The Development of a Hybrid Knowledge-Based System for Designing a Low Volume Automotive Manufacturing Environment. The Development of A Hybrid Knowledge-Based (KB)/Gauging Absences of Pre-Requisites (GAP)/Analytic Hierarchy Process (AHP) System for the Design and Implementation of a Low Volume Automotive Manufacturing (LVAM) Environment.

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 19^{th} 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 individual competitive strength, in order to compete in the marketplace. Furthermore, according to Balakrishnan et al. (2007), the global competitiveness of economic manufacturing requires high quality products and low prices. This is due to dynamic competition among the manufacturers to secure their customers (Kost and Zdanowicz, 2005). As a result, the demand for high quality, low cost and on-time delivery has increased product variety.

Quality conformance processes achieve reduced cost, higher productivity and higher reputation in the global market. According to Amoako-Gyampah and Acquaah (2008), quality strategy plays an important role in capturing customer satisfaction that can potentially lead to increased sales growth and market share. They also added that, a company which develops a strategy to achieve volume and mix flexibility while keeping low costs and high quality will be able to react faster to market demands and finally achieve higher performance. A recent study by Karim et al. (2008), revealed that product quality and reliability has become the main competitive factor in the global trend. According to Stewart (2010), too much growth in demand also takes focus away from quality with results of defects in finished products, such as the case for Toyota Motor with resulting tremendous costs (financial and reputation) for the company.

The strategies discussed above are related to the manufacturing processes shown in Figure 2.1. Depending on the nature of business of a company, the decomposition of manufacturing processes is categorised as high volume, medium volume and low volume.

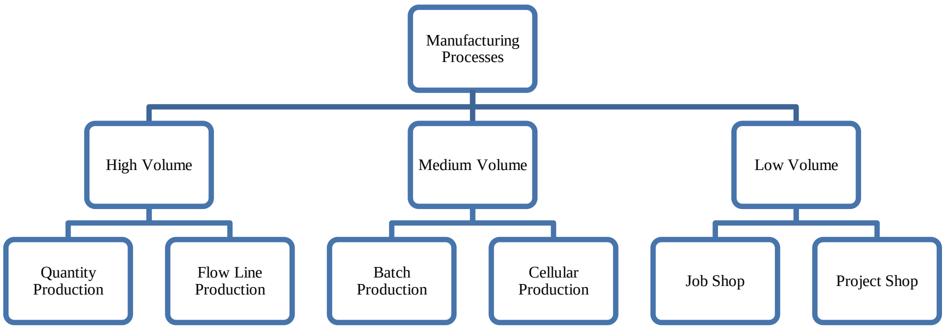


Figure 2.1: Decomposition of manufacturing processes

The decomposition shows that each sub-process has its own characteristics and depends on the nature of the company's business as illustrated in Table 2.1. Two extreme processes are continuous line production (extreme fast) and project shop (extreme slow). The other processes lie in between these two extremes of the manufacturing environment. It has been shown that process flow patterns become less complex with cellular, line and continuous flow compared to jobbing and project. When the product is high variety and low volume, it suggests that project or functional production is applied.

Table 2.1: Typical characteristics of process choices (adapted from Hill (1993))

	Low Volume		**Medium Volume**		**High Volume**	
Manufacturing aspects	**Project**	**Jobbing**	**Batch**	**Cellular**	**Line**	**Continuous**
Nature of the process technology	Orientated towards general purpose	Universal	Dedicated	Dedicated	Dedicated	Highly dedicated
Process flexibility	High	High	Low	Low	Low	Inflexible
Production volumes	Low	Low	High	High	High	Very high
Changes in capacity	Incremental	Incremental	Stepped change	Stepped change	Stepped change	New facility
Key manufacturing task	To meet specs/ delivery schedules	To meet spec/ delivery schedules	Low cost production	Low cost production	Low cost production	Low cost production

2.2 High Volume Manufacturing

High volume manufacturing (also known as mass production) involves producing products in large quantities (Váncza and Egri, 2006). According to Partanen and Haapasalo (2004), the term mass production is used because of the high demand rate of the particular product. Normally, for high volume manufacturing, only small numbers of different products are manufactured by the company. This type of manufacturing is associated with long assembly lines where factory workers or machines continuously turn out the same product month after month. There are two categories of high volume production; quantity production and flow line production as shown in Figure 2.2. According to Özcan and Toklu (2009), the obvious characteristic of a high volume production is that operations are linked together in an assembly line. After completion of one operation on a product, it moves directly to the next operation in the assembly line. The process is continued until the final station in the assembly line where the finished product is expected.

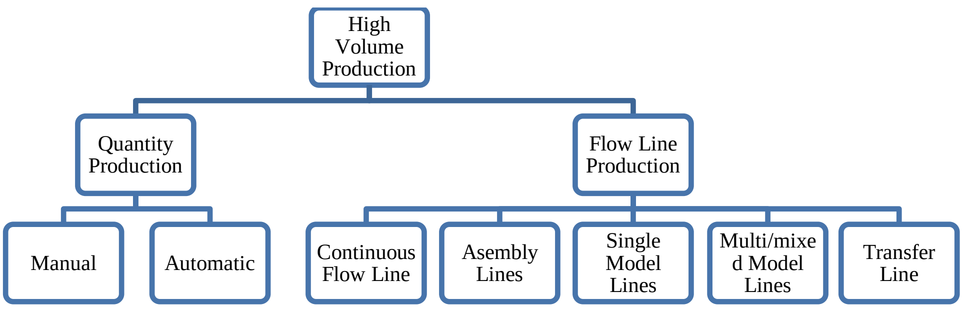


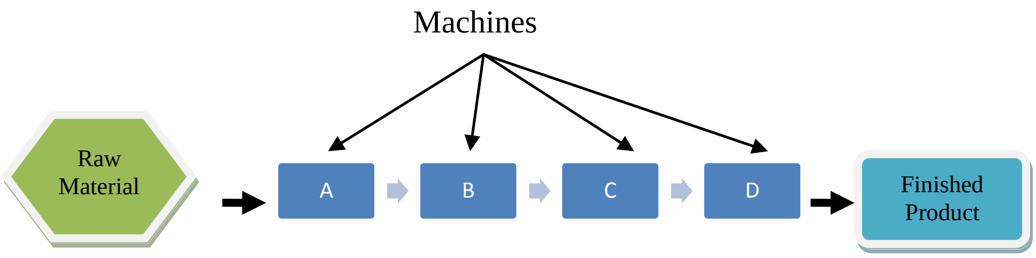
Figure 2.2: Categories of high volume production

2.2.1 Quantity Production

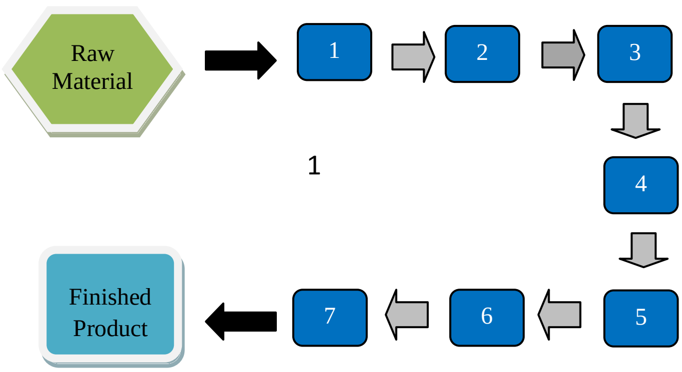
Quantity production is one category of high volume manufacturing, which concentrates on the mass production of a single product by using single standard equipment (Cárdenas-Barrón, 2009), for instance, products that come out from stamping press which is a repetitive process especially for the blank shapes (Kamalapurkar and Date, 2006). The process is a continuous operation whereby material is fed to the machine either manually or automatically. The machine will then turn the material into the final product and the same process continues until the desired quantity is achieved.

2.2.2 Flow line production

Flow line production is concentrated on multiple equipment or workstations that are arranged in the process sequence (Quadt and Kuhn, 2007). According to Drira et al. (2007), flow line production is characterised by high volume, repetitive and short cycle work. The work piece is physically moved through this sequence in order to complete the process and finally becomes the product. The sequence is also known as product layout because it is arranged in a long line of workstations and usually connected by conveyors. Product layouts, as shown in Figure 2.3, are designed for a specific product such as Product X and Product Y (Kara et al., 2009). In flow line production, machines are oriented such that the product flows in sequence down the line and has all necessary set-ups to perform operations on the products (Chen and Chen, 2009). For these reasons machines in flow line are often designed specifically for the products and are not easily adapted to other products (Quadt and Kuhn, 2007).



Product X – Straight Assembly line



Product Y – U-Shape assembly line

Figure 2.3: Product layouts (adapted from Kara et al.(2009))

There are several types of high volume manufacturing methods that are being implemented in various industries, those methods are described below.

2.2.2.1 Assembly lines

An assembly line is a manufacturing process which has linked workstations by conveyors or a similar material handling system so that each product goes from one operation directly to the next and so on (Özcan and Toklu, 2009). According to Maqsood et al. (2011), an assembly line consists of a number of workstations that consistently perform certain operations on a workpiece in a cycle time (maximum or average time available for each work cycle). As a result, each product follows the same routing of operations and identical final product is expected at the end of the line (Kara et al., 2009). The complexity in the process of producing a product is mainly depending on the number of its components and the assembly levels. The product's structure is defined as the Bill of Materials (BOM) (Chan et al., 2009). This category of production is best referred to as an assembly line of products such as cars. When every product is identical at the end of the assembly line, the line is classified as a single model production line. Fundamentally, assembly lines were developed for a cost efficient high quantity production of a single standardised product (Boysen et al., 2009).

2.2.2.2 Single model lines

According to Özcan and Toklu (2009), single-model assembly lines are purposely designed to produce a mass volume of standardized homogeneous products, which is not appropriate for high variety of products. This type of assembly line is commonly use in high volume manufacturing environment because it enables assembly of workpieces by operators with limited training (Cevikcan et al., 2009).

2.2.2.3 Multi/mixed model lines

According to Gamberi et al. (2008), there is a global trend that companies offer a wide selection of products to their customers. They are being used in a range of industries and it improves the flexibility to cope with the changes in the global demand (Özcan and Toklu, 2009). The producers of these products need to manage the product variety by introducing multi/mixed-model assembly line system that produces similar items or options of the same product requiring analogous tasks (Boysen et al., 2009). Multi-model assembly lines, as illustrated in Figure 2.4, produce a set of products before continuing with another set of products on the same assembly line. Therefore, the assembly process for these kind of products needs to be done in batches to avoid high set-up times and high costs.

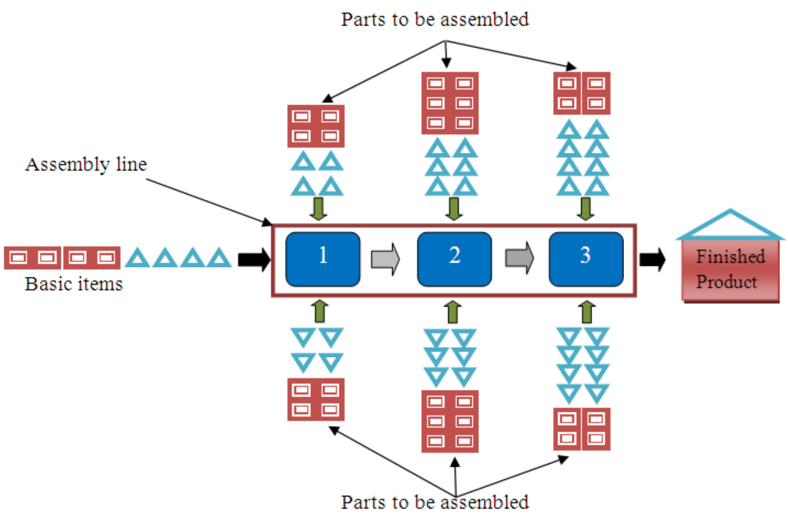


Figure 2.4: Multi-model assembly (adapted from Boysen et al.(2008))

In contrast, mixed-model assembly lines, as illustrated in Figure 2.5, produce products in a mixed sequence. According to Cevikcan et al. (2009), this kind of system has superior benefits compared to the traditional assembly line from the view points of system flexibility, lead time, cost, and product quality.

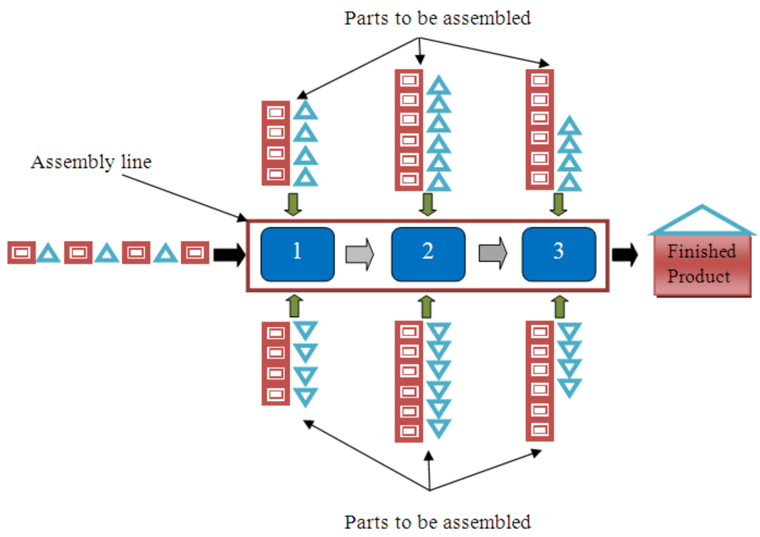


Figure 2.5: Mixed model lines (adapted from Boysen et al.(2008))

Boysen et al. (2008) stated that the versatility of the system with the application of flexible workers and machinery, can make the set-up times between models to be reduced sufficiently enough to be ignored. Hence, intermixed model of common base product sequences can be viably produced on the same assembly line.

2.2.2.4 Transfer lines

Transfer line or fully automated lines are implemented in the manufacturing environment mainly to perform the jobs more economically, precisely and safely (Boysen et al., 2008). The advantage of the transfer lines is variations of products can be produced by using the same production line. It creates the opportunity to cater the demands for product varieties. Normally, these lines are attached with machines that are capable of changing the tools automatically to perform multiple jobs at varying speeds. Transfer lines work by passing workpieces sequentially through all workstations at a constant and controlled speed (Dolgui and Ihnatsenka, 2009). These types of lines are designed for mass production of a single product or a family of similar products. Due to the high automation of the lines, the production period can be programmed for a very long production time. Among the applications of transfer lines are the weld shop, paint shop and body shop of the automotive industry (Boysen et al., 2008).

2.2.2.5 Continuous line production

The process works by passing the basic material through different stages and refined or processed into one or more products such as chemicals (Tousain and Bosgra, 2006), food (Brierley et al., 2006) and steel mills (Tang and Wang, 2008). According to Weinekötter (2009), the continuous line process is based on high volume demand and the materials involved moved easily and hardly ever pause from one stage of the process to another. Discrete units are not produced, but liquids or gases flowing through pipes of different stages are transformed into final products. With a continuous flow process, one can estimate realistically how long it takes to transform raw materials into a specific product (Floudas and Lin, 2004).

This kind of manufacturing involves a very high investment cost and must be justified by the high volume demand. According to Brierley et al. (2006), capital investments and automation are often the most expensive compared to those of other processes. This is because the processes are designed to run continuously with minimum shutdowns because of the high costs of starting up and closing down. In continuous processing, as materials flow from one stage to another, it is important to monitor and adjust the flow to ensure the quality and safety of the product (Shaik et al., 2009).

2.2.3 Material Handling Systems (MHS)

Material Handling Systems (MHS) are an important component of manufacturing systems which act as an inter-connector for facilities and facilitate the process of delivering the right amount of materials, to the right place, at the right time and at the lowest cost (Raman et al., 2009a). According to Mirhosseyni and Webb (2009), MHS are responsible for transporting materials between workstations efficiently by joining all workstations and workshops in manufacturing systems with minimum obstruction. Similarly Sujono and Lashkari (2007) state that MHS integrate functions within a manufacturing system and plays a very important role in the manufacturing system because they accounts for 30–75% of the total cost of a product. An effective MHS should improve the performance of a manufacturing system, especially by reducing Work-In-Process (WIP).

2.2.4 Facility Layout

In a manufacturing system, facility layout is considered to be one of the important criteria which has a significant effect towards manufacturing productivity in terms of cost and time. Raman et al. (2009b) suggested that the objectives of a layout is to minimise material handling cost, improve flexibility for arrangement and operation, utilise the available area and minimise overall production time. According to Drira et al. (2007), *"a facility layout is an arrangement of everything needed for production of goods or delivery of services"*. In general, the facility layout has a lifecycle which consists of design, implementation, growth, maturity and obsolescence phases (Raman et al., 2009b). In each phase of the lifecycle many considerations have to be made which include design, evaluation and selection of an effective layout, production planning and scheduling.

2.3 Medium Volume Manufacturing

Medium volume manufacturing has two types of facilities which depend on product variety (Das et al., 2007). The first type is known as batch production and the second type is cellular manufacturing. Batch production is used when products variety is substantially different. On the other hand, Cellular Manufacturing is used when product variation is very small between products (Groover, 2007).

2.3.1 Batch Production

Batch production is used when there are varieties of different products being manufactured but in smaller quantity (Kalpakjian and Schmid, 2006). Once a batch of products is finished, the manufacturing system is changed over to produce another batch of different products (Floudas and Lin, 2004). However, by sharing the machines, production time lost is high due to set-up time during the changeover process, and the nature of scheduling in batch production. According to Gamberi et al. (2008), the process will need to be reset each time the new batch is scheduled to start as to facilitate the model. Among the process constraints are cleaning, cooling and maintaining.

According to Drira et al. (2007), the layout in batch production groups the equipment by function rather than by product which is suitable for a wide variety of product factory. The product is moving throughout the process of completion from department to department within the factory. The batch flow depends on job order such as routings, process steps and time spent on certain department. Due to the competitive market, normally the batches are produced in an established lot size that moves into stock for future customer orders (Das et al., 2007). Examples of batch production are chemical industry, metal bending and steel pipe manufacturing (Gamberi et al., 2008).

2.3.2 Cellular Manufacturing (CM)

According to Li (2003), the main purpose of the CM is to group machines into machine cells and parts into part families. CM also arranges operators (multifunctional) according to machines in order to design a high performance factory. Angra et al. (2008) stated that the philosophy of CM is to capitalise on similar, recurrent activities with broad applicability and potentially affecting entire areas of manufacturing organisation. The concept of CM is to segregate a manufacturing system into sub-systems in order to improve the efficiency of the total manufacturing system (Drira et al., 2007). CM has become a new method to manufacturing systems which was traditionally based on functional tasks (Agarwal, 2008).

In CM, a cell is a small manufacturing unit, consisting of one to several machines as in Figure 2.6. A workstation may contain either one machine which is called a single-machine cell or several machines which is called a group - machine cell. Each of the machines performs different tasks on the particular part. The advantage of CM is that the machines can be modified, re-tooled, and re-grouped for different product lines within the same family of parts (Kalpakjian and Schmid, 2006).

The emphasis of CM is on group effort and individuals that may move the work piece from machine to machine through the cell without waiting between operations (Panchalavarapu and Chankong, 2005)

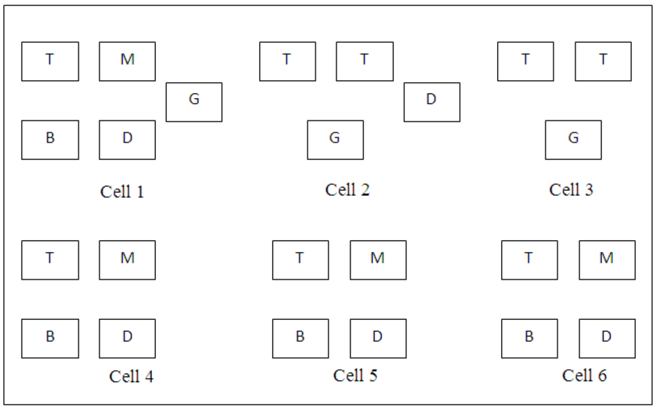


Figure 2.6: Cellular manufacturing layout (adapted from (Agarwal, 2008))

Therefore, by combining the advantages of process and product layout to optimise the job shop arrangement, CM is the alternative for the current needs of manufacturing systems (Nagalingam and Lin, 2008).

2.3.3 Flexible Manufacturing System (FMS)

According to Kumar and Sridharan (2009), a Flexible Manufacturing System (FMS) is a system which integrates Computer Numerically Controlled (CNC) machines and an automated Material Handling Systems (MHS) that work together under computer control. Flexibility deals with high quality customised products and focuses on fast delivery of products to markets with reasonable price. Basic flexibilities in manufacturing include product flexibility, machine flexibility, material handling flexibility and operational flexibility. The main purpose of FMS is to process medium-sized volumes of a variety of part types simultaneously. The aim of the system is to achieve both production flexibility and high productivity in order to meet the current global demands (Sujono and Lashkari, 2007).

In most FMS, the tasks to be manufactured are assigned to machines and the corresponding tools are loaded into tool magazines (Kumar and Sridharan, 2009). Workpieces move from one machine to another depending on the routing assignments based on operations–allocation decisions.

2.4 Low Volume Manufacturing

Low volume manufacturing normally makes low quantity of specialised, complex and customised products (Bellgran and Aresu, 2003). This type of manufacturing requires a highly skilled labour force and maximum flexibility in order to cater for product variations. Examples of this type of manufacturing are aircraft, ship and automotive. According to Williamson (2006), low volume manufacturing always works together with a high flexibility manufacturing program. To achieve this concept, manufacturers must consistently review the available technology for both product design and facility design in manufacturing a product.

Miltenburg (2008) suggested that a low volume manufacturing company should consider lean production and innovativeness in addition to flexible manufacturing as the most important manufacturing outputs. Engle (2008) suggested that design team should consider components sharing concept in order to produce the high variety of products. According to Wrobel and Laudanski (2008), low volume manufacturing performs production based on make to order. Koste and Malhotra (2000) suggested that worker's job rotation flexibility is also important because workers who are trained to perform different job rotation will make them multitasking experts and become an asset for low volume manufacturing environment. There are two types of low volume manufacturing methods, jobbing (or job shop) and project shop. These two methods will be discussed in the next headings.

2.4.1 Project Shop

Project shop is a low volume manufacturing process dealing with a single product, unique, customised and a one-time-only job (Bellgran and Aresu, 2003). Project shop is used for large product such as civil engineering contracts, ships, buildings and aeroplanes. Due to the nature of large products, the resources involved in manufacturing the product, need to be supplied to the site and released for re-use elsewhere when they are no longer required. According to Drira et al. (2007), the layout for project job uses a fixed position layout to manufacture large size products, while the resources, materials and equipment are supplied to it.

2.4.2 Jobbing

Jobbing is used to fulfil a special and particular product ordered by customers such as fabricating and metalworking (Dixon, 2008). Hence, it is the most flexible process in manufacturing a wide variety of products. Job shop typically uses a process layout in arranging the equipment (Bertrand and Sridharan, 2001). This is also known as functional layout because the equipment is arranged according to functions. For example turning machines may form one department, milling a second, and grinding process a third. The main reason to group the similar equipment together is because no single product contributes enough sales volume to justify the formation of a product-specific array of equipment. Normally a job shop has a diverse array of facilities and capabilities to choose from with possibly different efficiency (Gao et al., 2007). The responsibility for making the product is normally given to the highly skilled operators. The operators themselves decide the best way to make it, choose the equipment and then complete all or most of the operations involved including checking the quality at each stage (Kher, 2000). Furthermore, the material flow in job shop can be fed in many directions and can loop back to the same equipment later in the operation (Fan et al., 2007).

2.5 Lean Manufacturing

The oil crisis of 1973 generated great concern for Japanese manufacturing, especially Toyota Motor Company which pioneered the lean manufacturing process (Shah and Ward, 2007). Lean manufacturing process optimisation is a thorough assessment of each activity of a company with the aim of reducing waste at all levels. 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 Melton (2005), waste is defined as any activity in a process which does not add value to it and, is usually about 70% to 80% for most manufacturing process operations. According to Hicks et al. (2004), there are seven types of waste; namely, over production, waiting, transport, inventory, over processing, motion and defects. The priority to eliminate waste in manufacturing environment represents a huge benefit in terms of manufacturing improvements. The main goals of lean manufacturing process are speed of delivery, flexibility and quality, which can be achieved through dynamic partnerships, rich information sharing and the coordination of physical flows without rigid investments, in order to allow rapid reconfiguration (Cagliano et al., 2004).

The Toyota Production System (TPS) was developed in Japan by Ohno and Shingo and forms the basis of lean manufacturing (Liker, 2004). Toyota could not afford the capital intensive mass production systems used in the USA and so instead focused upon minimising waste in all aspects of its operations. Toyota used many techniques and tools to reduce waste including *Kaizen*, Cellular Manufacturing, synchronous manufacturing, *Poka-Yoke*, standardized working and work place organisation. The outcomes included significantly reduced inventory and lead-times, improved delivery performance, better space and resource utilisation, and enhanced productivity and quality.

The implementation of lean manufacturing techniques and philosophies requires the transfer of explicit and tacit (implicit) knowledge. It requires employee involvement and company culture change. The transfer of knowledge, particularly implicit knowledge, requires the abstraction and packaging of knowledge from a host. The application of the knowledge by a client involves an unpacking process. Lean tools, such as Statistical Process Control (SPC), Failure Modes Effects Analysis (FMEA), Single Minute Exchange of Dies (SMED), fool-proofing and process mapping, involve mainly tacit aspects of knowledge, which can be codified. These techniques are well documented and are relatively easy to learn from the literature. However, other tools such as Total Productive Maintenance (TPM), *Kanban*, 5S, standardised working and policy deployment require mainly tacit knowledge to apply them, which makes them difficult to implement without support (Herron and Hicks, 2008).

2.6 Summary

This chapter has provided review of manufacturing environment. It reviewed manufacturing processes and their decompositions including the spectrum of manufacturing processes involves with types of manufacturing that determine the volumes and varieties of products. A review of three types of manufacturing processes that involve high, medium and low production volumes was done. These manufacturing segments have different methods of processes depending on the types of business, products, facilities and lay-out. The concept of lean manufacturing, focuses on waste reduction at all levels throughout the company was also covered.

It is important to understand the manufacturing aspects that have been covered in this chapter, especially which are related to LVAM environment. Based on the understanding of the types of manufacturing practices, requirements and advantages, LVAM environment is to focus on aspects of the quality of the car produced, the cost of the whole processes, and delivery of the product to customers. The consideration should incorporate the elements of man, machine, method and material to suit the LVAM manufacturer's vision and mission.

In LVAM environment, as the nature of production is low volume, small batches with mixed model lines is important to be utilised to maximise space, labour, and cost (Boysen et al., 2008). Therefore, it is not suitable to use the quantity production, flow line production, and transfer line production, which are more suitable for HVAM environment. Another important aspect of LVAM environment is the flexibility and leanness of the manufacturing system. Flexibility includes the product flexibility, machine flexibility, material flexibility, and operational flexibility, which can support the LVAM environment tremendously. Moreover, the elements of lean manufacturing are very important to be implemented in both LVAM and HVAM in order to reduce waste which contributes 70%-80% of the manufacturing process operations (Melton, 2005). The following chapter will now review the literature of the automotive manufacturing.