CHAPTER 3

LITERATURE REVIEW: AUTOMOTIVE MANUFACTURING

3.1 Introduction to Automotive Manufacturing

The automotive sector is one of the most important economic catalysts in every country (Orsato and Wells, 2007). It creates direct and indirect industry covering almost all products of steel, rubber, plastics and electronics. According to Jahanzaib (2008), 66.5 million passengers and commercial vehicles were produced in the world, with the installed capacity of 85 million. A more recent report by OICA (2011) shows that the production has increased by 15% to 78 million vehicles. A typical automotive project will require direct and indirect human resources from many functional organisations and facilities such as workers, suppliers, consultants and partners spread across the country and throughout the world. According to Hallgren and Olhager (2009), increased competition, global markets, and more challenging customers are all contributing factors that should be the main focus of today's business environment.

Automotive projects require dedicated expert team of designers, engineers, planners and managers in order to control schedule, costs, delivery, regulations and customer needs. Traditionally, the processes of developing a new model were sequenced from the design stage until the product launch (Gao et al., 2000). This approach is too risky because once a problem happens it would affect the next stage of the process and would deteriorate the total program. Therefore, companies are likely to apply innovative features to avoid the delays of the program within a stream of new products and platforms (Beaume et al., 2008).

An automotive program begins with conceptual stage whereby design and business strategy concepts are blended based on current market desire and demand. Normally, this is the work of styling group who transform the current needs and business perspective into a product concept sketch (Kumar et al., 2006). A typical car making process is illustrated in Figure 3.1.

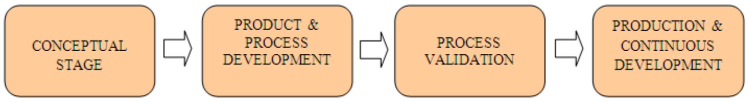

Figure 3.1: Product Development Stages (Mohamed et al., 2005)

The concept should consider the fundamental characteristics of the planned model, such as style, physical dimensions, image, options, and performance specifications. From the sketches, the clay modellers use this information to create detailed interior and exterior models of the vehicle that will physically represent the styling creativity into reality. The physical model will be carefully studied by other development team members from body design, equipment design, manufacturing, and potential part suppliers. This is to provide feedback to the styling and clay model team on the feasibility and limitations of manufacturing the vehicle and provide suggestions for improvement. After the refinement process is completed, the clay will be digitised for the purpose of detailed product design.

At the product and process development stage, product engineers will start to design hundreds of individual new parts such as doors, hood, roof and tailgate. With the current trend of speed to market, some of the parts are carryover parts especially the inner parts and floors that are hardly noticed by customers (Ghosh and Morita, 2008). Although it saves cost, this concept is a challenge to product engineers to manipulate the new parts that fix together and attach to the existing parts. Later, by using soft tooling process, these parts will be produced and assembled together to form a prototype car. The purpose of prototype car is to check abnormalities to the parts fitting, assembly process, and testing.

Concurrently, production engineers and suppliers use the completed product designs to design and build production tools to suit high volume output (Orsato and Wells, 2007). These tools are comprised of dies, moulds, and other similar devices that transform raw materials such as steel, rubber, plastics and glass into loose finished parts. In addition, assembly tools will act to weld or fasten two or more parts together into sub-assemblies, main assembly and finally transform into complete products. Checking fixtures act as measuring tools to confirm the parts are according to their designed specifications and dimensions.

Process validation stage is the stage of production trials take place. Prior to the trials, all the facilities and machines need to be installed to cater for the new requirements especially if the line is to accommodate for different models. Once the installation is finished, pilot trials will take place to evaluate and certify the ability of the entire production process that combines people and machines to produce quality products as intended at the beginning of the development stage.

Finally, the production of the car will be commenced once all the requirements have passed the standards and procedures of the company. This is the critical time for the company to monitor the performance of the production line as well as the quality of the produced cars. Feedback from production site, vendors and customers will help the company to perform a thorough study for continuous improvement, not only for the product development but also the production set-up. This is in line with Toyota Production System (TPS) which supports and encourages people to continuously improve the process that they work on (Liker, 2004).

3.2 High Volume Automotive Manufacturing (HVAM)

The development costs for automotive models have increased over the years due to the unavoidable resource costs such as raw material, labour and services. Hence, automakers are extensively doing research on how to reduce these costs. One attempt is to reduce the number of platforms, as suggested by Kim (2003). The idea is to have a multiple vehicle variant of a single platform. By implementing this concept, many parts can be shared between car models which reduce the tooling costs tremendously. High Volume Automotive Manufacturing (HVAM) involves many high technology tools ranging from such as dies, jigs and robots. Using this platform commonisation technique undoubtedly reduces cost, time to market and quality as well as more choice to end users.

Platform means the main framework of cars which are normally comprised of floorpan, drive train and axles, as cited by Ghosh and Morita (2008). According to them, there are three types of platform sharing. The first is different products with similar quality levels such as Mitsubishi Endeavour and Galant, and Honda CR-V and Civic 2. The second type is the platform sharing across manufacturers such as Nissan Micra and the Renault Clio. The third type is the platform sharing across multiple products with different quality levels or better known as vertically differentiated products within a manufacturer and across manufacturers. Toyota Land Cruiser/Lexus LX 470, and Honda CR-V/Acura RDX.3 are the examples platforms within the manufacturer. On the other hand, Porshe's Cayenne and Volkswagen's Touareg 4, are the examples of platform sharing across manufacturers.

On the specific manufacturer's approach, according to Cleveland (2006b), Toyota has implemented an approach known as set-based concurrent engineering.

The approach is basically a set of database of designs for various car components. By applying this approach, multiple design alternatives are created for each sub-component instead of a single design variant. They can easily change the design by selecting the alternative if the chosen design fails during simulation performance.

General Motors (GM) for instance introduced a Global Manufacturing System (GMS) with the aim of improving safety, quality, productivity and cost. The system stresses the value of teamwork and of an empowered environment. This means people at the shop floor control their working area and this embeds the spirit of the company's goal. GM realized that by having this GMS, everyone's experiences and insights are valued (Flores, 2003). This working culture has existed in Toyota Production System (TPS), whereby people are selected and expected to be employees for life. Toyota has been very selective in hiring the right people, at the right amount, in the right form and at the right time (Liker and Hoseus, 2008). By having these values in people at Toyota, the goal of having quality car, lower cost and speed to market can be achieved.

In the car assembly method, Toyota has introduced the so called *"Toyota Global Body"* approach. The concept is to use the common welding jigs for different platforms, meaning that, the master jig can accommodate any model variants from the same production line without the need to change jigs. The approach is duplicated at all Toyota plants in the world so that the output will be the same regardless of plant locations (Brown, 2004).

In the HVAM sector, automobile manufacturers have introduced new approaches to reduce cost, increase quality and shorten the timing especially in the area of method and machine. In HVAM, a break-even point of 250,000 units per annum is considered the lowest volume that a manufacturer must produce or 80%

capacity utilisation of 300,000 units per annum (Orsato and Wells, 2007). These figures place continuing pressure on the manufacturers to cut cost and seek new alternatives to meet the target. One alternative is to use the mixed model assembly lines to produce different product models with different processing time for a low volume manufacturing scheme (Heike et al., 2001). According to them, key elements for this type of assembly are flexible fixtures, flexible tooling, and a multi-skilled workforce.

3.3 Low Volume Automotive Manufacturing (LVAM)

Automotive manufacturing sector globally is increasingly becoming a competitive industry which requires new car models at a lower cost, but at higher quality (Miguel, 2006). Current market trends require faster product development, lower cost and higher quality products (Nagahanumaiah et al., 2008). Niche car models such as luxury, sports and special purpose vehicles are one of the viable strategies to sustain the market choices, which is achieved through Low Volume Automotive Manufacturing (LVAM), defined as 25,000 – 30,000 units per annum. The normal route of car making processes is not suitable to be implemented for LVAM, because the normal route involves higher costs and longer project scheduling. Niche models of LVAM require high customisation, especially when related to design concepts, manufacturing methods, and suppliers (Meichsner, 2009).

Automotive design normally requires experts who know the entire automotive production 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 Udin (2006), Khan and

Wibisono (2008), and Nawawi (2009), it is essential to have a systematic tool for generic design in automotive industry such as Knowledge Based System in order to achieve the manufacturing demands and the high standards of production quality.

3.3.1 Automotive Design Concept

Product creation processes or design concepts are the steps that generate insights into opportunities and focus on activities that help to prevent failures (Uffmann et al., 2006). The automotive industry should consider various aspects such as technology, manufacturing, regulations, suppliers and customers. According to Yadav and Goel (2008), vehicle attributes such as fuel economy, emission, vehicle dynamics, performance, NVH (noise, vibration and harshness), aerodynamics, climate control, packaging, cost, and weight are the characteristics or requirements needed in automotive industry. Therefore, it is important to integrate these attributes with the identified customer, corporate, and regulatory requirements into a vehicle concept such as LVAM.

Yadav and Goel (2008) suggested a way to priotise these attributes by using the Customer Satisfaction (CS) gap that ranks the improvement opportunities by multiplying a weight factor such as:

$$\Delta CS_i = CS_i\,(BC) - CS_i\,(CV), \qquad \text{Equation (1)}$$

where ΔCS_i is Customer Satisfaction (CS) difference between two vehicles for attribute i; CS_i (BC) is CS number of the best in class vehicle for a given attribute;

and CS_i (CV) is CS number of company's current vehicle. The weight factor is a function of qualitative factors:

$$\omega = f\,(\text{vision, goals, complexity, resource requirements, opportunities, etc}) \qquad \text{Equation (2)}$$

The weight factor above is a function of qualitative input factors, therefore Equation (2) can be used as a guideline by the management or design teams to give due consideration to all appropriate input factors before assigning weights to each attribute. As a result, the final prioritization ranking (PI) for attribute *i* is calculated as:

$$PI_i = \omega_i\, \Delta CS_i. \qquad \text{Equation (3)}$$

The attributes with higher prioritisation ranking offer greater opportunity for improving overall CS as well as guide the company's planning.

According to Uffmann et al. (2006), the automotive design concept should also prioritise to reduce time for producing a product in intended volume, with high level of quality and at competitive prices (time-to-volume). Thus, a thorough studied concept ensures the product will be launched on the scheduled date. Uffmann et al. (2006) stress the importance of overall timing as the profit of the new product may be reduced by 30% if the time to market is delayed by six months, as illustrated in Figure 3.2.

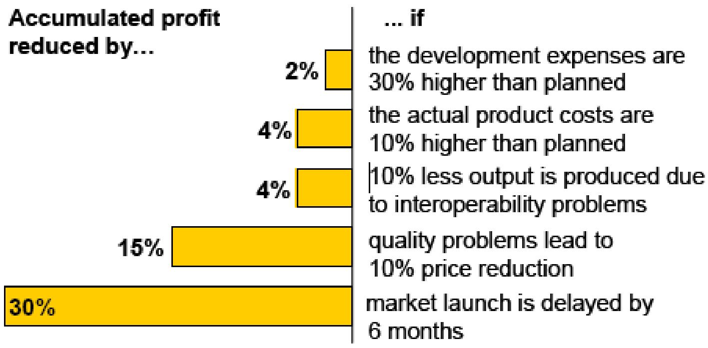

Figure 3.2: The effect of problems on profit (Uffmann et al., 2006)

Automotive manufacturing is a volume driven industry which depends on particular volume to justify the production (Jahanzaib, 2008). Therefore, in the conceptual design stage, it is important to consider the right type of manufacturing system to be used for all products including for LVAM model. According to Trappey and Hsiao (2008), collaborative product design is one of the important aspect to be considered at this stage. The concept of collaboration is that the project team members (comprising of experts, engineers, managers and workers) can jointly work and focus on the same project in order to achieve a common goal. This idea is shared by Forza et al. (2005), as they suggest the automotive companies need to integrate product design, process design, and supply chain design decisions in order to stay competitive.

Design concept stage, as Ferrer et al. (2009) consider, is a stage to study the manufacturing process constraints, capabilities and costs. Technologies to be used in the actual process could also be finalised during this stage. Furthermore, the availability of manufacturing information and knowledge will become key factor to achieve Design for Manufacturing (DFM) as early as possible in order to avoid re-designs at the later stage, thereby reducing wastes and costs. According to Shafia et al. (2009) common platform is one of the concept that maximise the components sharing amongst several models except the differences in the outer skin of the models. Thus, the common platform throughout the chain promotes the resource sharing such as materials, tools, processes and human resource (Shafia et al., 2009). This concept can help to reduce time especially when dealing with large number of models and parts**.**

The concept is practical for LVAM because many parts are shared between the HVAM models (Sawyer, 2008). According to Riesenbeck (2006), by applying this concept, not only can new product design be significantly reduced, but product quality, technology used, components, modules and systems can also be integrated. As a result, the manufacturer can adapt its volume to the target or niche market with significantly reduced costs. The manufacturer who has the ability to produce this kind of product will have a major advantage over the others. According to Alford et al. (2000), automotive manufacturers are able to reduce investment cost in body fabrication process by applying the common platform concept. Designers can focus on the exterior design and styling at relatively lower cost and timing to suit the regional demands. He cited an example from the Ford Puma project which was based on the Ford Fiesta platform. The model was delivered to market in 17 months from concept to production, showing how a profitable niche markets could be rapidly produced from a high-volume vehicle.

Another product design concept is customisation or the tailored product. Customisation allows the possibility of cars to be custom-made, not only by mixing and matching standard components but by actually customizing the shape and style of components, new materials and production processes (Seidel et al., 2005). There are two types of customisations; mass customisation and core customisation. Selladurai (2004), suggested that *"mass customisation refers to a process of production of goods and services tailored to suit the needs of customers in a mass* *market"*. The concept is being practiced by major companies like Dell, Motorola, Hewlett-Packard, General Motors, Ford, Chrysler, Toyota, Proctor and Gamble. With the availability of rapid manufacturing technologies, parts and products can be made very quickly to customer specifications at affordable prices. According to Seidel et al. (2005), the sales process also need to be changed from the traditional ''mass'' dealers to individual ''style advisors''. The advisors will help the customer to choose the right design for their personal requirements.

Core customisation, on the other hand involves the potential customer with the design process of the vehicle and is only applicable in LVAM and niche vehicles (Alford et al., 2000). In this concept, customers can discuss their specific requirements with the design team to have the special features of their tastes. Alford et al. (2000), gives an example of Land Rover that manufactures classic all-terrain vehicles, offers optional features available to the customer to satisfy individual preferences. Core customisation also occurs between low-volume niche car manufacturers and their customers, as the nature of the manufacturing process allows customers to modify designs to suit individual preferences.

3.3.2 Product/Tooling Design

In automotive industry, there are two types of designs, namely product design and tooling design. Product design is related to the parts of the entire automotive body and chassis structure such as side panel, doors, hood, doors that total up to more than 300 parts (Qiu and Chen, 2007). Tooling design is related to the tools required for transforming the material into parts such as dies and moulds. Tooling design is also required for body assembly fixtures fabrication. Normally, the automotive manufacturers design the parts according to their own specifications, systems and requirements (Park et al., 2001).

According to Trappey and Hsiao (2008), upon completion of the product design, Primary Manufacturing Enterprise (PME) or the automotive manufacturer will find suppliers to fulfil the product design with detailed tooling design. The suppliers or System Manufacturing Company (SMC) will design according to the requirements, fabricate the tools and produce the parts. SMC also has collaborative suppliers to supply components, parts and materials. This concept is illustrated in Figure 3.3, and consists of three tiers of participants; primary manufacturing enterprise (PME), system manufacturing company SMC, and SMC's suppliers. The system involves design phase and production phase that works in close loop such that PME set the system requirement and production order, SMC and suppliers will respond accordingly.

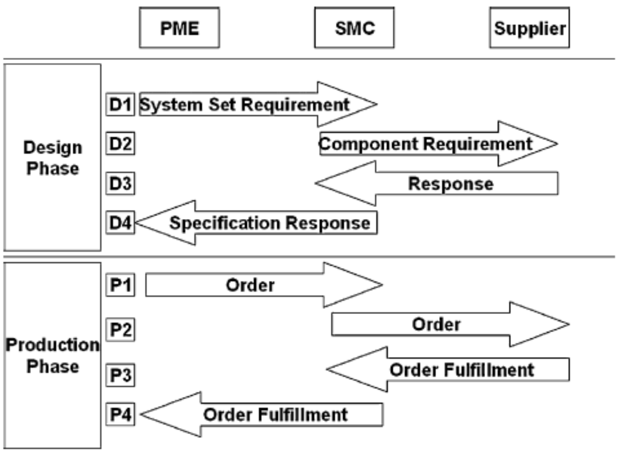

Figure 3.3: Current connection of automotive supply chain in design and production phases (Trappey and Hsiao, 2008)

González-Benito and Dale (2001) suggested that suppliers need to be involved in the early design stage with the automotive manufacturers in order to share ideas, improve quality and innovation. However, close partnership with suppliers during product development need to be very careful to avoid the information leakage by restricting the information only to their specific components (Harmancioglu, 2009). Therefore, the possibility of the information leakage of the entire projects is minimised.

3.3.3 Manufacturing

The manufacturing process for automotive industry is normally complicated, expensive, long and risky (Nobelius, 2004). However, different companies have various strategies to achieve their goal (Crawford and Bryce, 2003) such as platform sharing (Kim, 2003), data base design (Cleveland, 2006b), lean manufacturing system (Flores, 2003) and common tooling (Brown, 2004). For LVAM, the manufacturing environment is different from the HVAM because the nature of LVAM is slower in production speed compared to mass production, hence, there must be a new approach to shorten the processes without compromising on the quality, cost and delivery of the car. Those approaches will be discussed in the following sections.

3.3.3.1 Material

Material is one of the most important aspects in every manufacturing industry. Due to the low volume environment, the correct choice of material will definitely become an advantage to this automotive segment. According to Cui et al. (2008), generally, the car body and its interior accumulate for about 40 % of the total vehicle weight. Multi-material designs provide more opportunities for weight saving and lower cost compared to single-material structures. Multi-material combination method provides opportunities for designers to fully exploit the benefits of each material and achieve the optimal production efficiencies.

The application of new materials such as carbon fibre–polymer composites for Body-In-White (BIW) closure steel panels has successfully reduced weight (Turner et al., 2008). According to Turner, LVAM can take the advantage of this material because it has only become cost effective for small and mid-volume production levels of up to 500 parts per annum. As an example, BMW has adopted a thermo plastic composite for its low volume M3 model's underbody shields (Jacob, 2008). The advantage of this material is its lightweight, optimised aerodynamic, corrosion resistance and fuel efficiency (Sapuan et al., 2005). Besides that, BMW also uses thermoplastic polyester for the front frame of sunroof for BMW Series 1 and 3 models (Jacob, 2005).

In another application of material for LVAM approach, Hypercar, Inc. uses carbon-fiber composite body structure as the basis for design, fabrication, and assembly of the Revolution concept car (Cramer and Taggart, 2002). Glass-reinforced sheet moulding compound (SMC) is chosen for the material due to its ability to be stamped into shapes which make it much lower in capital costs relative to steel. According to Cramer and Taggart (2002), with the aims of having low-cost fabrication and assembly, each part is designed to reduce sharp edges, shallow draws, enhance repeatability, and eliminate the need for labour-intensive pre and post-process steps. Through this concept, the body structure is 57% lighter than a conventional steel body structure of the same size and yet offers better crash protection, better stiffness and favourable thermal and acoustic properties. Furthermore, it is a very suitable concept for LVAM because according to Fuchs et al. (2008), the cost competitiveness for this approach is achieved at annual production volumes of 30,000 or less. Then direct substitutions of glass-reinforced composites for steel components for body-in-white are likely to reduce costs.

Grujicic et al. (2009), suggest that polymer–metal-hybrid (which is the combination of two classes of materials into a singular component/sub-assembly) should be fully utilised for automotive components such as Rear Cross Roof Beam as in Figure 3.4. It works by placing a stamped part in an injection mould in order to coat its underside with a thin layer of reinforced nylon. The benefits from this method among others are reduction of the number of components, production of the integrated components ready to assemble, and weight reduction compared to the all-metal parts. Furthermore, the hollow core of the part allows functional integration such as cable housings, air or water channels.

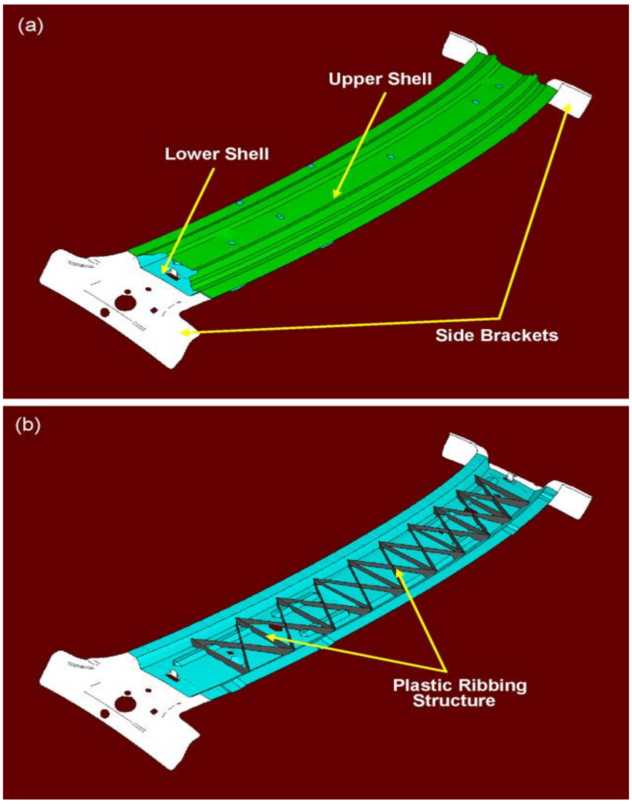

Figure 3.4: A rear cross-roof beam with the adjoining side brackets analyzed in the present work: (a) the all-metal design and (b) the PMH rendition (Grujicic et al., 2009)

In the recent study by Borsellino and Bella (2009), biomimetic cellular cores of recycled paper is used to form sandwich materials for interior applications such as door trim panels, headliners, package trays and trunk floors panels as in Figure 3.5. However, this technique is only suitable for use in non-structural components because of its failure during the impact test.

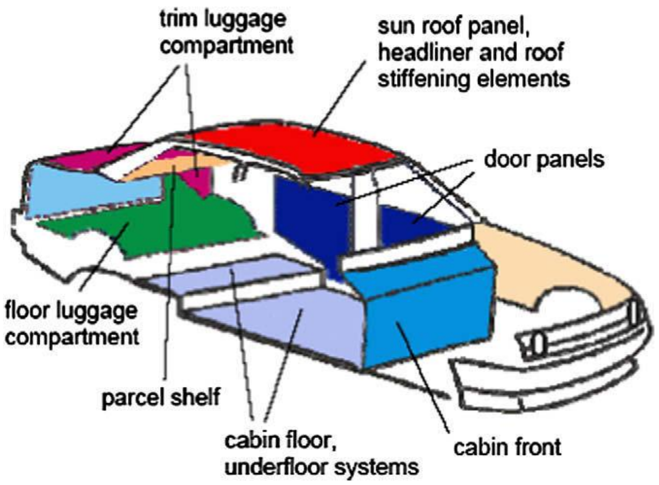

Figure 3.5: Automotive components (Borsellino and Bella, 2009)

3.3.3.2 Tooling and Process

In automotive manufacturing plant, there are four major shops that have different functions in the manufacturing processes, namely; stamping shop, body shop, paint shop, and trim and final shop. However, according to Joly and Frein (2008), production process involve three shops: the body shop, the paint shop and the assembly shop. This is because the stamping shop in the automotive environment is separated from the main production line and has its own production line that produces stamped parts. These parts will be transported to the body shop for assembly process at the main line based on the scheduled date.

3.3.3.2.1 Stamping

In the stamping shop, stamping dies are required to produce 250-300 of the automotive body-in-white parts (Sweeney and Grunewald, 2003). Stamping process transforms flat sheets into a complex geometry parts including various forming, cutting and bending techniques (Shivpuri and Zhang, 2009). According to Nakagawa (2000), in general, metal forming is suitable for high volume production, but not for low volume production. This is because each part shape requires individual die to form the geometry resulting in high costs. However, the press sheet forming is still a very practical method to produce a part even for small lot production.

There are options for new forming process that are more cost effective such as 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). Normally, a particular part requires different process dies: draw die, trim die, pierce die and flanging die. LVAM manufacturer can take advantage of these options by developing only the forming die to form the shape of the part quickly and inexpensively (Nakagawa, 2000). This will avoid the fabrication of dies for the following processes such as trimming and flanging. These processes can be done manually as well as flexible automation of laser cutter (Qiu and Chen, 2007) and bending machine (Nakagawa, 2000). These flexible processes will give options to the manufacturers to maximise their output and minimise the process (and hence costs).

Tooling cost for LVAM is one of the major concerns among the automotive producers. Cleveland (2005), suggested that soft tooling that is normally used to produce prototype parts is designed so that the tooling can reliably produce parts in the 15,000 to 20,000 range. Normally the soft tooling is made of soft casted material compared to the high carbon steel for high volume tooling. Cleveland (2005) also suggested another option which is to lean down the design of high volume tooling that is targeted to run 750,000 parts and above so that it can run for several thousand parts.

One way to reduce the cost is to reduce the number of parts through the combination of different thickness of material known as tailor welded blanks (TWB) (Jeswiet et al., 2008). This technique combines two or more sheet materials together by using laser welding prior to the stamping process (Shi et al., 2007). The sheets of identical or different materials of strengths, thicknesses or coating types represent different parts that are combined to become a single part. According to Gaied et al. (2009), a typical application of TWBs is the Door Inner as in Figure 3.6. The function of the inner reinforcements is replaced by combining 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. Qiu and Chen (2007), suggested that by adopting TWB technique, 66% of the total number of body and chassis parts are reduced. Hence, TWB can significantly reduce weight, process and cost besides create the opportunity to maximise the consumption of material.

Laser forming technique is another solution for forming automotive body parts. According to Jeswiet et al. (2008), a laser is used to assist in the forming processes by directly heating the forming zone while the pressing rollers are used to form the sheet. It works by placing the laser directly in front of the pressing rollers. This technique is suitable for LVAM because it requires lower forming force compared to the conventional die, it increases the flexibility and it also reduces the tool wear.

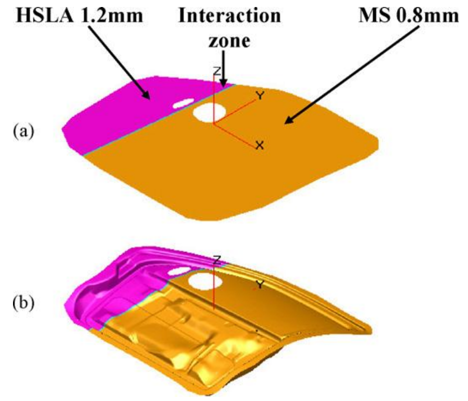

Figure 3.6: Door Inner based TWBs (a) developed blank and (b) formed sheet (Gaied et al., 2009)

Spray forming is another technique which is a rapid solidification process of spray materials onto the ceramic mould. According to Yang and Hannula (2008), the process starts by filling the metal in a tundish; the metal is then atomised by an inert gas into droplets of 10–200μm in size, spraying at subsonic speed onto a ceramic mould as in Figure 3.7. In this technique, the thickness of the metal layer is controlled by the duration of spray to ensure the uniformity of thickness on the mould. By applying this concept for the dies inserts, the time and cost are significantly reduced due to the rapid process of converting the molten alloy directly to a semi-finished product (Yang and Hannula, 2008).

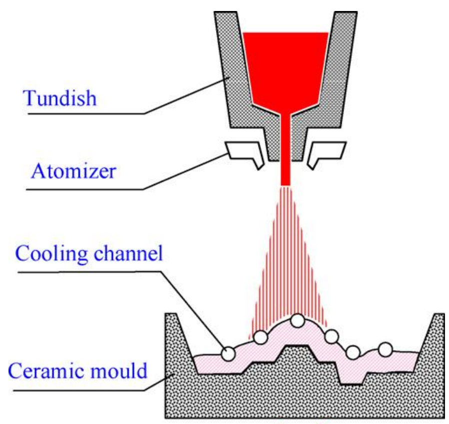

Figure 3.7: Spray forming process (Yang and Hannula, 2008)

Another way to form a body part is by using a Single-Point Incremental Forming (SPIF) technique. According to Jeswiet et al. (2008), SPIF as illustrated in Figure 3.8 uses a combination of blank holder and a semi-spherical head forming tool to form a body part. According to Jackson and Allwood (2009), this technique is flexible because specialised tooling is not required in the forming process as the semi-spherical head tool moves over the surface of the sheet according to the tool path computer numerical control (CNC) planning data resulting in a highly localised plastic deformation.

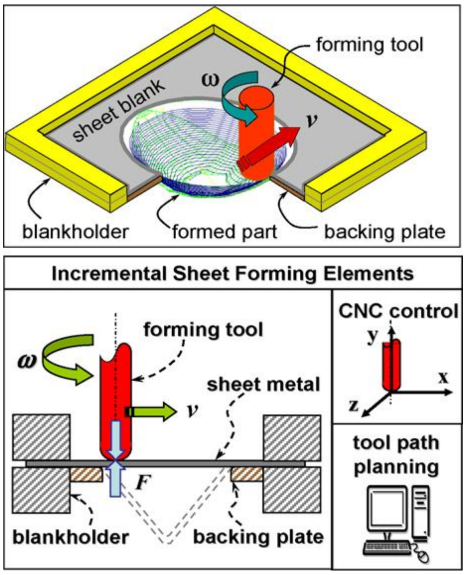

Figure 3.8: Single-point incremental sheet forming (Jeswiet et al., 2008)

The tool trajectory is generated from the CAD data of the part to be produced which can include a basic geometry supporting die or not, depending on the complexity of the shape (Cerro et al., 2006). Therefore, various 3D shapes can be formed by moving the forming tool according to a programmed path. The main goal of this technique is to avoid the need to manufacture specialised and expensive dies (Lamminen et al., 2003). Due to a long processing time, the application of SPIF is suitable for automotive body parts such as prototype, low volume production

(Jeswiet et al., 2008); small batch or customised production (Jackson and Allwood, 2009).

Liquid pressure is also being applied in metal forming industry, especially for small lots production of complex forming shapes (Alberti and Fratini, 2004). This technique, illustrated in Figure 3.9, usually known as hydroforming or hydromechanical forming processes which uses fluid counter pressure as female die. As the rigid punch and the drawn cup enter into an enclosed liquid container, an opposing hydrostatic pressure of the liquid is generated by pushing the drawn component against the punch which finally transforms it into the desired shape. This not only produces the complex shapes but can also be applied for tube hydroforming of hollow components with variable closed-sections (Yuan et al., 2006). Hydroforming can reduce the number of parts and weight as well as improving their stiffness. According to Nakagawa (2000), liquid pressure technique is able to reduce processes which proved difficult in conventional sheet forming methods. However, this technique is only applicable for the first drawing process, the processes of trimming and bending are replaced by laser trimming and bending press.

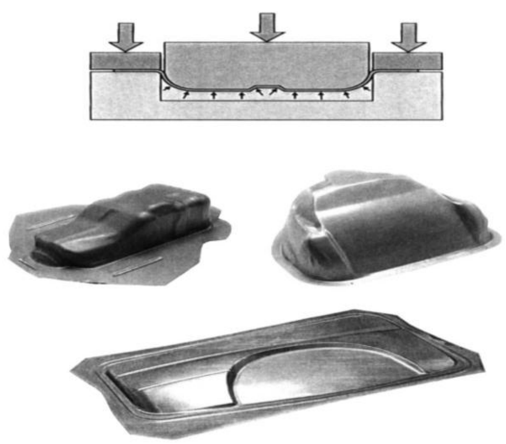

Figure 3.9: Hydraulic counter pressure deep drawing (Nakagawa, 2000)

Roll forming is another flexible process for forming a long body part that requires constant cross sections, as illustrated in Figure 3.10. Sweeney and Grunewald (2003) mentioned that *“roll forming is a continuous bending operation in which flat sheet metal (from coils or pre-cut blanks) is plastically deformed along a linear axis. Tandem sets of rolls shape the metal stock in a series of progressive stages until the desired cross-section is obtained”*. Roll forming is a continuous manufacturing process for a long part passing through the tooling and cut into different lengths without changing the tool set-up. It is also possible to change the geometry of the parts by simply changing the dies on the machine which makes this technique cheaper compared to stamping and hydroforming (Sweeney and Grunewald, 2003). The typical applications of roll forming are bumpers, door beams, frame rails and roof bows.

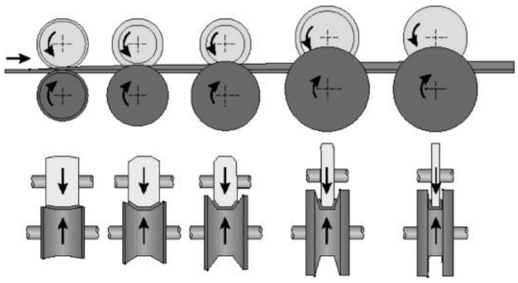

Figure 3.10: Roller forming (Sweeney and Grunewald, 2003)

3.3.3.2.2 Body Assembly

Body assembly is the second process in the automotive production which combines individual parts or components to become a complete body in white. It is a complex architectural systems which requires synchronisation and interaction of many components (Mondragon et al., 2009). According to Miguel (2006), modularity is an approach for building a complex product or process by combining smaller subsystems that can be designed independently and then assembled together to become a complete system. This modularity can be applied both in design and in production. Modularity in design means the design boundaries of a product and its components; whereas modularity in productions is related to plant design boundaries to cater for manufacturing and assembly requirements such as product variety, production flow and quality (Miguel, 2006).

The modularity concept is applied in designs of seats, cockpits, or external structures such as bumpers (Howard et al., 2006). The cockpit module design for GM Celta program for instance was joint developed by VDO and GM by sharing costs and knowledge with regard to the concept design, prototyping, product specification, and tooling development (Miguel, 2006). The Front End Module (FEM) is also one of the body assembly concepts for reducing parts assembly as well as weight. According to Kim (2007), FEM is an assembly which is made up of the bumper beam, the head lamp, the radiator, the carrier and so on as a component module. Then, the module is connected to the front side member and the fender of the particular car. Goede et al. (2008) proved that by using the FEM, 12 steel components are combined into a single component which significantly reduces assembly operation, weight and cost. Among automotive manufacturers, Volkswagen (VW) and Mercedes–Benz/Smart also use the modularity concepts in their Resende plant in Brazil and Hambach in France, respectively (Doran and Hill, 2009).

An additional way to produce a low volume car or niche model is by re-using the existing parts and platform, thereby reducing product development time as well as the engineering and production costs. According to Hat (2009), due to advances in Computer Aided Design (CAD) and Flexible Manufacturing Systems (FMS), these carry-over parts are covered with different body styles or top hats. This approach assists the car makers to concentrate on the design of the overall car body styling. However, designers always need to keep all the fixing points, gaps and dimensions of the existing parts or platform in the new design so that they will fit perfectly to the existing panels and platform.

Daimler Chrysler for instance, is using this approach of assembly line sharing. They are converting their assembly lines from the traditional approach of dedicated line to a more flexible assembly line (Bogue, 2008). The Company’s FMS allows the programming of their robots to weld and assemble a range of different models and variants at the same location. The shift in the strategy will also balance production against demand and to accommodate building lower volume vehicles that take advantage of market niches. Bogue added that due to automotive business trend’s perspective, today production runs are more commonly in the 70,000-100,000 unit range.

Lotus Engineering (in UK) for instance, use the method of Versatile Vehicle Architecture which is to share the same platform with other automakers with the aim of having high commonality and reduced investment (Kermit, 2004). According to Sawyer (2008), in spite of LVAM being normally run on its platform, the niche model can also use the same platform for HVAM. He added that, with minor modification to the platform, Toyota's Scion offers the best example of this approach. However, to implement this method, the existing production line of HVAM must have balanced capacity in order for this niche model to be integrated into the main production schedule.

In the body assembly process, individual panels and components are joined and assembled through a variety of processes, such as welding, riveting, and bonding

(Chen et al., 2006). LVAM has the opportunity to use different joining techniques such as a structural adhesive which is suitable for aluminium and composite materials. Because of the lightweight materials, it also reduces the vehicle weight (Jeff, 1999). This joining techniques has been used by Lotus since 1996 and has proved to be successful because over 23,000 cars have been built using adhesives with no reported failures (Kermit and Christopher, 2004). This technique eliminates the traditional use of welding guns or robot which will reduce the investment cost of these heavy machines as well as working space required. The continuous bond along the joints gives improved joint stiffness compared to mechanical fasteners or spot welds. The benefits of adhesive bonding have been now proven in many concept cars and low volume niche products such as Jaguar's XJ220, Ford's AIV, Rover's ECV3, the Lotus Elise, and Honda's NSX (Barnes and Pashby, 2000).

Besides adhesive, self-piercing rivets and clinch joints are two types of fasteners that have been identified as potential for use in automotive parts (Barnes and Pashby, 2000). Self-piercing rivets work by piercing the upper sheet of material and then expanding in the lower sheet without piercing it to form a mechanical interlock, as illustrated in Figure 3.11. According to Barnes and Pashby (2000), this single operation requires large setting forces (typically 40 kN) and a C-frame structure in order to hold the forces as well as allowing access to both sides of the joint.

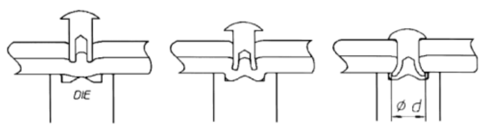

Figure 3.11: Self piercing rivet process (Barnes and Pashby, 2000)

The clinching process, on the other hand uses a punch instead of rivet to deform the material being joined to form a mechanical interlock. As shown in Figure 3.12, a joint in the clinching process interlocks the sheets to form a sealable joint against moisture. Barnes and Pashby (2000) added that clinching process has been tested at Volvo, whereas self-piercing rivet has been applied at Audi and Lotus. Lotus applies self-piercing rivets as the secondary protection against peel in its adhesive bonding extrusion structures.

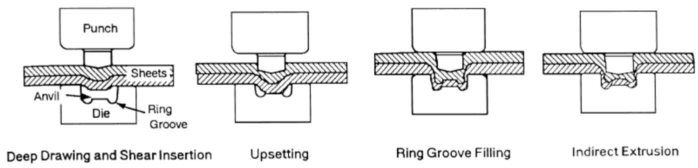

Figure 3.12: Clinching process (Barnes and Pashby, 2000)

Closure parts are always referred to as automotive body-in-white opening parts, such as doors, deck lids and hoods (Thuillier et al., 2008). These parts are the assembly of the outer skin and an inner reinforcing part by a hemming process. It is a process which avoids the use of traditional assembly such as welding in order to maintain the outer surface quality. In a normal table-top hemming of HVAM, the whole edge of outer skin is hemmed at the same time, as in Figure 3.13. An alternative to tabletop hemming, LVAM uses the roll hemming process. In this process, a roller is guided by a robot along the hemming edge, bending the flanged 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 tooling from prototype to production and reduction tooling development time.

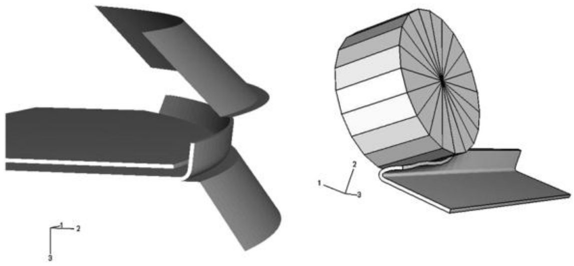

Table-top hemming Roll hemming

Figure 3.13: Schematic view of hemming tools (Thuillier et al., 2008)

3.3.3.3 Quality

It becomes a difficult task for automotive manufacturers to meet not only the must-be-quality but also to reach the level of attractive quality (Hassan et al., 2000). Kim (2007) suggested that the automotive manufacturers should consider good/attractive product appearance, high surface quality as well as superior performances in durability, NVH characteristics and crashworthiness. Therefore, it is very important to consider all aspects related to the product 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 Johnson and Khan (2003), *"Process Failure Mode and Effects Analysis (PFMEA) technique evaluates the potential failure of a product or process and its effects, identifies what actions could be taken to eliminate or minimise the failure from occurring and documents the whole procedure"*. This technique is applied from the initial planning stages of designing and continues throughout the end of its life. This technique continuously improves products, processes, reliability, reduce warranty and finally increasing customer satisfaction. PFMEA supports the practice and philosophy of problem prevention and continuous improvement, which are key elements of Total Quality Management (TQM) (Liu et al., 2011).

Another key element in manufacturing is Quality Function Deployment (QFD). QFD is a well-structured, cross-functional planning technique that is used to hear the customers' voice throughout the marketing analysis, product planning, design, engineering, manufacturing and supply processes (Bhattacharya et al., 2010). A complete QFD involves the House of Quality (HOQ) construction diagram, which helps company views the relationship between the requirements of the customer and the design characteristics of the new or improved product. It is also considered as crucial for the TQM implementation programme because the function of HOQ is to identify what are the customer requirements and then to relate to measurable and prioritised engineering targets (Jia and Bai, 2011).

According to Flynn et al. (1994), a quality product design involves concurrent engineering, reliability engineering and design for manufacturability. Concurrent engineering establishes relationships among representatives from manufacturing, purchasing, quality assurance and suppliers that meet and discuss the details with the designers. It helps to achieve the ultimate quality goal by having all the inputs from all related parties. Reliability engineering involves designing process from the basic components that anticipates the failure probabilities of each individual system and subsystem. Finally, design for manufacturability concentrates on the design of parts which are simple to fabricate and assemble. The main considerations are the use of modular designs, flexible materials, flexible tools and ease of assembly process. Hence, these three components are very essential in an LVAM environment.

The LVAM environment involves automotive manufacturing in slow speed production. Most of the tools used are special purpose tools and also involve a lot of manual processes. Therefore high process variations among the products are expected in this kind of production. Sources of variations are from the single component, locating sources and assemble components (Cai, 2008). Cai (2008) suggested that in automotive assembly, such as in Figure 3.14, a typical tolerance model requires input data from all single components geometry and tolerance information as well as the assembly specifications such as locating, clamping and assembly sequence.

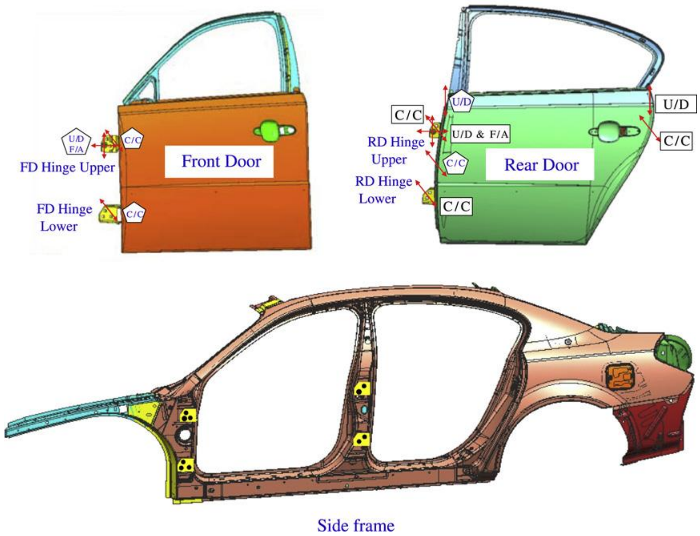

Figure 3.14: Schematic of a body side assembly (Cai, 2008)

From these data, the final dimensional output for the assembly such as gaps and flushness can be produced so that the final product is within the controlled tolerance. According to Yu and Xi (2009), variations in production need to be monitored and analysed. They suggested that Statistical Process Control (SPC) is one of the most effective tools of TQM in monitoring and minimising process variations. Control charts are the most widely applied SPC tools for revealing and controlling the abnormalities in the monitored measurements.

Quality assurance and reliability assurance are very important for both HVAM and LVAM environment. González-Benito and Dale (2001) defined quality assurance as practices aimed at reducing defects and improving performance features of products; whereas reliability assurance aimed at minimising suppliers' failure in production and delivery. Therefore, automotive manufacturers should focus on both product quality assurance and supplier reliability assurance in order to capture the automotive market.

3.3.4 Suppliers

Suppliers and manufacturers play important roles in delivering products to customers (Shafia et al., 2009). Effective supplier management is essential in automative industry which involves materials, components and services because it will determine the performance of the particular manufacturer. According to Udin (2006), the performance of suppliers is critical to the automotive quality and it is directly related to the supplier quality management. For this reason, the automotive industry has developed its own QS 9000 standards to be practised within the automotive supply chain (Nawawi, 2009). In the current global competition environment, suppliers should increase their innovation capabilities by taking the advantages of new technology and work as solution providers rather than just supplying (Mondragon et al., 2009).

LVAM should take advantage of the flexible processes by using “Distributive Product Development” (DPD). This is a sharing concept of designing a product development process whereby portion of the process is done by suppliers or third-party company and in different geographical locations (Cleveland, 2006a). Rather than managing the entire product development in-house, the burden is shared among the suppliers. The suppliers are selected based on their expertise, track records and lower cost due to their geographic locations and labour cost, such as the investments of Ford, GM and Chrysler in Mexico (Sturgeon et al., 2008). Spatz and Nunnenkamp (2002) also stated that automotive parts and components are adjusted to globalisation by specialisation and low income countries. However, close monitoring is required to ensure the quality of the products is achieved as well as to reduce the total product development cost and time.

Another flexible approach is known as supplier park whereby clusters of suppliers are grouped together close to automotive manufacturers' production site (Howard et al., 2006). The objective of a supplier park is to easily integrate orders made by the main automotive production based on production schedules. According to Harmancioglu (2009), modularity which is the standardisation of component interfaces reduces the manufacturers' dependent on a particular components for the continuation of productions. Modularity also helps reduce cost by reducing the wages, inventory reduction, increase space and simpler transactions. According to Howard et al. (2006), examples of supplier parks are Seat at Abreara, Spain; Ford at Bridgend, Wales; Volvo at Gent; Jaguar at Halewood and Audi at Ingolstadt.

According to Langner and Seidel (2009), automotive manufacturers collaborate with their skilled suppliers not only to access existing technologies but also to jointly develop new concepts. Doran et al. (2007) cited an example of modularisation from 'Smart' car project, a collaboration between Mercedes-Benz and the watchmakers Swatch. The project only uses 25 module suppliers instead of normally around 200 – 300 suppliers that supplied dashboard systems, body structure, breaking control systems and seating modules. In the 'Smart' car project, the assembly plant only uses 20% of value-creating activity within the assembly plant, whereas the rest of the activities are done by the suppliers. It is obvious that modular approach gives more opportunities to the suppliers to become more involved in the supply chains (particularly, tier one, tier two and tier three suppliers) as illustrated in Figure 3.15.

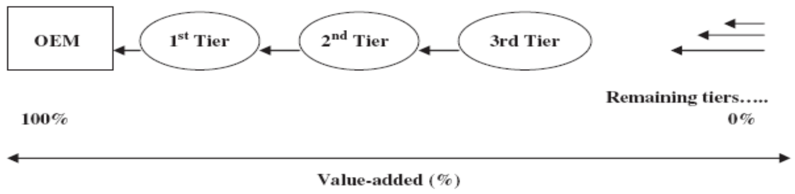

Figure 3.15: Typical value chain (Doran et al., 2007)

3.4 Summary

The manufacturing process involved in automotive industry (including HVAM and LVAM) was covered in this chapter. A typical automotive project involves direct and indirect of people from many functional organisations and facilities. Automotive model’s development cost has increased over the years, which leads automakers to do research on how to overcome this problem. The review revealed that automobile manufacturers have been introducing many new approaches, especially in the area of design, product/tooling design, manufacturing and suppliers. The concepts reviewed/covered in this chapter focused on manufacturing automotive components and for HVAM and LVAM environments. The knowledge gained from this review will form the foundation for developing the KB System for LVAM.

In LVAM environment, the quality in every manufacturing process starting from automotive design concept, product/tooling design, tooling process, production and supplier involvement is very important in order to produce a high quality LVAM model. Therefore, TQM approach is so important in all elements of LVAM manufacturing which controls every aspect of quality including the people, method, machine, and material. TQM acts as a controller to the entire LVAM environment which embodies the waste elimination philosophy in the system. TQM is a close loop system which triggers the LVAM manufacturer on the problem prevention and continuous improvement to the whole LVAM process and activities. Hence, every aspect of quality in the LVAM process loop is controlled and rectified accordingly. This model covers different aspect of quality, although it is not explicitly indicated as part of the formal TQM methodology.

The following chapter will now review the literature on Artificial Intelligence (AI) and Knowledge Based Systems (KBS).