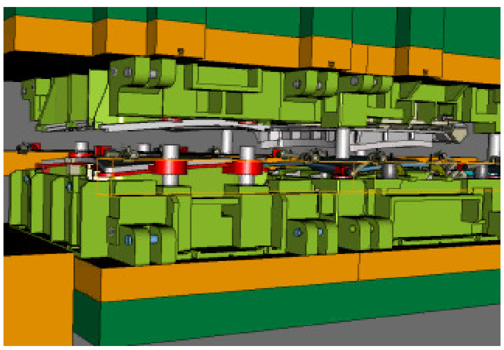
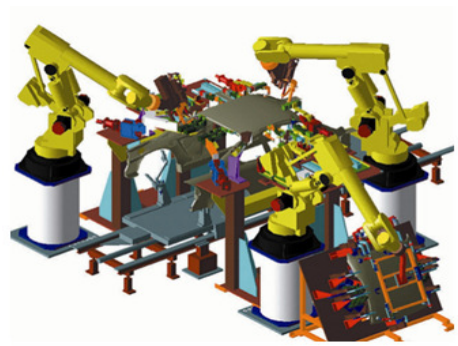
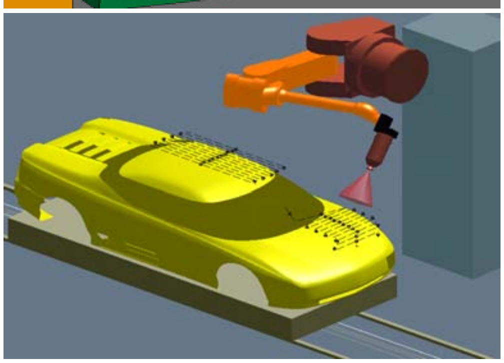
Siemens PLM Software

Digital Manufacturing and China Automotive Industry

—Value and Trends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1. Preface

The automobile manufacturing industry in China is experiencing a key development stage with both opportunities and crises. On the one hand, large amounts of capital inputs and continuous prosperity of the consumption market drive the rapid development of the automobile manufacturing industry. In 2006, China produced 7 million automobiles, ranking the 3rd in the world, and became the second largest seller of automobiles in the world, approaching USA. On the other hand, the problem of automobile manufacturers being "big but not strong" is rather outstanding. Specifically speaking, (1) resources for complete automobiles are spread around. By the end of 2005, there were dozens of complete automobile factories, but they had small size in general; (2) the automobile industry lacks innovation abilities in China. As to some high-end automobiles made in China, pattern design and product line layout (including hardware, layout and planning) are imported; (3) With rather weak international competitiveness, China's automobile manufacturers have difficulty in walking out of China. As the domestic market is becoming mature increasingly, the profit rate of automobiles is also decreasing to the average level of the global automobile industry, and the survival of automobile manufacturers is being threatened. Under such rigid circumstances, domestic automobile manufacturers have to seek innovation in terms of management and technology.

Looking at the world, the automobile industry has always been going forward with both difficulties and challenges. With the globalization of the supply chain, customization, and increasingly strict environment and safety regulations, automobile manufacturers are witnessing an unprecedented unfavorable environment. To raise core competitiveness, many automobile manufacturers are committed to learning and utilizing advanced management concepts, and are committed to combing advanced manufacturing technologies and information technology to create new values. Among these advanced concepts and approaches, lean production or JIT is the long-standing key with far-reaching implications, while Digital manufacturing (DM), based on Product Lifecycle Management (PLM), is a new driving force. At present, many leading automobile manufacturing companies in the world are persistently promoting the application of DM technologies, which has resulted in encouraging returns on investment. Form 1 presents several cases(including complete-vehicle manufacturers, parts supplier). According to a survey made by CIMdata Consulting Corporation in 2003, as to automobile manufacturers that have adopted DM technologies, the marketing speed of their products increases 30%, duplicated design decreases 65%, production and planning process were streamlined 40%, and the average output increased 15%. The successful application of DM in foreign counties has set a good example for domestic automobile manufacturers in China.

Table 1: Remarkable Benefits Brought by DM Application

Manufacturer	Presentation of Benefits and Effectiveness
Audi	Process planning became faster (80%), it realized standardization and the product quality increased.
GM	The cost of body-in-white decreased $2.5 million. It saved $30 million for 3 consecutive years. It supported the coordinated design of body-in-white process among the whole extended enterprise.
BMW	It shortened 22% of process planning time, saved 10% unnecessary production capacity, and saved 5% of investment expense.

Webasto Feel the drive	It saved 5% of investment expense, decreases 30% of change management expense, and decreased 10% of commissioning and trial-operation expenses.
HELLA Ideas today for the cars of tomorrow	It decreased change management expense, shortened commissioning and trial-operation cycle and supported coordinated projects.

The "Product Lifecycle Management (PLM)" concept created in the late period of the 20^{th} century is the extension of product data management (PDM) to planning and manufacturing chains. Previous PDM only pays attention to product definition data, while PLM seeks the full management in the whole lifecycle period, including data, technology, techniques, manufacturing, process, material, and repairs and scrapping. On the integrated PLM platform, not only design, techniques and manufacturing are easily coordinated, but also imitation analysis and optimization of the manufacturing process in the virtual environment become more convenient than ever. The application of digital modeling and imitation technologies in planning and manufacturing processes forms Digital Manufacturing (DM). As the core component of the PLM strategy, DM invites special attention recently because of the importance of the product manufacturing process. Any innovative product which can not be produced effectively will become meaningless. Since the cost of manufacturing process accounts over 70% of the total cost, the application of DM to optimize the manufacturing art and to increase manufacturing effectiveness will have significant effect. According to the forecast by CIMdata, the PLM market of China will increase 29% per year, and the increase of annual investment on DM capability from manufacturing enterprises will exceed 25% in 2007 - 2009.

The successful application of PLM-based DM technologies in foreign automobile manufacturers cannot be separated from the support of some excellent software products. For example, Tecnomatix, a solution from Siemens PLM Software, has already had many successful cases. In domestic China, due to outdated concepts and technologies, information software companies have not released mature DM software products made in China.

As international automobile giants will progressively move DM solutions which have proved successful overseas into joint ventures in China, as domestic industry community, software companies and the academic community will further understand and pay more attention to DM, therefore, in several upcoming years, domestic DM market will achieve vigorous development, and more and more automobile manufacturers will get benefits from DM.

This report was based on detailed on-site research at many domestic automotive manufacturers (including complete-vehicle manufacturers and suppliers) with the purpose of providing domestic automotive manufacturers with directions and suggestions in terms of implementation of digital manufacturing. The structure of this report is as follows: First of all, it provides detailed analysis of the pressures faced by both domestic and foreign automotive manufacturers and the countermeasures taken by them, expounding the meanings and features of digital manufacturing solutions for the automotive industry; then it summarizes the needs, challenges and current status of implementing digital manufacturing; finally, it provides several suggestions on the direction and steps for implementing digital manufacturing solutions in the future.

2. Challenges faced by automotive manufacturers

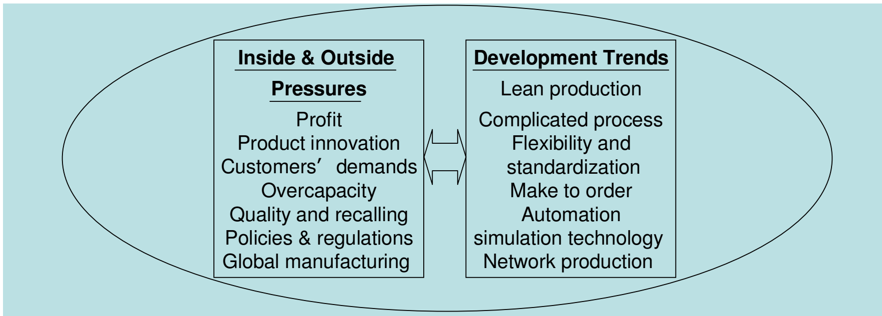

Chart 1: Living Environment of Automobile Manufacturers

See Chart 1 for the living environment of domestic automobile manufacturers. Inside and outside pressures promote these enterprises to seek innovation in terms of management and technology. The overall development trends of the automobile manufacturing industry provide the future direction for domestic enterprises.

1) Inside & Outside Pressure of Automobile Manufacturers

Since China's accession to WTO, some international automobile giants have entered China to establish joint ventures one after another. Facing these intense competitions, automobile manufacturers are feeling more and more pressures. These pressures from the outside world of these enterprises will become their driving force for changes and continuous improvement. To be specific, these pressures include:

Pressure for Profit——The domestic market will become mature progressively, which will directly result in continuous falling prices and little profit-making space for manufacturers. It is accepted internationally that an automobile manufacturer must have the production scale of at least 1 million automobiles to survive. By the end of 2006, no manufacture has reached the level. Since making profits through high prices has become a thing that is stale and unfashionable, automobile manufacturers have only three ways to go: Firstly, expand production and promote new automobiles to quickly enter the market to raise the market share; Secondly, try all means to decrease costs and stock, especially manufacturing costs, and speed up capital turnover; Thirdly, produce high-quality automobiles, and go out of China as soon as possible.

Pressure for Production Innovation——To turn "Made In China" into "Created In China" in the automobile industry, the key is innovation. Innovation is the base for enterprises to live long. Innovation includes design innovation, process innovation, and management innovation and so on. At present, many domestic manufacturers are importing, imitating or learning from foreign automobile manufacturers, and their abilities in finish production innovation independently are very limited. Under current market circumstances, the production lifecycle of a new car is at most 2 or 3 years. Therefore, automobile manufacturers must have abilities in developing innovative product continuously.

Pressure for Meeting Customers' Demands——The automobile market has turned into a buyer's market from a seller's market in China. Customers are becoming more and more demanding, customers will raise more and more customized demands, and they will require higher and higher automobile performances (safety, oil consumption, comfort, etc). So, automobile manufacturer must produce products with increasingly complicated focuses, must increase different configuration choices, must ensure the product quality, and must raise after-sales service standards.

Pressure for Controlling Overcapacity——Even though the Automotive Industry Development Policy issued in 2004 established a high access threshold, a statistical report from National Development and Reform Commission (NDRC) in the end of 2005 still shows that China has the overcapacity problem in the automobile industry (with a surplus of 2 million automobiles). According to the report, if the current situation continues, the surplus will reach 10 million automobiles by the end of the 11^{th} five-year plan. Due to the overcapacity problem, automobile manufacturers are forced to manufacture more types of automobiles with existing product lines, which raises a high requirement to the flexibility of their production lines.

Pressures from quality assurance and the automotive recall system – In Oct. 2004, the Provisions on the Administration of Recall of Defective Auto Products officially took effect. Statistical data ended in February 2006 shows that 30 domestic and foreign automotive manufacturers have proactively implemented 41 recalls, involving 48 models and nearly 400,000 vehicles. In 2006, 22 domestic automotive manufacturers proactively recalled 280,000 vehicles, representing a significant increase in quantity. The year-by-year incremental increase in the quantity of recalled vehicles reflects higher customer requirements for auto quality as well as higher quality requirements for automotive manufacturers as the production volume of the automotive industry increases rapidly.

Pressure for Addressing National Policies & Regulations——Policies and relevant regulations are becoming more and more strict in China's automobile industry. In addition, with pollutants and emission control regulations, safety performance regulations, capacity utilization rate regulations (New product lines are not allowed with the capacity utilization rate below 80%), local content requirement (not less than 80%) and other regulations, automobile manufacturer are restrained to a large extent.

Pressure for Addressing Labor Division and Global Manufacturing——Automobile manufacturers are not "large and comprehensive" enterprises any longer. Manufacturers of complete automobiles are outsourcing from independent suppliers which are responsible to manufacture automobile parts and components, while these manufacturers themselves focus on the development of new automobiles and improvement of four big procedures. At present, over 80% parts and components are finished by suppliers. So, manufacturers of complete automobiles must keep close cooperative relationship with more suppliers, and must ensure high quality of automobile parts and components and their timely delivery. In addition, at this time when global manufacturing is becoming more and more obvious, almost all large domestic automobile manufacturers, such as SAIC, CHERY, NAC, have R&D institutes or plants. How to ensure coordinated work without errors in such "design and manufacturing in many different places" is the difficult and urgent problem for mobile manufacturers.

The above internal and external pressures will necessarily push the automotive industry to continuously improve their product manufacturing processes and increase the technical content, thus driving the automotive manufacturers to adopt integrated, digital and agile manufacturing technologies.

2) Overall Development Trend of Auto Manufacturing Technologies

The innovation of automobile manufacturing technologies is the miniature of the development of advanced manufacturing technologies. The overall development trends of automobile manufacturing technologies are listed as follows:

Lean production towards product lifecycle——Initially, lean production aims to decrease wastes in the manufacturing process and to improve the manufacturing process. Nowadays, the thought of lean production has been spread across the whole product lifecycle. To be specific, lean production aims to shorten the development time through concurrent engineering, to utilize DFX technology(the design facing to manufacturing/assembling…)to raise the manufacturability and assembly, to decrease changes; to shorten layout, design and commissioning time of production lines; to optimize manufacturing procedures and to increase manufacturing effectiveness; to shorten trial-production time and scale production time; to raise product quality and to achieve production without defaults.

Manufacturing procedures become increasingly complicated, and technical content becomes higher and higher——The design complexity of automobile products is continuously increasing, and light weight requires more types of materials for automobiles, which raises the complexity of body welding and assembly procedure. Some advanced manufacturing technologies, such as laser welding technology, are applied to weld automobile body, parts and components progressively. It can decrease the number of parts and components and moulds, decrease the number of welding spots, optimize material consumption, decrease the weight, decrease the cost, and increase the size accuracy. In addition, various kinds of robots used for paint spraying, arc welding, dot welding, assembly, transportation and other work, which also enriches the technical content;

Flexibility and standardization level of product lines are improving——Mixed production has become the basic characteristic in the production process, which restrains layout design of product lines and production design. At present, as to assembly and coating procedures, mixed production can be easily achieved. However, body-in-white procedure have many difficulties, and it needs to establish modularized and standard welding positions, to strengthen labor division coordination among robots, and to adopt new tools and means to increase of the manufacturing flexibility.

Customized making-to-order is a common thing——At first, customers choose their favorite automobiles and fill orders, then manufacturers start production after receiving such orders and pre-payments. It increases choices for customers, and can better meet their demands, and helps to decrease the cash flow pressure of manufactures. In European countries and the USA, 100% making-to-order is becoming a trend. This brings about many challenges to automobile manufacturers. On the one hand, automobile manufacturers have to provide more configuration options, which increase the complexity of automobile products. On the other hand, for the timely delivery, requirements for the logistical links between manufacturers of complete automobiles and suppliers are much stricter than ever.

Automation level in workshops is increasing, and equipment are more expensive——Take the production of body-in-white as an example, automation tools are mainly used to transport, catch and hold metal sheet and make complicated body-in-white structure. In terms of automation equipments for clamps, transportation and holding parts, manipulator for welding work, and measuring/testing equipments for quality certification, large amounts of investment are required. Therefore, automobile manufacturers must analyze and optimize the layout and configuration of such equipments, increase the flexibility, operating reliability and utilization rate of such equipments, and achieve maximum values of existing capital equipments.

Extensive application of virtual simulation technologies – In order to ensure better product design and process planning quality, it is required that over 95% of actual manufacturing processes shall be able to be analogued and simulated so as to achieve analysis and optimization of manufacturing processes, accurate equipment designs, analogues and production tact, thus reducing the commissioning and ramp-up times and the impacts of changes.

Manufacturing is networked——The unavoidable trend in restructuring the automobile manufacturing industry is to separate manufacturers of complete automobiles and manufacturers of parts and components apart, and to establish cross-region dynamic alliance of enterprise. Collaboration and communication between manufacturers of complete automobiles and between them and suppliers are finished through the network. A lot of production information and manufacturing information are transferred via the network. For the purpose of timely production, process sharing and interoperability between automobile manufacturers are becoming more and more urgent.

As can be seen above, in order to develop and grow stronger, domestic automotive manufacturers must follow these development trends in the automotive manufacturing industry and continuously learn successful foreign experiences by adopting more advanced digital manufacturing technologies to improve corporate competitiveness.

3) PLM-based DM, the Inevitable Choice of Automobile Manufacturers to Address Challenges

To promote the digital application is an important way for automobile manufacturers to raise their core competitiveness. The scope of digital manufacturing is far beyond than digital equipments. Facts have proved that advanced management methods and advanced manufacturing technologies can only play their roles to the largest extent via digital means. Taking concurrent engineering concept as an example, if an automobile manufacturer cannot build the 3D digital model for a product, then it will be hard to verify the manufacturability and assembly during the design period, therefore, the manufacturer has to make more expensive physical automobile samples. In addition, collaborated design, virtual product development and networked manufacturing have digital technologies as the basis. Advantages can be seen as follows after the digital description of data related to products: Firstly, it is convenient for information management, consistent maintenance, inquiry, statistics and repeated utilization. Secondly, it is convenient for the virtual analysis and verification of products and the manufacturing process, and helps to optimize the design plan and process plan. Thirdly, it is convenient for network sharing and collaborated work.

According to surveys, to realize the comprehensive digital application, domestic automobile manufacturers have a long way to go now. When people know about the digital manufacturing are mainly what in the product design period, such as 3-D digital molding (CAD), pre-assembly, interference examination and dynamic analysis (CAE), product data and process management (PDM), etc. The basic direction of digital development is to realize the digital process in the integrated product lifecycle. As to automobile products, an integrated lifecycle should include design, process planning, manufacturing, maintenance and other stages. Usually, the manufacturing chain is more important than other chains. A good product design can only create values for enterprises after being effectively manufactured.

However, the application of digital manufacturing is rather hard mainly for: (1) It is hard to manage data due to the huge amount of information. According to GM statistics, the data related to the product production process is 100 - 1000 times of the data flow for design. (2) Integrated digital design has to be taken as the base. (3) It involves many parties (such as design, planning, production, logistics and other departments of such manufacturers), it raises high and comprehensive requirements for manufacturers, and they need to reconstruct the process. So, it is very important to choose an excellent DM solution and take reasonable implementation strategy.

3. Meaning of DM and its current development in the automotive industry

1) Meaning of digital manufacturing

According to the definition of CIMdata, DM is a solution in which support, design, manufacturing and engineering teams undertake plan procedure collaboration. It adopts the most viable process, and allows access to tools and manufacturing process design and other digital product. It is consisted of a series of tool sets of analysis activities supporting tool design, manufacturing process design, visualization, assimilation and other optimal manufacturing processes. DM, in wider definition, means to use digital technologies to the product planning process and the practical manufacturing process. It aims to improve manufacturing procedures, increase manufacturing efficiency and product quality, and decrease manufacturing cost through information molding, assimilation analysis and information processing.

DM can be taken as DP^4R, i.e., digital product definition (Product), digital process planning (Process), digital plant layout planning (Plant), digital management of workshop production (Production) and DM resources (Resource). Resources here include both digital equipments (such as NC processing center, robots, etc) and tools and operators.

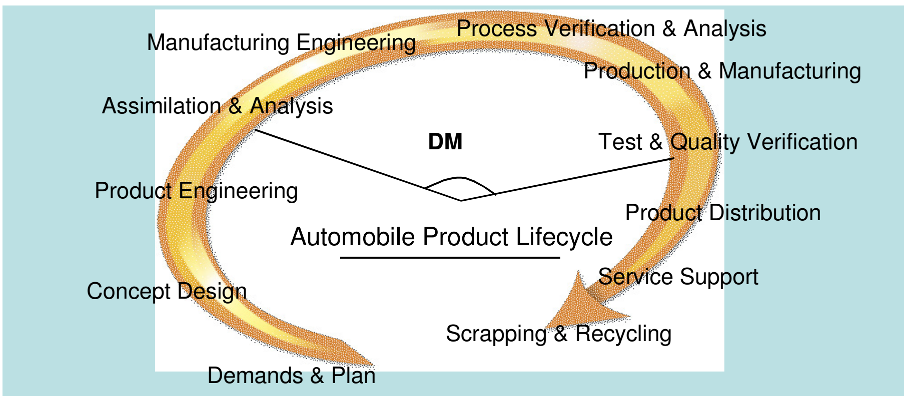

Chart 2: DM in Automobile Product Lifecycle

As is shown in Chart 2, DM spans product design, process planning, process analysis and verification, product manufacturing, quality assurance and other stages in the product lifecycle. At present, only a few leading software companies have the ability to provide integrated DM solutions.

2) Results of application of digital manufacturing in leading foreign automotive manufacturers

Up to now, digital manufacturing has been widely applied in leading foreign automotive manufacturers. Research shows that all of the world's top 15 automotive manufacturers have adopted digital manufacturing solutions, although varying in scope, and have received return in several aspects, e.g. lower planning cost, higher planning quality, shorter planning time, etc. The benefits realized by foreign automotive manufacturers from digital manufacturing are as shown in Table 2.

Table 2: DM Values in Foreign Automobile Industry

Value Point	Value Externalization	Case
Identify and correct errors in time	Product design defects or process errors, if identified in the practical production process only, usually will lead to a significant cost. By using DM technologies, automobile manufacturers can assimilate, analyze and certify the manufacturability, assembly, reasonableness of the manufacturing process, and the effectiveness of product lines in a virtual environment, and can find and correct mistakes in time.	Through the assimilation work before assembling automobiles, DaimlerChrysler saved operating time, optimized process, and made the process accuracy reach 100%.
Higher reusability of best practices	In the digital environment, existing optimal knowledge is easy to be used repeatedly, such as product design, process planning, product line design, etc. .	GM uses 80% of models of engine production equipments, and saves a lot of time and investments.
Encourage innovation of design/process plan	since the cost of digital model adjustment is small, engineers can continuously try seeking and verifying optimal process plans. While in the traditional physical environment, since risks of changes are high, engineers usually are restricted to recognized experience, and dare not to make innovative modifications	By using digital tools without increasing costs, VW uses more optimization methods to ensure more accurate and optimized data and models
Decrease changes	Too many changes not only increase the production development time and trial-production time, but also increase the cost. After adopting DM, many automobile manufacturers increased the mission success rate in terms of design and process once for all, and significantly decreased changes.	GM estimates that it can decrease about 60% of project changes with DM.
Decrease the quantity of physical model machines	The purpose of trial-production of the physical sample machine is to examine the manufacturability and assembly so as to verify automobile performances. After DM technologies are used, many analysis and verification work can be finished by the digital sample machine.	The digital sample machine of DaimlerChrysler is more effective than its physical sample machine. It can significantly decrease the cost, and can help to release its products in the market quickly.
Benefit concurrent work	In the digital environment, many jobs, from design to product line work, are easily to be done concurrently, which helps to release products in the market quickly.	From design finalization to production startup, Toyota decreases 2/3 of the time in advance to 13 months.
Optimize product line design	Before laying out the product line, continuously analyze, certify and improve design plans in the virtual environment. It can greatly optimize the quality of the product line, and can decrease losses caused by work adjustments.	Volkswagen saved $2.5 million for every body-in-white project, and the 3-year budget decreased $30 million.
Optimization of	The process planner provides product designer with the means for computer-aided simulation of the	After the implementation of the simulation software, GETRAG

manufacturing process	manufacturing process, so that the designer, through simulation, can identify such problems as the manufacturing bottlenecks, low utilization of equipment, etc, and better utilize manufacturing equipment, reduce the machining and idle times of machines, and, before making the purchasing decision, simulate new tools and manufacturing process	FORD can manufacture clutches with only one clamping fixture instead of three, thus lowering the manufacturing cost of parts by 10% and improving the production planning efficiency by 18%
Optimize assembling sequence and process	Through the virtual assembly and analysis in DM environment, the feasibility of the assembling sequence is certified, and the product line can be also balanced easily.	Ford increased 50% of the scheduled cycle in commission for new automobiles, and decreased 5% of the investment cost.
Helping improving production efficiency through production reorganization	Design and analyze production processes in the software environment to virtually assess alternative layouts and logistics programs and, before changing the production layout, predict the results of change, thus making the production reorganization process simpler and more reliable before removing or integrating the plant	MACK TRUCKS completed plant integration within only 14 months, thus avoiding adjusting the ineffective production layout and saving millions of dollars
Simplify communication and information exchange	Manufacturing information about plants, planning, production, logistics and other aspects are under digital management, which greatly simplifies data sharing and process interoperability. Information exchange among plants and between complete automobile manufacturers and suppliers(parts supplier, product line manufacturer, etc) becomes more convenient.	After adopting DM, Mazda decreased 48% of the negotiation time with manufacturers of product lines in the design process of engine product lines.
Increase production flexibility	Through the flexibility design of product lines, produce more types of automobiles with a product line. It significantly increases the utilization rate of product lines, saves costs sharply, shortens time, and gain more benefits in the process of new model development.	Within Ford's Dearborn truck plant, the same processes used by all types of automobiles account for 80% of all processes. It decreases 10% of the product line cost, and saves 55% of the product line remodeling cost.
Improving suppliers' ability to cope with challenges	A standard process can improve the planning efficiency, enable better cross-department collaboration, drive data flows to run through the development and planning stages, lead to quicker response, and better meet customer requirements	HELLA achieves higher planning quality and production quality with the same number of planners

As can be seen from the above, the results of digital manufacturing implementation in foreign automotive manufacturers are very outstanding, which is very attractive to domestic automotive manufacturers and provides them with a lot of experiences in terms of implementing digital manufacturing.

3) DM Understanding and Application of Domestic Automobile Manufacturers

Besides some joint ventures, the majority of domestic automobile manufacturers did not touch the DM conception for a long time, and their understanding of DM is still in the preliminary state. Some results of our surveys are listed in Table 3.

Table 3: DM Understanding of Domestic Automobile Manufacturers & Problem Analysis

Problem	Understanding or Current Situation	Analysis
Starting point and main contents of DM	The starting point of DM is the time when process planning starts and the ending point is the time when the products are in the formal batch production. DM mainly means the virtual manufacturing work with the computer, including the assimilation of manufacturability, the virtual planning of product lines, etc.	DM is a part of the product lifecycle process. It not only includes process planning, but also includes production management and quality analysis and verification and other stages.
Relationship between DM and CAD/CAM	They think that, process assimilation and analysis in DM is or is similar with disassembly analysis, assembly interference examination as well as ND code production in CAD/CAM.	The process assimilation in DM is carried out on a platform that is consisted of plants, products and resources. Compared to CAD/CAM, it obviously looks like a real manufacturing environment.
Relationship between DM and CAPP	Most of them have used domestic CAPP software. CAPP is playing a positive role in terms of process information management and process statement output. So, they think that DM is not so important.	CAPP does not support 3-D platforms, and has no process analysis and verification functions (movement interference examination, accessibility and assembly verification, robot movement path optimization and off-line programming, etc). So, CAPP is not helpful for process optimization and improvement.
Automobile manufacturers don't fully understand the importance of plant design and the layout optimization of product lines in 3-D environment	After developing a new type of automobiles, generally speaking, manufacturers need to adjust product lines or import new product lines. At present, these jobs are done in the 2-D environment, and can be done well.	To ensure design reasonableness, automobile manufacturers need to evaluate and modify design plans for several times with the involvement of experienced engineers. The period usually exceeds half a year. If such jobs are done on 3-D platforms, visualization can be realized, design speed can be increased, and errors can be found in time by means of assimilation.
Preliminary recognition of manufacturing execution system (MES)	In their opinion, MES is a workshop-oriented management system between ERP and distributed control system (DCS) and only focuses on how to improve production efficiency and solve production line bottlenecks	In addition to connecting the ERP and DCS functions, MES is also an important link in the overall PLM strategy of an enterprise. It manages the real-time records and data of all workshop-level production activities and connects the design, process to service and maintenance in the PLM, so it is an indispensable link in the

	from the prospective of equipment automation	process of implementing corporate collaboration
Automobile manufacturers only get a perceptual understanding of DM values.	Although DM technologies have been widely used by foreign automobile manufacturers, they are new things in China. There are few successful cases. Automobile manufacturers still have a perceptual understanding of DM values, and they lack true experience.	On the one hand, automobile manufacturers are looking forward to DM technologies. On the other hand, they lack confidence in their own information base and personnel quality, and they don't know how to implement DM, when DM takes effect or how many practical benefits which DM can bring about to them.

In order to accelerate the time-to-market, improve product quality and reduce production cost, domestic automotive manufacturers are actively learning the advanced management philosophies and technical means from foreign peers, e.g. concurrent engineering, product lifecycle management, lean manufacturing, total quality management, Six Sigma, etc. Below are three typical types of domestic automotive manufacturers. It can be seen that there are some differences among their current applications of manufacturing technologies (including digital manufacturing)

Complete automobile joint venture——As domestic leading automobile manufacturers, such as FAW-VW, SAIC, Shanghai GM, these enterprises have the following characteristics and current situation: (1) Personnel quality is high, plant equipments are advanced, and the automation level of product lines are high. (2) They have mastered foreign advanced management experience, and are successfully implementing lean manufacturing, timely production, comprehensive quality management and other management strategies. (3) Most of their automobiles are imported (and possibly had been sold), and design and procedures are relatively mature, therefore, they need not to make much improvement and changes on their own. In recent few years, they have obtained some design patents by changing some old automobiles, and have actively participated in globalized design and development. Therefore, their abilities in terms of design and procedures are increasing progressively. (4) Generally speaking, they lack abilities to plan and design plants on their own, their product lines are generally imported from foreign countries and installed and commission in China and they need some adjustment and optimization work in terms of procedure planning. (5) In the production process, quality detection tools are relatively advanced, and quality control is strict. (6) They import information systems from the parent company in foreign countries, such as document management system, project change management system, product configuration system, production management system, etc.

Complete automobile manufacturers with self-owned brands ——There are considerable complete automobile manufacturers with self-owned brands in China. They produce car, truck, minibus, commercial automobile, coach and other type of automobiles, such as Chery, Jianghuai and Geely. These enterprises have the following situation: (1) Except some leading ones, most enterprises are in very bad conditions and are seeking foreign partners to form joint ventures or are on the verge of closing down.(2) Most of these manufacturers are implementing low-priced automobile strategy and their technical content is low. Parts of powerful manufacturers have a certain size of product research & development team, and can design new automobiles and plan procedures on their own. They have widely used CATIA, NX and other 3-D CAD software. They use CAE software to analyze design results. They finish planning, layout and implementation of product lines by cooperating with suppliers. (3) They start to pay more attention to information construction. They have implemented ERP, PDM (though the use of PDM is still in the grinding stage, and it has not play its full role) and project change system. Parts of these manufacturers have started to use MES system. (4) The automation level of product lines are moderate, robots are only used for few jobs, and the remaining jobs are under manual operation, workers have heavy workload, many plants have rather bad working environment, and the extent of the mixed flow is low. (5) Levels of product design and manufacturing are low. However, due to featured automobiles, quality problems are not serious (such as minibus. Customers' requirements in terms of aesthetics, comfort, safe and environment are not high. (6) Main automobiles (truck, minibus, etc) in China's automobile export market must abide by regulatory requirements in importing countries.

Suppliers of parts and components——The overall situation of numerous domestic suppliers of parts and components is seen as follows: (1) Besides few joint ventures, the product level and technical development ability of the industry of parts and components is more backward than that of complete automobiles, which directly leads to slow growth of the quality of complete automobiles. Due to the implementation of the "Recall System", some suppliers will pay huge prices and face the crisis of going bankrupt;(2) Complete-vehicle manufacturers transfer the pressure of lowering prices to parts/components suppliers, so the latter face the double challenges - complete-vehicle manufacturers demanding lower prices and rising prices of raw materials; (3) Complete automobile manufacturers adopt the lean manufacturing approach, and provide customers with increasingly abundant choices, which brings about huge pressure for downstream suppliers: the time in advance is shortened, procedures become more and more complicated, while quality needs continuous improvement. modular supply intensifies the polarization between strong automotive parts suppliers and weak ones, so those suppliers that can only supply single parts/components are faced with the risk of losing customers;(4) Since parts and components have not realized generalization and standardization as seen in the international market, due to the local protection related to parts and components, the production of parts and components has not reached the required economic scale, and it is hard to decrease cost.

4. Analysis of requirements for DM in the automotive industry

The manufacturing of a automobile can be divided into the following processes: pressing, body-in-white welding, spray coating, general assembly, power assembly (engine) and manufacturing/assembly of other parts. Body-in-white welding, general assembly and power assembly are the most complex processes. The analysis of the features and digital manufacturing requirements of these three processes is as below .

1）Features and DM requirements of body-in-white

The basic manufacturing process of bodies-in-white is using robots (or manual operations + auxiliary robots) to transfer, grip and clamp discrete sheet metals and pressed parts and weld them into complex body-in-white structures. The body-in-white welding process has many operational steps and is complex. It is one of the processes about which automotive manufacturers are most concerned. Statistics show that the body-in-white of a saloon car will undergo 3,000-5,000 spot welding steps in the welding process and use 100 plus big clamping fixtures and 500-800 retainers. A lot of process information is closely related to the 3D geometric characteristics of parts, thus presenting many challenges in terms of selecting parameters for the car body welding process, planning the process, controlling the quality of car body welding and even designing car bodies. In planning the body-in-white process, it is difficult to manage the thousands of welding points so as to avoid missing welding points and re-welding. Generally, the features and development trends of the body-in-white process are as follows:

(1) The process is becoming more and more complex and advanced. In order to produce lightweight vehicles, more and more new types of materials are being applied in the manufacturing of bodies in white, which undoubtedly increases the difficulty of the welding process. So the current development trend of the body-in-white welding technology is to minimize the number of welding points and extensively use the advanced laser welding technology.

(2) The manufacturing process is a highly capital-intensive one. Huge investments are required for clamping fixtures, automotive equipment for transferring and clamping parts, robots for welding, measuring/testing equipment needed for quality validation, etc.

(3) It uses a lot of robots and automation technologies. In order to ensure the tact of the welding process and the overall quality of bodies-in-white, at foreign automotive manufacturers, at least 90% of the body-in-white welding operations are done by robots. The control, automation and programming of robots are very sophisticated.

(4) It has very high requirements for the quality of product designing and process planning. In order to ensure high reliability, it requires that over 95% of the actual manufacturing be simulated and requests accurate equipment designs, simulations and production tact so as to shorten the debugging and ramp-up times.

(5) In order to maximize the value of existing capital equipment, the requirement for mixed line for body-in-white production is becoming more and more obvious and the requirements for standardization and flexibility are becoming higher and higher. All this requires modular and standard welding workstations, standard-driven flexible manufacturing, new tools and means improving the flexibility of manufacturing, and the division of work, collaboration as well as sharing of the saloon car platforms among robots.

However, for many years, in the body-in-white welding field, most domestic complete-vehicle manufacturers are still at a very low technical level. Either for project bidding or for project implementation, most of relevant data is still based on AutoCAD drawings. The main work of welding process engineers is to complete Excel sheets and cut pictures, so they hardly have the time to consider the problems of the manufacturing process, e.g. tact balancing, production line layouts, workstation simulations, etc. The existing problems of the body-in-white manufacturing process include the following: process design data and means still remain at the 2D age; no means available for effectively managing information about welding points; no consistent platform for data management; no means for accurately analyzing the welding process; no more intuitive and accurate means for factory layout and simulation; no accurate means for analyzing the logistics process; no more competitive technical means for bidding and tendering. These problems are the main reasons why automotive manufacturers actively adopt digital manufacturing technologies for the body-in-white process and the manufacturing process. Generally speaking, a digital manufacturing solution supporting the body-in-white process shall have the following characteristics:

(1) It shall be a complete solution supporting the "concept planning – rough planning – detailed planning – production & operation management" of the body-in-white process; it shall have a consistent work platform and data management layer; it shall support process planning and simulation of the production area; it shall adopt advanced 3D graphic engine; it shall support the special functions of the body-in-white process, e.g. layout of welding points, simulation of production lines, simulation of robots, etc.

(2) It shall support the planning of the body-in-white process. It shall acquire product data and 3D assembly information, define the sequence of work steps, optimize the layout of welding points, use 2D and 3D methods to allocate and arrange resources, manage changes, assess investment costs, and finally generate process cards and relevant documents.

(3) It shall support simulation of the body-in-white process. It shall be able to model the body-in-white welding information, e.g. workstations, clamping fixtures, car body parts/components, welding points, welding guns and operators, and generate the work cells for simulation, manage and analyze the results of simulation, and simulate production lines through the combination of work cells.

2）Features and DM requirements of the general assembly process

The basic process of general assembly is using the manual means (or manual operations + auxiliary robots) to assemble parts on moving car bodies in the predetermined order and finally generate finished automotive products. In the past 10 plus years, the number of automotive models has increased dramatically. Product configurations are becoming more and more complex. It has become very common to produce general assemblies on mixed production lines, so general assembly lines have become the most time-consuming part of the process planning and designing. Generally, the features and development trends of the general assembly process and manufacturing are as follows:

(1) The manufacturing process is a highly labor-intensive one. It has several objectives of optimization: a) optimization of the value of labor by making full use of the online work time; b) balancing the overall production line to maximize output; c) meeting the ergonomic requirements to realize safe production; d) meeting logistics requirements to realize JIT manufacturing. In order to maximize the efficiency and quality of the manufacturing process, each and every work step

must be understood and defined in detail, i.e. the process must be planned in detail.

(2) Due to the complexity of automotive products, the huge number of assembling tasks and mixed production of multiple categories of products, it is critical to validate and optimize the planning of the assembly process before the beginning official production and to efficiently manage the production process after the beginning official production. Let's take Shanghai Volkswagen for example. SVW plans to introduce 7-12 new models within three years and adopt flexible and mixed manufacturing to improve the output to 2,500 cars per day. So, the planning department is facing bigger and bigger pressures – they have to continuously improve their planning capability as well as the quality and efficiency of planning

(3) The characteristics of mixed general assembly production lines are changing from relatively certain and static to uncertain and dynamic. In an environment of mass customization, the objects of production need to change within a certain scope according to the changes in customer requirements. Sometimes the product object may exceed the predetermined capability of the production line, so the production line shall be able to be dynamically adjusted. It shall be able to allow the insertion of new product categories through quick adjustment of workstations, materials transfer systems, tooling and clamping fixtures, etc.

(4) Improve the "commonality" of process planning by globally creating and reusing the best process planning practices: a) different models share the manufacturing planning information to improve the ratio of reuse and minimize repetitive work; b) globally distributed factories (these factories may carry out the same general assembly operations) share the manufacturing planning information.

Currently, most domestic complete-vehicle manufacturers are not able to confidently meet these challenges. In these enterprises, the automotive assembly process is usually manually designed by process planners first, empirically and analogically, and then process engineers make appropriate adjustments on basis of the experimental results of prototype cars and the actual conditions of the workshop. This involves huge amounts of work and takes a long time and cannot provide any guarantee for the quality of process planning, so it is difficult to achieve ideal optimization effects in terms of assembly task planning, production line balancing, etc. The most serious problems are that many problems will arise during debugging and ramp-up due to the flexibility and complexity of the manufacturing process and that, in subsequent production, design and process changes will also give rise to many new problems. The frequent occurrence of these problems not only elongates the cycle time between planning and commissioning the general assembly line and that between commissioning and mass production, but also significantly increases costs. So, virtual technologies must be extensively used to enable computerized planning and validation of the assembly process so as to discover and correct problems in time and minimize changes after actual commissioning. Generally speaking, a digital manufacturing solution supporting the general assembly process shall contain the following functions:

(1) Digital Pre-Assembly (DPA): for a new car, usually 20,000 DPAs are needed. At the initial process planning stage, each DPA will be simulated and tested for several times in a 3D virtual environment to assure that it is free of errors, thus lowering the possibility of problems occurring during production. The tasks of DPA include assembly checking, dynamic assembly section testing, assembly path analysis, dynamic assembly interference checking, tooling and clamping fixture checking, etc. The purpose of DPA analysis is to validate product design from the perspective of assembly. Simulation enables designers to discover assembly sequence and

assembly interference problems that may arise in the assembly process, thus lowering design-associated risks and improving design and planning success rate.

(2) Digital Process Planning (DPP): a) define product variants; b) define the operations at every workstation, determine the sequence of operations within a workstation, optimize and integrate the whole production process within one tool module, and establish a model that can calculate man-hours, analyze costs, manage documents and manage product changes; c) define all tools and clamping fixtures on an assembly line, which involves all the resources used in a workshop, e.g. clamping fixtures, slide rails, lifting equipment, auxiliary equipment, etc; d) define the detailed operations of every workstation and acquire the accurate times needed for various operations at every workstation and use this as the basis for assembly line balancing and optimization; e) analyze assigned operations, e.g. judge if it is limited to operate on this side of the car, if it more suitable to operate on the other side, etc.

(3) Digital Planning Validation (DPV): It provides 3D simulation and workstation layout optimization for the whole workplace and validates if there is any mutual interference between workstations; it can design the layout of a production line to ensure logical and continuous operation; it can dynamically simulate a production line, assess its production capability, check bottlenecks and assess the utilization of production resources; it can provide managers and workshop operators with the current process plan and receive feedback from them.

(4) Production management and supplier collaboration: efficient production management requires making full use of the manufacturing execution system (MES), real-time process and control (SCADA/HMI) and process planning capabilities. The objective of supplier collaboration is to ensure the quality of parts and realize JIT production.

3）Features and DM requirements for the power assembly process

An engine is a key part of a car. The manufacturing process of engines is very complex. An engine manufacturing factory consists of the mechanical machining lines (engine bodies, cylinder heads, crankshafts, etc), the engine assembly line, and the engine testing line and equipment. The quality of engine manufacturing directly affects the performance and reliability of automotive products. As engines are becoming increasingly lighter and structurally simpler, while the quality of engines is becoming increasingly higher, engine manufacturing technologies and processes have also undergone very big changes. High speed, high efficiency and flexibility are the main characteristics of current manufacturing processes. Meeting these challenges requires not only advanced technologies and manufacturing equipment are required but also digital process planning and simulative validation - digital process planning and simulative validation are also important approaches to improve the level of power assembly process.

Basic requirements for digital process planning are:

(1) Plan the machining process: a) identify the machining features of the engine design model, and perform knowledge-based work step selecting, tooling designing and multi-axis program planning; b) automatically generate the NC code for the machining process and improve the quality and performance of the NC program; c) determine the machining line, assign work steps and balance the machining line.

(2) Plan the assembly process: an engine assembly system consists of the parts assembly lines, general assembly line and the corresponding tests and controls, e.g. the cylinder head assembly line, the piston connecting rod assembly line, the main bearing shell testing, crankshaft rotation

and the axial gap checking, torque testing, seal testing, cool testing, etc. Whether or not the whole assembly production system is complete and advanced mainly depends on the control of the key workstations (control points) of the assembly line. These key workstations are critical to the quality of the final engines, so, during assembly process planning, planners must analyze and optimize the operational steps of key workstations, control assembly deviations and improve quality.

Basic requirements for digital manufacturing simulation are:

(1) Establish simulative models for the engine production workshop: a) establish solid models: 3D models needed for process layout, e.g. engine frame, assembly, test, warehouse, etc; b) establish process simulation models: assembly, machining process, testing process, auxiliary production process, materials handling process, etc.

(2) Use simulation to generate the program for optimizing the process layout of the engine production line and perform data analysis: a) analyze the space utilization of the production line; b) simulate the operational process (based on the final program) for different business decisions, analyze the load balancing of the production line, improve the utilization of various kinds of equipment, and improve the efficiency of the production line; c) ensure that, when the system is dynamically operating, no blockage or interference occurs due to the inconsiderateness of the layout.

(3) Use simulation to generate the material flow analysis and materials distribution plan after mass production of the engine begins: a) collect relevant data to get the volume of material flows, the intensities of material flows in various paths, etc and offer the proposal for mitigating the pressures of the paths or cells with big material flows, thus optimizing the transportation routes; b) output a materials distribution plan and, through manual correction and supplementation, offer a reasonable materials distribution plan; c) establish a dynamic simulation model for the inventory of materials to dynamically simulate the inventory status and offer a program for minimizing inventory investment and determining a reasonable inventory level.

(4) Use simulation to generate reports for engine workshop production and logistics cost analysis; output the production cost, calculate the ratio of the logistics cost in the production cost, generate a report and analyze the reasons.

5. Brief introduction to the DM solution for the automotive industry

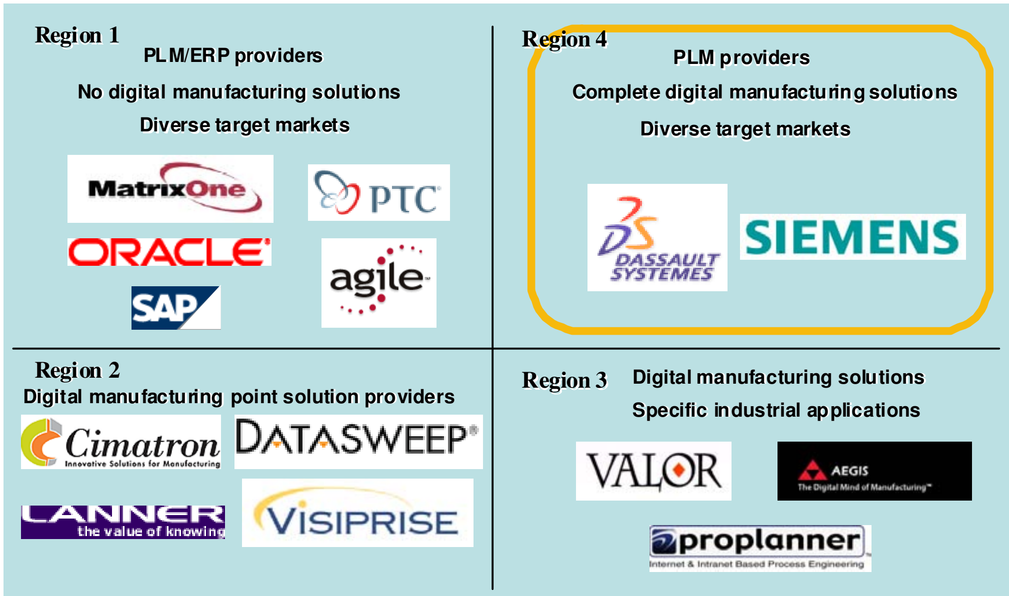

Chart 3 Providers of Digital Manufacturing Solutions

Chart 3 lists some of the important international providers of digital manufacturing software. According to the completeness of the provided digital manufacturing solutions, they can be divided into the following four classes::

(1) Leading PLM/ERP software providers that provide services for multiple industrial applications; however, currently they do not focus on the concept of digital manufacturing or launch corresponding digital manufacturing solutions. These providers are located in Region 1.

(2) Providers of point solutions for digital manufacturing: they only provide some discrete point applications for digital manufacturing, e.g. process planning, production system modeling, MES, etc. These providers are located in Region 2.

(3) Providers of relatively complete digital manufacturing solutions: they can provide solutions designed for specific industrial applications, but do not have their own PLM platforms, so it is hard for them to provide diverse services. These providers are located in Region 3.

(4) Providers of complete digital manufacturing solutions: they have the market-leading PLM products. The digital manufacturing solutions provided by them are complete in terms of category and functionality and are well integrated. They can provide tailor-made applications for such industries as automotive, aerospace, electronics, etc. These providers are located in Region 4. Currently Siemens PLM Software (USA) and Dassault (France) are the only software providers in the world that have such characteristics (note: after acquisition of Polyplan, PTC also has its own digital manufacturing solutions, but it will take time to integrate Polyplan and Windchill).

A digital manufacturing solution specific for the automotive industry must embody the characteristics of automotive manufacturing. It shall focus on improving the whole automotive manufacturing process and covers all the functions from the power system, blank car bodies, coating, final assembly and plain arrangement of workshop through to the supplier and system management. Below is a brief introduction to the digital manufacturing solutions of Siemens PLM Software.

1）Tecnomatix Solution of Siemens PLM Software

Siemens PLM Software is the worldwide leader in PLM field, and its Tecnomatix Platform is a complete DM solution with the basis of open PLM, that is Teamcenter main frame which consists of core modules, such as parts manufacturing, assemble planning, resource management, plant design&optimization, labour performance , product quality planning and analysis, production management. The Tecnomatix solution for auto industry is as Chart 4.

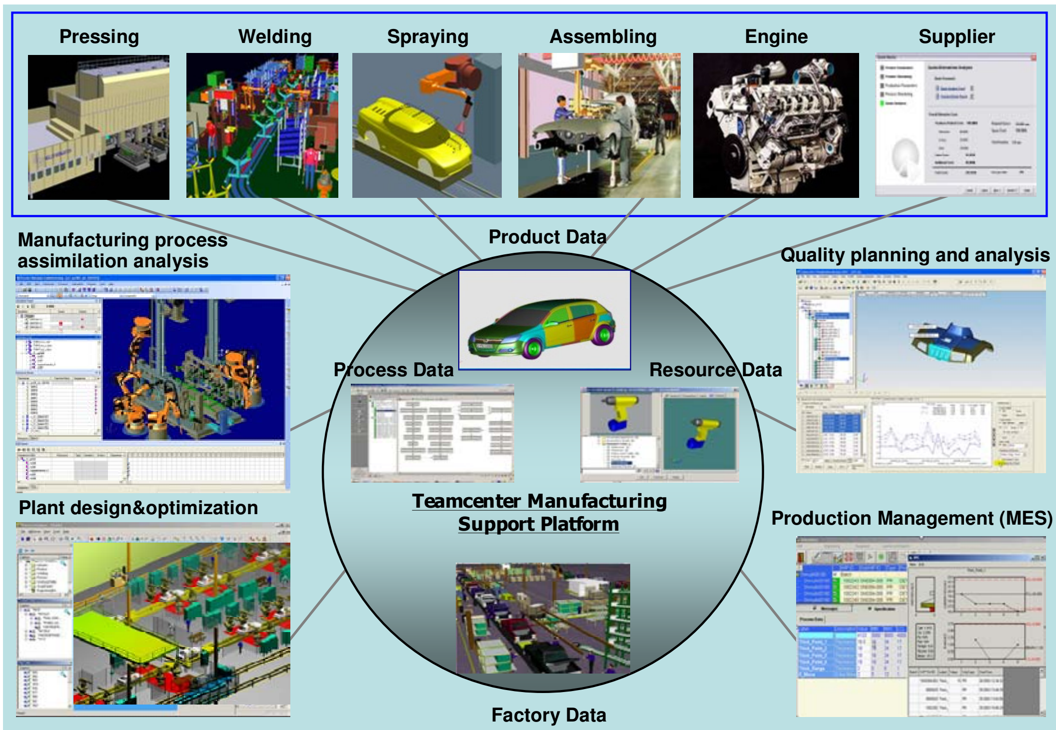

Chart 4 Tecnomatix DM Solution of Siemens PLM Software (Auto Industry)

3-D plant design and layout optimization——Reasonable workshop layout is the base to keep long-term profitability, the perdurability and flexibility of the production process, as well as the maintainability. Plant design by means of object module in 3-D environment can present vivid images, and can describe and utilize information to the full extent. It can store demands and logistics equipments so as to optimize facility layout and to achieve better performances of product lines and logistics.

Planning and design of a full set of automobile processes——Tecnomatix solutions include the auxiliary planning and design capabilities for complete automotive processes: body-in-white, general assembly, engine, pressing, spray coating and process planning of parts supplier.

(1) Solution for body-in-white process: it is mainly used for planning body-in-white welding process and for planning the welding and assembly production lines. This solution enables: a) the planning of body-in-white process with multiple users and multiple points of operation. The user creates the layered description of the body-in-white manufacturing process, and generates an electronic process table on basis of the relations between the process logics, processes and defined business, resources for manufacturing and parts/components, and then allocates the welding points to the corresponding operations and resources, and use the standard equipment and tools in the

system resources library, e.g. robots, clamping fixtures, welding guns, airbrushes, etc, to plan the spot welding or painting process in a 2D environment; the system can also track and manage product design changes and check their impacts on the manufacturing process; b) designing, optimizing and offline programming. Automatically select the welding gun from the system resources library and check it via the sectional function; simulate the robot path in a 3D environment to check collisions, the reach zone and the optimization cycle time; use the discrete event process to simulate the production line performances, including output, utilization of resources, bottleneck searching and buffer size; finally automatically generate robots, programmable logic controllers and operational instructions; c) information exchange within the whole enterprise. It allows users to access various customized production reports, cost estimations, training materials and process simulations stored in the system. All the complete-vehicle manufacturers, production line builders and constructors can cooperate in a collaborative environment focusing on contents and finally form a continuous cycle of development and improvement.

(2) Solution for general assembly process: it is mainly used to solve problems associated with manufacturing processes of general assembly lines, e.g. process planning, manufacturing management of mixed lines for multiple models, optimization of logistics for general assembly, order-based production scheduling, etc, and to complete staff simulation, line balancing and planning of time sequence. This solution enables: a) the planning of assembly processes with multiple users and multiple points of operation. First of all, the user creates the layered description of the general assembly process, and generates an electronic process table on basis of the relations between the process logics, processes and defined business, resources for manufacturing and parts/components, plans the general assembly process in a 2D environment on basis of the containers, stillage, conveyors, etc in the system resources library, and then assesses the manufacturing and assembly times, investment in the project and manufacturing cost, balances the production line and analyzes the assembly line performances, including output as well as utilization of resources; b) designing, optimizing and recording workshop files. It supports detailed 3D design from analysis of the assembly sequence to assembly workstations, and enables 3D simulation of complex robots and manual operations, e.g. insertion of seats, dashboards, windshields, ergonomic analysis, optimization of the work sequence and execution time, etc; it uses the discrete event process simulation to plan the production of different order and product mixes and optimize production line performance, utilization of resources, bottleneck searching, buffer sizes, etc; it also enables offline programming of machining programs and generates operational instructions for assembly line operators and suppliers; c) information exchange within the whole extended enterprise. It allows users to access various customized production reports, cost estimations, training materials and process simulations stored in the system. In this way, when a new model or a new category is introduced, it can easily enable real-time updating. Complete-vehicle manufacturers can transfer the manufacturing information to suppliers as if they were exchanging information within one enterprise.

(3) Solution for machining process: it is mainly used to solve the problems of machining production lines for engines, e.g. process planning, optimization of machining strategies, tools and tooling fixtures, NC simulation, production line balancing, etc. This solution enables: a) machining line planning, i.e. drawing a complete engine production line, taking into consideration all available and existing mechanical and machining line components. First of all, us 3D CAD

data to automatically or manually define the features and layers of machining parts/components, and then automatically select the appropriate operations and tools from the system knowledge library and best practices library, and, on basis of considering the machining time, cutting tool and the cost of cutting balance, estimate the cost of the selected operation, and finally compare and analyze the performances of various production line proposals, including the output of each production line proposal, utilization of resources, work in progress, utilization of buffers and bottlenecks; b) engineering and process optimization, i.e. it allocates operations on basis of the mechanical specifications to design efficient and balanced machining lines. This module can generate separate NC paths and calculate every set of features and its machining cycle time; it use 3D to simulate the NC path to find out the collision between this part and the mechanical clamping fixture, analyze the machining allowance and optimize the cycle time; the optimized program will be automatically downloaded into the machine in the NC program format; it can generate discrete event simulation models and provides users with dynamic perspective drawings for the production line, and analyze output, work in progress, utilization of resources and buffer sizes; c) exchange within an extended enterprise. The user can exchange, review and share information on manufacturing processes via the web. All the complete-vehicle manufacturers, production line builders and constructors can cooperate in a collaborative environment focusing on contents and finally form a continuous cycle of development and improvement.

(4) Solution for parts suppliers: it is used to manage all the operational activities and information of automotive suppliers. It can be seamlessly integrated on a set of open manufacturing data platforms to meet the requirements of suppliers for more effectively realizing the processes of quoting prices, commissioning and manufacturing execution, and successfully keeping good cooperative relations with complete-vehicle manufacturers. It covers all the manufacturing stages of a supplier: proposal, design, design validation, production validation, production initiation, execution and release. This solution: a) provides automotive suppliers with a complete solution for planning. In the lifecycle of the whole manufacturing process, from production program establishment, program selection, product and process designing through to commissioning and production, it can, in an integrated planning environment, complete the designing, validation and optimization of the manufacturing process and production system and archiving. Web-based tools allow an extended enterprise to manage and distribute all related information; b) enables file recording, exchanging and collaboration. The electronic process table stored in an open manufacturing platform is a central information repository that enables traditionally independent departments to work collaboratively. Web-based tools enable users to remotely record files, and exchange, review and share information on manufacturing processes. All the complete-vehicle manufacturers, production line builders and constructors can cooperate in a collaborative environment focusing on contents; c) analyzes and optimizes logistics and materials management. Tecnomatix simulation tools enable automotive suppliers to model, simulate an optimize all main logistics operations, including logistics, output analysis, bottleneck searching and timely and as-demanded delivery of goods; d) provides quality management: Tecnomatix Quality Management is a complete solution for defining, analyzing, measuring and controlling form-position tolerances. At various links of the process, it can minimize production variations, reduce engineering changes, cut rework and enable production and assembly to meet design requirements.

(5) Other process modules: the pressing process solution is used to analyze the moving

mechanisms and check interferences in the pressing lines; the spray painting module is used as the tool for designing the spray painting process. It is used for the whole spray painting process, from the designing of the robot movement path and determination of coverage parameters and thickness through to simulation and downloading of the optimized program to the production line

Manufacturing process assimilation analysis——Before the practical operation of product line, use 3D layout model and process planning result of parts and components, combine discrete event assimilation theory, and make the assimilation analysis to workshop production process in the virtual environment to (a) Certify the feasibility of the process plan, and optimize the process plan; (b) Eliminate bottlenecks, identify potential output, balance production beat, and arrange procedures reasonably; (c) Examine the reasonableness of ergonomics; (d) Assimilate and optimize complicated manufacturing and logistics system, such as analyzing bottlenecks, defining the size of the buffer area, evaluating manufacturing capacities, arranging production plans, etc.

Production Management——Provide functions of manufacturing executing system (MES) to (a) During the batch automobile production process, arrange production plans reasonably; (b) Monitor and control the production process through the real-time data collection system, and deal with abnormal situation rapidly; (c) Track every environment during the production process, run down to logistics flow, work-in-process situation and product pedigree; (d) Integrate ERP information.

Quality planning and analysis——Before the practical production, assimilate the manufacturing process of 3-D digital prototype, certify fitting allowance of parts and components, optimize the allowance chain, use multivariate analysis tools to forecast the scope and reasons of manufacturing allowance occurring in the manufacturing process, so as to decrease the negative effects of allowance on quality, cost and time. In the practical production process, collect quality data on line, and share such data by means of image within the whole enterprise. In this way, quality is improved, and the team will obtain and use such information in a timely manner.

Management of manufacturing data and manufacturing knowledge——Through Teamcenter Manufacturing support platform, manage products, process, resources, plants and production data, share and allow quick access to data, eliminate inconsistency, and help to integrate ERP information and PDM information. Manufacturing data forms manufacturing knowledge after analysis and processing. Use manufacturing knowledge repeatedly to shorten the development time of derivative products and to continuously improve the manufacturing process.

2）Domestic software products related to DM

No domestic software company has its own complete and high-end digital manufacturing solution as of yet. CAPP software is the main low-end product that is usually based on 2D platforms. It can manage process data and edit process documents, but it cannot simulate or analyze processes, nor can it design the layouts of factories, production lines, work cells, etc. A few leading enterprises are making some exploratory efforts intended to research & develop high-end digital manufacturing solutions. For example,

(1) CAXA has launched the CAXA V5 MPM (manufacturing process management) module that focuses on improving the management and control of the product manufacturing process. It has such functions as order management, production plan management, process design, workshop production management, etc.

(2) Wuhan KM Information Technology Co., Ltd has expanded the 3D CAPP module on basis of the 2D CAPP platform, thus enabling the designing of simple 3D machining and 3D assembly processes.

6. Implementation of DM---expectations, effects and suggestions

1) DM Demands & Expectations of Domestic Automobile Manufacturers

As is shown in surveys, all domestic automobile manufacturers are actively improving and developing manufacturing information system to increase their core competitiveness, but none of these manufacturers is satisfied with the current situation of information management and information utilization. These manufactures feel that they need make improvements in many areas, which drives them to pay attention to DM. Due to different posts, different users have different expectations to the implementation work of DM as shown in Table 4.

Table 4: DM Expectation of Different Roles in an Automobile Manufacturer

Role	Expectation
Company leaders	Hope to develop more salable automobiles as soon as possible and to shorten the trail-production time and the scale production time so as to grab the market; Hope to further decrease the production cost, to decrease wastes in the manufacturing process, and to achieve lean production; Hope to increase product quality, and to decrease users' complaints.
Design engineers	In designing products, they hope to deepen the understanding of the current situation of product lines in workshops, and to have close communications with planning engineers, so as to ensure the manufacturability and assembly of design results once for all.
Planning engineers	Hope the planning work and the design work to be done concurrently, to improve heavy tasks caused by design/manufacturing changes; Hope to use some powerful and visualized auxiliary analytical tools to simplify the process planning work, such as distribute welding points and data quickly and accurately for all manufacturing posts, and to verify the reasonableness of process plans prior to the practical production; Hope to strengthen the versatility of mixed product lines, and hope to have some tools to adjust and optimize product lines.
Production engineers	Hope to monitor and manage the manufacturing process in workshops; Hope to improve the communication among process, control and logistics departments, and to optimize/balance product lines; Hope to track work-in-process and manage product pedigree.
Information engineers	Hope to break the information separating wall among different departments and factories within the company, and hope to achieve integral management and sharing of product design, planning and manufacturing information; Hope to have more electronic data and electronic processes to substitute paper data and processes so as to increase the operating efficiency.

In addition, due to different product characteristics and their own situations, different types of automobile manufactures have different priorities on DM. Generally speaking, they pay high attention to a functional module in their urgent need. For example:

Complete automobile Joint ventures (car factories)——Such enterprises have relatively high confidence in the quality of their products. But, their product costs are usually high. Compared to foreign manufacturers, especially Japanese manufacturers, they usually release new products slowly. They lack independent design and planning abilities. They are looking forward to decrease cost and strengthen their product design and planning abilities through DM. They wish to participate in more and important product design work in this way (as an effort of the global design of their parent companies). Therefore, they are highly interested in body planning and design, assembly planning and design, plant layout and optimization and other similar work.

Complete automobile manufactures with self-owned brand (car manufacturers, minibus manufacturers, commercial automobile manufacturers, and etc)——They have independent product design and process planning abilities. However, they mainly depend on experience to finish the process design work, and they invite some senior craftsmen for approval and check. They lack means of virtual analysis and verification, such as assembling assimilation means, welding assimilation means. The automation level of their product lines are relatively low and the workshop management work is rather outdated. Besides welding, assembling and other process planning modules, they have strong demands for the production management module.

Automotive suppliers – Domestic automotive suppliers are facing increasing pressures: a) complete-vehicle manufacturers are continuously pressing them for lowering prices; b) as the whole industry develops towards "Just-in-Time" production, enterprises need to build new factories in several locations; c) there is surplus production capacity, so competition is intensified; d) complete-vehicle manufacturers are accelerating their paces in launching new models and requesting suppliers to deliver designated parts to the designated places within the specified time; complete-vehicle manufacturers not only compress the lead time for issuing requirements plans, but also specify that penalties will be imposed on suppliers for late deliveries. So, if suppliers fail to have timely and accurate information about the production conditions and requirements of complete-vehicle manufacturers, they may have big difficulties in production. Automotive suppliers' requirements for digital manufacturing are embodied in the following aspects: a) they need a complete set of solutions to support process planning, plant layout, simulative analysis and quality assurance. These solutions shall cover the whole lifecycle from production program establishment, solution selection, product and process designing through to commissioning and production; b) they shall together with complete-vehicle manufacturers implement the supplier management module to improve the collaboration between complete-vehicle manufacturers and suppliers in a global sense so as to more effectively match the requirements of complete-vehicle manufacturers with those of automotive suppliers; c) improve production response through reuse of knowledge so as to better meet customer requirements; d) realize collaboration among factories at different locations.

As is shown in surveys, domestic automobile manufacturers think that they can benefit from DM: (1) Increase production planning efficiency, and decrease process planning cost and general product development cost; (2) Prior to the production, determine the manufacturing feasibility by assimilating the manufacturing process; (3) Shorten the process planning time and the time from the trial production to the scale production, and quickly release new products in the market; (4) Link the product design work and the manufacturing planning work, and improve design in allusion to the manufacturing feasibility; (5) Verify and improve product design, and improve product quality from the prospective of the process; (6) Use digital assimilation and product line assimilation, and decrease the quantity of sample machines; (7) Improve the collaboration among various functional departments and manufacturers between suppliers. See Chart 5 for the proportion of Number One Ranking of each value.

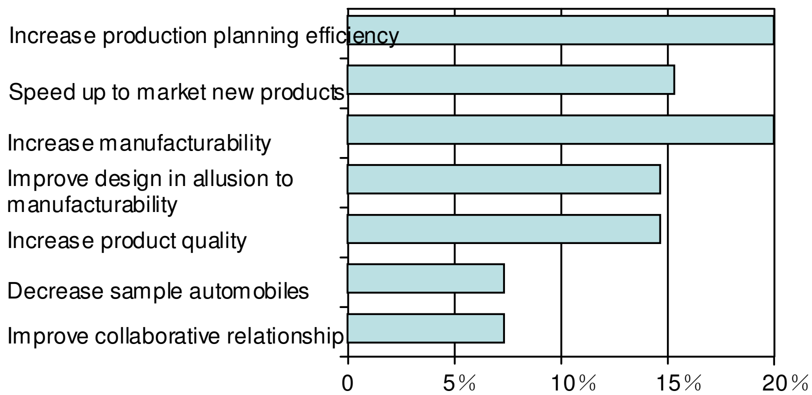

Chart 5: DM's Value and Its Number One Importance proportion

When considering DM solutions, besides the price factor, automobile manufacturers usually consider the following factors:

Advantage of the solution——Whether there are some successful cases for presentation in the automobile industry;

Completeness of the solution——Whether it covers all processes, plant planning, quality and supplier and other modules;

Openness and integrity of the solution——Whether it can be integrated with other different types of CAD, PDM and ERP.

2) Fruits & Difficulties of Domestic Automobile Manufacturers in the DM Implementation

In recent few years, domestic automobile manufacturers are also increasing investments on DM technologies and software, and received some effects. Here are some cases:

Case 1: In 2003, a domestic car joint venture introduced the "Digital Plant" software (the predecessor of the DM solution). The software contains assembling, body, painting, engine and other modules. In consideration of the complexity of DM and high requirements for personnel quality, the company adopted a progressive implementation strategy. At first, it carried out the assimilation project related to the body-in-white process. It verified and analyzed body lines by assimilating them, which made engineering familiar with software quickly and acquire experience, and avoid losses caused by improper use. Starting from 2005, the company started to use DM software to plan practical body lines. Now the application of digital process planning and validation methods has already produced significant actual benefits for enterprises. According to statistics, with traditional process methods, it will take 24 months to complete process planning for a new model through to commissioning and, after the project is implemented, it will take 14.4 months to make production preparations. In the past, 20 process planners were needed for planning the process of a new production line. Now only 10 planners are needed. In addition, the number of man-hours is reduced by 30%; repetitive work is reduced by 5%; each of planning efficiency and accuracy is increased by 50%; process planning time is reduced by 22%; production line capacity is improved by 35%; utilization of resources is increased by 70%; engineering changes are reduced by 20%; overall project investment can be reduced by 20%. One third of the work of the digital general assembly project has been completed. Thanks to the simulative validation of the production lines for the dashboards and chassis for some models, hundreds of kinds of prototype designs for tooling fixtures and parts (e.g. robots, chassis carriages, etc) have been reduced. It is estimated that, after the project is completed, the production capacity will be improved by 20%-30%, engineering changes will be reduced by 10%-20%, investment in physical prototypes will be reduced by 20%, and 10% of resources can be reused. In addition, the company decreased welding points which are missed during welding process of carbody , and increased the product quality.

Case 2: Starting from 2002, a domestic car manufacturer with its self-owned brand implemented Teamcenter Engineering via PLM system from Siemens PLM Software, and integrated the product design chain and the production chain. The PLM system managed digital sampling machines after the 3-D modeling work, and designed BOM data. CAE Department can directly assimilate and analyze digital models. From digital modeling and virtual assembling of complete automobiles, whether the assembling work is hard or not, potential problems can be identified in time. After modification and commission of digital sample machines for several times, the company started to manufacture physical sample machines. In this way, the quantity of physical sample machines is significantly reduced, and the product development speed is greatly raised. Now, the company has noticed that the CAPP system used by planning institutes cannot effectively manage process BOM data and cannot assimilate or verify 3-D digital models. So, the company is starting to introduce more DM modules so as to promote the application of PLM solutions.

Case 3 : In 2005, a domestic commercial automobile manufacturer with its self-owned brand started to implement the MES module in DM, and greatly improved the collection and communication process of workshop information. Before MES is implemented, production orders were mainly issued by manual means, assembling information of key parts and components is managed by operators depending on their experience, the collection of production site data is finished by HMI of ERP, the operation was inconvenient, various workshops manage work-in-process according to different marks, production data can not be reflected in the system, various workshops manage work-in-process separately, management departments cannot control the whole situation, material distribution lists were established manually, and the workload was rather heavy. After MES is implemented, the company can distribute production site time in a real-time manner, used the automobile configuration lists to guide the production, collected manufacturing data in the production site in a real-time manner, monitored and managed the whole assembling process, achieved the material distribution function, assisted the execution of production orders, and integrated MES and planning management layer and process monitoring layer.

Generally speaking, the application of DM technologies, especially of complete DM solutions, is still in the starting stage. Besides few leading companies, many automobile manufacturers, especially manufacturers of parts and components, still have doubts with the “wait and see” attitude. As is shown in surveys, those enterprises that took the lead to adopt DM solutions, did meet with some difficulties and challenges:

Lack of patience——When making information investments, automobile manufacturers all pay much attention to the short-term return on investment, but DM has to go a long way to achieve success. Automobile manufacturers have to learn how to use software and have to accumulate experience. They may meet with many setbacks, such as hard beginning, habit and other problems. It is common that DM can only play the normal role after the trial use for 2 to 3 years.

Negative influence of weak IT base on the deepened application of DM——The 3-D CAD application is the necessary premise of the implementation of the process planning module and the plant planning module, and the PDM application is the necessary premise of the implementation of the manufacturing information management module.

Lack of emphasis on DM from senior management——Some enterprises, after purchasing digital manufacturing solutions, do not commit dedicated personnel to learn and trial use the software, so no in-depth application of the software can be achieved.

Fear of restructuring of business process——The implementation of MES, the supplier management module and other modules in DM will unavoidably lead to adjust organization adjustment and restructuring of business process. In addition, sharing of manufacturing information will incur safe access problems. Enterprises need to take positive actions to address such changes.

3) Suggestions for Domestic Automobile Manufacturers for the DM Implementation Work

When domestic automobile manufacturers are implementing DM, the following lessons are worthy of being learned from:

Select experienced software vendors and industry-proved reliable solutions—— Implementing "digital manufacturing" will change the enterprise's existing process planning and manufacturing. Both the "technical level of the solution itself" and the "vendor's experiences in implementing solutions" are indispensable. No one wants to be the "guinea pig" of a solution that is not mature. So it is critical to choose the high-quality solutions widely proved by foreign automotive manufacturers.

Adopt progressive implementation strategy (from the single spot to the whole), and do not stride too far once——Taking the implementation of the Tecnomatix solution from Siemens PLM Software as an example, engine process planning, assembling planning, and assimilating/welding robot planning and other applicant tools are relatively independent spot plans. Their characteristics are few departments and personnel, short implementation time, and quick benefits. Therefore, automobile manufacturers can start with the application of these spot plans at first, then progressively introduce management module of planning data and production data, and finally integrate with the design information system so as to form a complete set of PLM system.

Manufacturing enterprises should not completely rely on independently developing DM software——The advantage of open software developed by the dedicated R&D team of an enterprise is that it is practical, but the disadvantage is that it is hard to ensure the quality of the software. In addition, due to high turnover of employees, it is hard to guarantee subsequent services. If such services are outsourced to a software vendor or if the IT personnel of the enterprise collaborate with the software company in implementing the software and engineering supervision, these problems are very easy to solve.

Do not blindly spend less while wanting to do more——Digital manufacturing requires manufacturing enterprises to give full consideration to the performance (including services)/price ratio instead of considering prices only. It requires a lot of time and monetary inputs to implement software, so if an enterprise blindly wants to spend less while hoping to realize digitalized manufacturing, it is very difficult to achieve satisfactory results.

Closely link to the practical situation of enterprises, and adjust measures to local conditions——Every enterprises has its own special condition, and cannot take and use successful experience of other companies, especially of foreign companies, without changes and adjustments. Taking a domestic minibus manufacturer as an example, the automation level in its workshops is relatively low, it rarely uses robots, and its requirements for product performances are not too strict. So, such enterprises do not strongly hope to implement virtual planning, verification and quality planning solutions, while the implementation of MES and the supplier management module is their urgent mission.

Pay more attention to develop implementing personnel——DM implementation work is a work with high technical requirements. Company leaders need to pay much attention, and enterprises also need to establish an excellent implementing team, including engineers from the planning department, the production department and the information department. After the team is familiar with DM software, other personnel shall be included.

Carry out the implementation work with the guidance of PLM system framework——DM is the core composition of PLM strategy. Although DM application can start with the spot plan, management, integration and application of PLM manufacturing information are the ultimate goal. So, before investing on DM application software, automobile manufacturers have to consider long-term PLM goals in future, otherwise, the integration work for future system will be hard.

7. Conclusion

To raise the information level in the manufacturing process is the key to strengthen the core competitiveness of enterprises. From 3-D CAD and PDM/CAPP to virtual manufacturing and till DM which now attracts wide attention, IT application fields are extending from the design stage, the upstream in the product lifecycle, to the process planning stage and the production stage, the downstream in the product lifecycle. Objectives of digital manufacturing is, to get started with manufacturing reality, describe and process data from the manufacturing preparation process and the manufacturing process in a digital way, store and transmit such data in the manufacturing system, use such data in auxiliary process design and management & control of the production process, form relevant knowledge, and improve the intelligence of the manufacturing system.

The automobile manufacturing industry has always been the place where domestic advanced manufacturing technologies are utilized. These manufacturers have sound manufacturing equipments and IT application foundation. They take the lead to implement DM, which is both the general trend and the necessary result. On the one hand, national guidelines and policies are leading them to march towards continuous innovation. "Build innovation system, and form independent development abilities" is one of nine strategic objectives specified in the 11th five-year plan in China's automobile industry. To strengthen innovation abilities, the automobile manufacturing industry has to achieve digital product design, digital process planning and digital production management. On the other hand, the market competition promotes the transition of traditional manufacturing modes into the DM mode. Since products, production equipments and manufacturing systems are becoming increasingly complicated and expensive now, with the premise of manufacturability, automobile manufacturers can only achieve the rapid, cheap and quality manufacturing analyzing and optimizing manufacturing procedures by quantitative means with virtual DM verification functions.

It is worth rejoicing that, more and more domestic automobile manufacturers are starting to pay attention to DM, and some leading manufacturers are trying implementing DM. At the same time, the academe, IT consulting companies and software companies are increasing their DM enthusiasm, which will undoubtedly promote DM application. Of course, some difficulties and challenges are unavoidable in DM implementation process. DM implementation is a complicated and systematic project, and it requires huge investments. If inappropriate technical means and implementing methods are adopted, certain risks will exist. Therefore, we not only need to learn from successful experience overseas, but also need to notice gaps between domestic and foreign automobile manufacturers in terms of management, technical accumulation, IT application and other aspects. Domestic automobile manufacturers mush adopt implement DM according to the practical situation in China.

We believe that, in upcoming years, DM will bloom and enjoy the fruits in many more domestic automobile manufacturers, and will achieve its application values.