensity of Importance* in the AHP technique. The GAP analysis in the research is achieved through the feedback from the users to the KBLVAM System's designed questions. The responses from the users trigger the system on the possible problems faced by the users, whereby the problems are categorised as negative replies. Each negative reply captured in the system is classified into nine problem categories, in descending order of importance, as shown in Table 5.3.

Table 5.3: Problem categories and description of GAP analysis technique

Category	Code	Description
1	PC-1	This indicates a **very 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 benefit.
2	PC-2	This indicates a **serious problem**, which involves **pre-requisites to the system** and requires appropriate and logical improvement and implementation plan.
3	PC-3	This indicates a **major problem**, which is likely to have **pre-requisites to the system** and is better dealt with as part of an appropriate and logical improvement and implementation plan.
4	PC-4	This is **quite a major problem**, which is likely to have **pre-requisites to the sub-system** and is better dealt with as part of an appropriate and logical improvement and implementation plan.
5	PC-5	This indicates a **problem** and can be dealt with now. If resolved, it is likely to produce short-term benefits.
6	PC-6	This indicates a **minor problem** and can be dealt with now. If resolved, it is likely to produce short-term benefits.
7	PC-7	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.
8	PC-8	This is **not really a problem**, However it is important to consider certain situations as future improvement.
9	PC-9	This is not **really a Good or Bad** point itself. 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.

Coding is used to identify whether the responses provided by users are in the Good Point (GP) Category or Bad Point (BP) Category (BP Category is considered as Problem Category (PC). The PC is ranked from 1 to 9, as shown in

Table 5.3, with the Code PC-1 being the worst condition and PC-9 being the least critical condition. This novel approach developed for this research of considering a 1 to 9 GAP category is a more detailed and complete approach than the previous attempts; like the 1 to 5 GAP category developed by Wibisono (2003), Udin (2004) and Nawawi (2009). Based on the GAP analysis methodology, only the BPs are categorised into PC in order to identify the necessary pre-requisites that are needed in order to achieve the LVAM implementation. Finally, the necessary pre-requisites of the current position of LVAM manufacturers can be identified through the number of BPs.

The KBLVAM System will utilise the algorithm developed by (Wibisono, 2003), and supported by (Udin, 2004) and Nawawi (2009). In order to integrate these scales from the two different techniques, all nine-point scales of PC in GAP need to be transferred into AHP's nine-point scales. The algorithm begins with the weight allocated to all nine PCs by using the pair-wise comparison technique of AHP. The nine-point PC scales are then structured in the form of a matrix as illustrated in Table 5.4 by considering PC-1 (as the least point PC) to be more important compared to the higher point PC (such as PC-9) in terms of problem identification. Hence, the logic for this comparison is PC-1>PC-2>PC-3>PC-4>PC-5>PC-6>PC-7>PC-8>PC-9.

Table 5.4: Pair-wise Comparisons for Problem Category (PC)

	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7	PC-8	PC-9
PC-1	1	2	3	4	5	6	7	8	9
PC-2	1/2	1	3/2	4/2	5/2	6/2	7/2	8/2	9/2
PC-3	1/3	2/3	1	4/3	5/3	6/3	7/3	8/3	9/3
PC-4	1/4	2/4	3/4	1	5/4	6/4	7/4	8/4	9/4
PC-5	1/5	2/5	3/5	4/5	1	6/5	7/5	8/5	9/5
PC-6	1/6	2/6	3/6	4/6	5/6	1	7/6	8/6	9/6
PC-7	1/7	2/7	3/7	4/7	5/7	6/7	1	8/7	9/7
PC-8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	1	9/8
PC-9	1/9	2/9	3/9	4/9	5/9	6/9	7/9	8/9	1

The value of weight for each PC is determined by identifying the highest value among PCs and then dividing it by the corresponding PC value. The logic of this process can be calculated as follows:

V = highest value of category (e.g. in this case, 9 is the highest value)
x = value of category (e.g. in this case, PC-1 has a value of 1)
Therefore, W (weight) = V/*x*

For instance, the highest value among the PCs is 9; divide it by 1 for PC-1 which make the weight for PC-1 is 9 (9/1=9; meaning that PC-1 is nine times more important than PC-9). The next step is to divide the highest value by PC-2 to find the weight for PC-2 (9/2=4.5; meaning that PC-2 is four and a half times (4½) more important compared to PC-9). The process is continued to find the remaining weight for PC-3, PC-4, PC-5, PC-6, PC-7, PC-8, and PC-9 as summarised in Table 5.5; whereby PC-9 being in a neutral position that it is not really a good or a bad point.

Table 5.5: Comparative weight of Problem Category (PC)

Category	Code	Weight
1	PC-1	9
2	PC-2	4.5
3	PC-3	3
4	PC-4	2.25
5	PC-5	1.8
6	PC-6	1.5
7	PC-7	1.3
8	PC-8	1.13
9	PC-9	1

The next stage is to assign each component 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. In this case, the Consistency Ratio (CR) for each matrix is measured to confirm the result validity and the consistency of the pair-wise comparison. If the CR is bigger than 0.10, it implies that there is a 10% chance that the components have not been compared well and the decision-maker must review the comparison again. The example of the mathematical process for performing the calculation in the AHP in this study is described in Appendix B.

5.4 Summary

This chapter has described the development of the proposed KBLVAM model, which consists of two stages of Planning (Stage 1) and Design (Stage 2). The research has developed a conceptual model that divides the Planning (Stage 1) into two major components in consideration of the strategic issues of an actual organisation, namely *LVAM Manufacturer Business* Perspective and *LVAM Manufacturer Resource* Perspective. The Design (Stage 2), which is the operational level in KBLVAM consists of three main components; *LVAM Manufacturer Capability - Car Body Parts Manufacturing* Perspective, *LVAM Manufacturer Capability - Competitive Priorities* Perspective and *LVAM Manufacturer Capability - Lean Environment* Perspective. These three operational components are developed based on the tactical issues of an actual organisation.

This conceptual model is then converted into a structured KBLVAM system based on *AM Enterprise* software capability. This framework consists of six interrelated levels with five main perspectives; *Manufacturer Environment, LVAM Manufacturer Business*, *LVAM Manufacturer Resource*, *LVAM Car Body*

Parts Manufacturing, *LVAM Competitive Priority* and *LVAM Lean Process Optimisation.* The developed KBLVAM System also integrates the use of GAP analysis and AHP technique in the formation of the model to assist in the prioritising the decision making process. The detailed design of all the components and perspectives of the KBLVAM model will be discussed in Chapter 6 and Chapter 7.