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A MULTILEVEL RECONFIGURATION CONCEPT TO ENABLE VERSATILE PRODUCTION IN DISTRIBUTED MANUFACTURING

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ABSTRACT

The manufacturing industry is confronting challenges due to high diversity of product variants, reduced product life cycles, short innovation cycles, faster time to market as well as strict environmental regulations. These challenges have persuaded manufacturers to exploit concepts related to open innovation, distributed manufacturing, modular and scalable production system design and eco-efficient production. This paper aims at providing a short review of state of the art in reconfiguration of distributed production systems and focuses on new strategies to resolve complexities that arise subsequently. Therefore a reconfiguration concept based on new strategic objectives has been proposed to enable customized production. The approach will be implemented and validated in the collaborative projects.

KEYWORDS

Optimization Module, Plug and Produce, Smart Robot Tooling

1. INTRODUCTION

The manufacturing industry is subjected to numerous current and future challenges. These challenges need drastic changes in their operating environment to achieve future strategic goals. It is particularly important when they intend to compete in the global environment. As a matter of fact, the manufacturers particularly the OEMs have focussed on getting quick and easy access to the segregated markets as a strategy to raise their competitiveness and market share. In doing so, they need to address individualized customer demands in a shortest possible time.

The manufacturers are consolidating resources as well as relying on high outsourcing strategies in design and production to bring innovations in the shortest possible time. Furthermore, the current and future challenges concerning environmental regulations require alternative choice for materials and processes that are environmental friendly. They also require adaptable and eco-efficient manufacturing systems by exploiting reconfigurable and lean production concepts. Better organizational structures have been identified and explored to achieve responsive, expandable, adaptable, reconfigurable and eco-efficient systems. These characteristics demand intensive and systematic collaboration among all manufacturing stakeholders i. e. OEMs, subcontractors, suppliers, dealers, retailers as well as customers in the form of collaborative networks. These networks act as strategic capacity builders to foster manufacturer’s competitiveness. Likewise other industrial sectors, automotive industry has been going through a huge change in their organizational structures since they initiated exploiting mass customization principles. The increasing competition, for satisfying customer requirements along with declining product costs reducing innovation cycles and increasing production volume mix, has compelled manufacturers to interact to a deeper extent with their suppliers as well as with customers without relying completely on their own competencies and solutions (Scavarda and Hamacher, 2007). Several strategies have been adopted along the time history of production in the automotive industry to address customer demands. Most notably they are named as make to stock, build to order and assemble to order. A hybrid strategy combining assemble to order and make to stock is practically adopted in the vehicle manufacturing sector to achieve short delivery times as well as minimizing production capacity constraints (Brabazon and MacCarthy, 2006). The build to order strategy has its advantages for large, expensive and customized parts. In the car industry that would be e. g. engines or entire cars (Alicke, 2005). In Germany, build to order strategy has a long tradition and more than 60% of the cars are built to customer orders (Parry and Graves, 2008) connected through highly dynamic value chain management process. The value added chain in automotive is characterized by intense flow of materials, information and components along with the tremendous amount of collaboration activities among suppliers, manufacturers, dealers, retailers as well as customers in ever expanding production networks. Consequently, the collaboration requires intense involvement of stakeholders in common design, production as well as aftersales services. Corallo and Lazoi (2010) have highlighted some of the recent practices being adopted by value added network actors in an aerospace company to manage and perform innovation activities. Similarly issues related to the future collaboration between the stakeholders of automotive production to get highly individualized and environmentally friendly cars are reported in an article by Daum (2005). The emphasis has been laid on better understanding of customer needs in order to bring innovations in shortest possible time. It has triggered the expansion of collaborative networks by enhancing roles of tier 1 suppliers and customer’s role in the product development phase. The advent of internet based technologies has revolutionized the communications possibilities in collaborative networks. In the context of B2C, it is particularly seen as product configurators in consumer products as well as in modern vehicles. The car configurators introduced by every manufacturer for instance provide customer a set of options to customize vehicles according to their choices. In B2B relations, the existing communication infrastructure at manufacturers as well as at the suppliers is not sufficient enough to deliver satisfactory performance for effective collaboration (PTC, 2009). Additionally, the short innovation cycles have compelled OEMs to rely on more extensive partnerships with other stakeholders for better utilization of capabilities and capacities within the production networks. However, some highlighting challenges being faced due to multiple data repositories, insufficient process support and integration issues between various tools at manufacturers and supplier sides. It has made the development process sluggish often prone to time delays and losses of investments are reported in (PTC, 2009). Consequently an effective collaboration cannot be made due to information and data exchange issues. This necessitates searching for innovative solutions for collaboration at the product design side among potential customers and manufacturers. Moreover, the collaboration between suppliers and dealers must embrace ideas concerning innovative collaborative platforms to connect heterogeneous software tools or exchange of data in production networks.

Another issue in focus in the scope of this paper relates to the environmental impact of production activities in the collaborative networks. The diversified product requirements from heterogeneous markets, global distribution of manufacturing and supplier locations have generated a pool highly diversified manufacturing and supply alternatives. Each of the manufacturing and supply process originates environmental emissions. Subsequently, a huge variety of alternative production schemes can be generated. They should be optimized based on cost, time and environmental efficiency to decide for the feasible production scheme that can manufacture the customized product. Currently, the shop floor processes are optimized considering their associated costs and manufacturing time. There is no significant contribution found in the scientific literature that gives conception for the assessment of the environmental impact of customized manufacturing in distributed production system. Previous studies mentioned in Olugu et al. (2010) have focussed mainly in the areas of sustainability costs, process optimization to reduce ecological load and recycling. A much attention is given on limiting wastes disposals from processes less than 5% of the 90% of end of life vehicles (Olugu et al., 2010, Schultmann et al., 2006) to comply with the aspirations of the European Commission. The environmental assessment of production processes i. e. manufacturing process chain or supply chains are generally carried out on the manufacturing site basis and with respect to the specific product. In some cases it is even neglected as the assessment has not been enforced strictly by laws or any other influential factor. Furthermore, the responsivity and reconfigurability of the production system have posed question on productivity while conceding changing requirements in the customized production. The diversified customer demands are fulfilled by introducing a huge vehicle variant diversity. OEMs follow this practice as a strategy to gain competitive advantage. Wemhöner (2006) indicated that new models of Mercedes Benz in the last 15 years increased an average from one to 2.5 models per year and the product life cycle of these models reduced from 9 years to 5-7 years respectively. BMW also claims that the possible variations in BMW7 series can reach to 10^{17} (Hu et al., 2008). This diversity is not only seen in vehicle drives, power trains and other accessories but also in the new body structures constituted of new materials such as light weight materials (Goede et al., 2009) and multifunctional materials (Salonitis et al., 2009) to achieve fuel economy as well as the eco-efficiency. The high diversity has increased the complexities in controlling the production internally as well as externally. Internally it has posed a big challenge to the order fulfillment process (Salvador and Forza, 2004) as well as to the optimal configuration of production setups. Externally, the configuration of supply chain with the changing customer requirements and environmental regulations concerning materials and processes has raised enormous complexities. One of the main challenges in controlling the production is the configuration the automotive production system to new production requirements and reusability of resources for new processes, operations and applications. The automotive production setups configuration process is accompanied by several activities related to resource planning, designing, simulation, optimization, commissioning and sequencing and scheduling of tasks to be accomplished on the specified resources in a production network. The production configuration process mainly constitutes commissioning of resources. This process is quite repetitive and sluggish accompanied by technical complexities. The complexities in optimizing resources to reach production objectives have imparted negative impact on the technical and economic objectives of manufacturers in serial startup of production. A case study mentioned in (N. N., 2005) depicts some of interesting statistics about serial startup of the production in European automotive industry during the year 2004-2005. These statistics indicate that during that period, about 60% of the running serial startups missed their set objectives. Approximately 23% of the startups were neither economically nor technically successful. The main problems that arise during commissioning are the unsuitable resources, missing resources, resources with incorrect or misfit specifications, desired cycle time. Besides, setup time and costs are extremely high. Furthermore, the exchange of planning and commissioning related data is not consistent and involves high risk in loss of accuracy in information exchanged through heterogeneous software tools. Additionally, the coordination with the external suppliers is extremely sluggish due to absence of seamless and standardized communication and data exchange means and tools. Today, the commissioning time shares about 11% of the time for vehicle volume production up to five years (Schuh et al., 2008 , Barbian, 2005). With the increased customization, resources must incorporate fast reconfiguration possibilities with minimum setup times or they must be completely transformable with least changeover time. It also requires adoption of fast commissioning strategies to achieve customized production with even shorter lead time. To sum up the presented facts and trends, the future manufacturing systems need distributed production networks that can be adjusted and configured dynamically to enable customized production. Besides, the optimization of production processes and the resources used in the collaborative networks must be made by considering cost, time, quality and environmental efficiency. Furthermore, at the resource level, the corresponding process setups must be reconfigured fast to achieve high responsivity and reusability. It will help reducing changeover time and the associated development costs and delays.

2. STATE OF THE ART ON DISTRIBUTED PRODUCTION SYSTEMS

The production is a totality of all functions that are required to design, produce, distribute and service products. A distributed manufacturing system (Figure-2) is comprised of geographically networked value adding resources and material handling resources that are interconnected with transported resources meant for producing variety of products for segregated markets (Farid et al., 2006). Until now, production systems have been under continuous process of alteration as well as consolidation due to changing product specifications. Furthermore, governmental legislations demand eco-friendly vehicles that have less environment impact in production, in use and after use cases. Taking the example of automotive industry, the corresponding production systems are comprised of dense network of geographically distributed manufacturing sites as OEM global infrastructure. Japanese concept for just in time production as well as the subsequent supply chain management has made geographically distributed suppliers to be linked directly with respective vehicle manufacturing production phase. The distribution of suppliers and manufacturing locations is uneven due to inconsistent customer demands or choices.

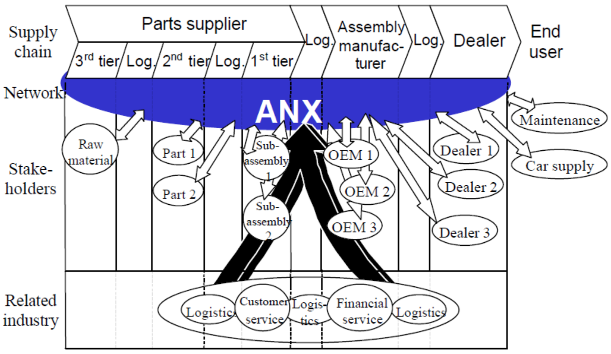

Figure 1 – ANX platform for collaboration between OEMs and suppliers (Cassivi et al. 2000)

Modularity is regarded as a key factor in organizing not only the product customization but also the supply chains (Ro et al., 2007). It has facilitated the collaboration activity with suppliers, which are integrated bilaterally with manufacturers through indigenous electronic data exchange tools (Koperberg, 2007). The German automotive manufacturer for example Daimler is believed to have strong partnership with its suppliers through common platform like ANX (see Figure-1). Through this platform not only the manufacturer, but also tier 2 and tier 3 suppliers are able to work with tier 1 supplier in an effective and much easier way (Cassivi et al., 2000). The collaboration through ANX allows real time interaction between product developers and production engineers. The most common means known today are namely the video conferencing, data visualization tools easy data analyzation, digital mockup tools, application control and data exchange to avoid any duplication of files and messenger for exchange of office files (Cassivi et al., 2000).

The distributed manufacturing system in automotive manufacturing is illustrated in the Figure-2. The shops related to each manufacturing facilities are closely or loosely coupled with suppliers, subcontractors and distributors etc. The production planning in such a distributed supply and manufacturing chain is a highly complicated task as the optimization of processes is to be done locally as well as globally along the whole manufacturing interconnected network. Consequently, decision making in distributed production system has become problematic due to constraints related to time, cost and environmental emissions. The scope of this paper is restricted to the planning issues in the distributed manufacturing systems as well as configuration issues at the resource level focussing on body shop development and machine shop respectively.

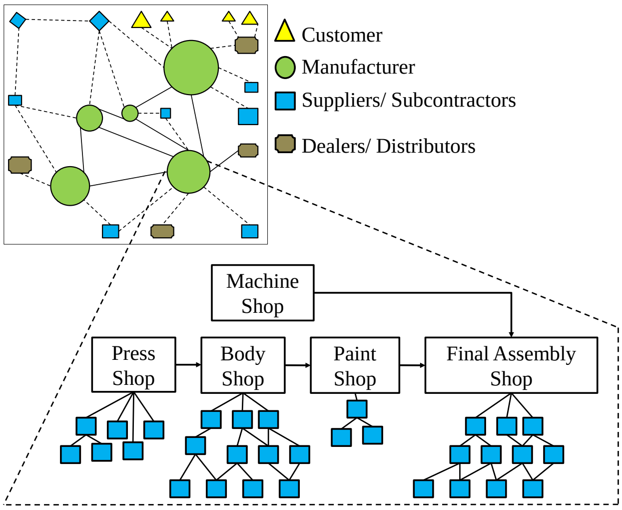

Figure 2 – Distributed Manufacturing System (Network and Automobile Manufacturing Phases)

The configuration or reconfiguration of manufacturing system is comprised of following steps shown in the block in Figure-3. At the network level, the decision regarding selection of production location as well as the supply chain for manufacturing each of the anticipated products is defined. At the site level, the processes and the corresponding resources are optimized based on the production goals i. e. cost, time and quality. As the process quality has direct influence on the product quality, the processes are selected depending upon the quality that can be achieved through the processes as well as resource related constraints.

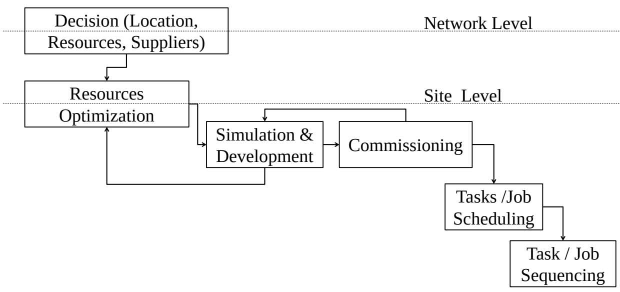

Figure 3 – Main phases of configuration of distributed production system

Furthermore, the process cycle time has direct influence on the production rate; therefore the processes are not optimized based on their feasibility to accomplish tasks but also the inherent costs, cycle time and the product quality.

In the simulation phase (see Figure-3), tasks are simulated using the selected resources in digital factory tools. This is particularly meant for the assessment of the process and production related metrics. After simulation, new resources are added or altered. This activity is specified by intensive collaboration from material, components and equipment suppliers on one side and on the other side from the system integrators to assist in finalizing commissioning and performance evaluation. Afterwards, the scheduling and sequencing of the jobs or tasks are carried out by assigning them to resources in an optimal way.

2.2.1. Distributed Production Planning and Scheduling

Production planning and scheduling refers to activities that deal with selection and sequence of production processes as well as the optimal assignment of tasks to manufacturing resources over a specific time. Several methodologies have been introduced in the literature to enable computer aided process planning namely feature based planning (Cai, 2007) (Mokhtar et al., 2007) (Berger et al., 2008), artificial intelligence i. e. neural networks and genetic algorithms) based planning (Joo, 2005), (Monostori et al., 2000) (Venkatesan et al., 2009), (Zhang et al., 1997) and knowledge based approaches (Wu et al., 2010) (Tsai et al., 2010). A handful of paper discusses planning and scheduling related issues in the distributed manufacturing environment. Recent literature e. g. discusses the coordination of local schedulers by using heuristics algorithms (Xu et al., 2010). Agent based concept has emerged as an innovative solution to solve planning and control problems in distributed production systems. Lima et al. (2005) presented a model for agent based production planning and control to dynamically adapt to local and distributed utilization of production resources and materials. In a highly individualized customer demand scenario i. e. one-of-a-kind production, incremental process planning has been proposed for extension or modification of primitive plan incrementally according to the new product features (Tu et al., 2000). Likewise, agent based approach is used to enable manufacturing organizations dynamically and cost effectively integrate, optimize, configure, simulate, restructure their manufacturing system as well as supply networks (Zhang et al., 2006). Agent based approaches are more flexible, efficient and adaptable to dynamic and distributed manufacturing environment. However, none of the contributed work addresses planning based on strategic production goals. This means that no one has ever addressed the optimization of processes and activities on cost, time and potential environmental impact of manufacturing and supply processes for automotive manufacturing. A very confined number of research papers address the issue of optimization of energy consumption at individual machine level optimization of sequence or ordering of activities based on energy consumption at individual machine (Mouzon et al., 2007) or shop floor level (Vijayaraghavan and Dornfeld, 2010). Therefore the future manufacturing setups and processes need to be optimized based on cost, time and environmental efficiency to help manufacturers in gaining competitive advantage in bringing cheap, high quality and innovative products to the market in a short delivery time.

2.2.2. Configuration at Resource Level

The second issue addressed in this paper is the configuration of resources to achieve customized production at the shop floor. The configuration activities at this level are mainly dominated by commissioning of shop resources, to enable smooth execution of intended tasks with the anticipated quality. The commissioning process is comprised of several distinct activities. The major part of these activities is assisted by digital tools to enable smooth and fast ramp-up as well as reduce development commissioning costs. The commissioning activities use advanced robot simulation tools to virtually simulate, validate and commission robot application environment. It allows experimentation possibilities which may be difficult to test using real systems. The commissioning process may involve intensive repetitive activities accompanied by tedious testing and hit and trials procedures to achieve the robot movements. The simulation of new robot or robot with unknown characteristics is needed to specify the positions of tool center points (TCP) to execute intended tasks precisely. Until now, robots have been used in high volume production applications. Besides, robots are typically programmed for new tasks by first teach in procedures and then programmed offline to get the desired path. The changeover for robot from one process application scope to another is a time consuming process. Furthermore for each of the changed product features, the robot have to be programmed through teach in procedures or through virtual simulation tools and then programmed offline. The process is also time consuming as they lack absolute positioning accuracy and the programming and simulation tools are unreliable to configure robots in a short time for executing complex tasks such as machining. These limitations need configuration strategy to enable reusability of robot as a plug and produce device used in execution of various processes.

3. CONCEPT FORMULATION

The concept for reconfiguration of production systems is presented by considering two distinct cases. The first one is taken from the automotive body shop while the other one from the machine shop. The formed, stamped and roller components of body-in-white are sent to the body shop to develop complete body-in-white after assembly. The machine shop is an auxiliary part of the automotive production setups. In automotive industry, vehicle components for the end assembly are machined in the shop and delivered to the final assembly shop. The body shop is taken as a case study to present reconfiguration concept at the network level and machine shop to introduce resource reconfiguration concept. Hence the mass customized manufacturing of products with small changing lot sizes is possible.

3.1. RECONFIGURATION AT NETWORK LEVEL

Currently the complete vehicle body-in-white is developed at one particular location in a centralized body shop. The body shop at each of the vehicle manufacturer follows either of the basic layout forms as shown in the Figure-4.

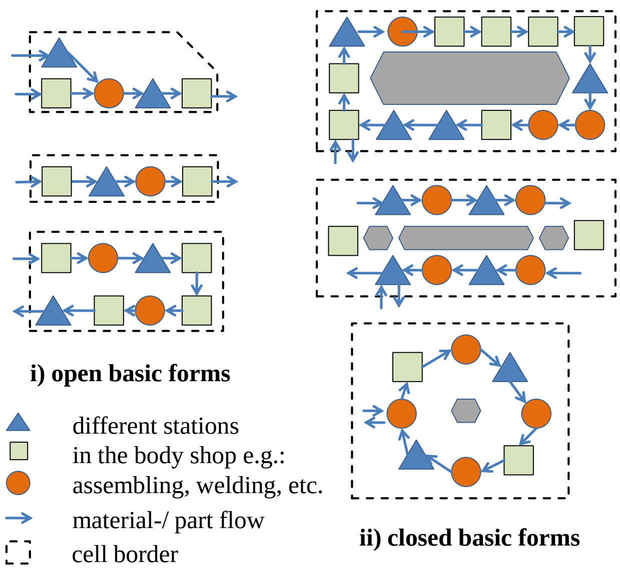

Figure 4 – Basic Body Shop Layouts

Hesse (2006) describes different basic layout forms for assembly systems. These basic forms are followed also in the body shop assembly lines. However, most prominent layouts are Z shaped assembly layout, C form assembly layouts and fishbone assembly layouts.

Considering body-in-white as a product, the current body-in-white is modularized (Paralikas et al., 2011) to generate product families from the basic platform easily. Furthermore, parts or modules can be either carried over or reused after slight modifications. The modular body-in-white design has open up many new possibilities for redefining new layout inside the body shop of manufacturing plant as well as among different manufacturing facilities in a distributed manufacturing scenario.

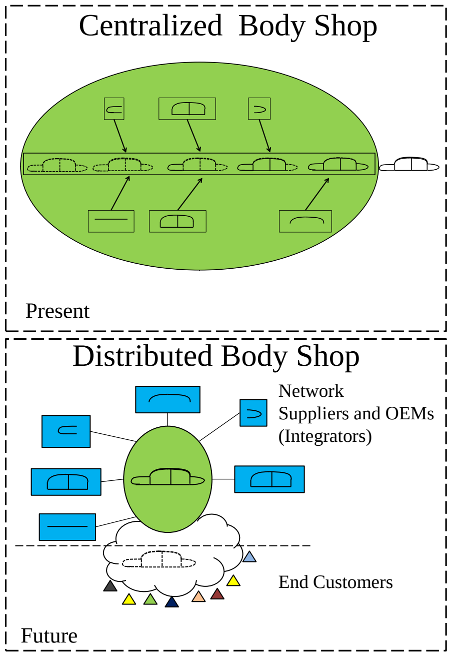

Figure 5 – Distributed Body Shop (OEM and Supplier Network)

Figure-5 describes the present and future layouts for the automotive body shops. Currently modularization of body-in-white has promoted structuring of body-in-white assembly lines on fish bone layout. Various vehicle modules are produced separately at various sub assembly lines and then body-in-white is integrated in a stepwise fashion. The flexibility at the cell level and assembly line level is very limited due to the dedicated joining stations and the assembly robots. The cycle times are also fixed at the cell as well as at assembly lines. Askar and Zimmermann (2007) states that the body shop has generally no technical flexibility because the robots used have fixed cycle times. The handling of variant diversity, modularity (Pandremenos et al., 2009) and metal hybrid body-in-white concepts (Grujicic et al., 2009) concepts are adopted. Furthermore, new production concepts based on migration manufacturing principle (Meichsner, 2009) have been exploited to develop various vehicle shapes. This principle, however, cannot be easily mapped to handle diversity of luxury vehicle segments. All these efforts are based on modularization of the products to handle variety in the manufacturing systems; however, the manufacturing setups are not reconfigurable to develop products that are modularized at the product level. Minhas et al., (2011) and Zipter et al., (2011) introduced two novel concepts to make the production setups reconfigurable or transformable to handle diversified assembly tasks. The versatile production setup (Minhas et al., 2011) concept in the form of multi-technology joining cell to join body-in-white subassemblies is a specific case to make the joining cell scalable, modular and responsive to the changing product development requirements. The robot farming concept (Zipter et al., 2011) is envisaged to meet the challenges of volatile markets by dynamic resource management concept. These concepts have not addressed the open innovation as well as environmental impact challenges that the body shop layout and production processes may face in the near future. Moreover, no contribution has been so far made in configuration of body shop production considering distributed production. It is a required production scenario when the manufacturers are not able to meet short innovation cycles and higher lead time and the body-in-white variants are developed through mutual collaborations of suppliers and OEMs.

The current trends show that new assessment of role of supplier and manufacturers as well as relationship between the manufacturers enable customized production. Figure-5 shows the graphical representation of distributed body shop. The manufacturer will analyze customer requirements based on the vehicle style as well as external accessories such as roof and assess the production schemes based on the available suppliers to deliver required modules or parts in a specified time. The configuration or reconfiguration of the potential manufacturing or supply scheme will be made on considering the associated cost to manufacture the product as well as the production and delivery time. Additional factor will also be considered to assess the potential production schemes based on their environmental impact. The architecture for decision support tool is shown in the Figure-6 as block diagram. The modular and scalable body-in-white is customized based on the style specifications from the potential customers. The customized version of body-in-white is compared with the bill of materials and bill of processes of the reference body-in-white to decide for the customized bill of materials and bill of processes. This information is used to decide about the locations where the production will be carried out to manufacture the specific body as well as integration takes place. The environmental impact of each of the production scheme will be assessed by getting direct information from the knowledge base to calculate the environmental impact metrics of the production processes as well as supply means. In case of missing information or completely new production case, the production chain will be simulated in the environmental assessment tool.

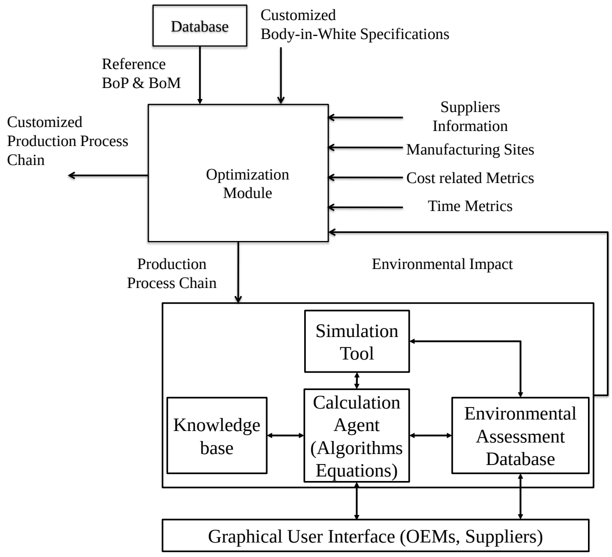

Figure 6 – Distributed Production Network Optimization Module

The final decision about the production at the supplier side or at the manufacturing side will take place considering the cost, time and environmental impact of the production as well as supply chains. It will enable economic, quick and eco-efficient production in mass customization scenario.

3.2. RECONFIGURATION AT RESOURCE LEVEL

At resource level, the reconfiguration process must be fast enough make the resource ready to accomplish the task and deliver customized product in a short time. The customized products for automotive industry are machining of complex automotive parts, moulds and dies. The machine shop today is comprised of various stand-alone as well as flexible CNC machines connected in flexible layouts and transfer lines to allow machining of parts of complex geometries in a multi-stage process (Eversheim, 1989). This structuring of machining is one of the most challenging tasks as it is structured according to the product specifications, processes and operations. Furthermore, the resources such as CNC machines are very expensive. Moreover, the NC process chain has become very complex and dynamic. Along with that, huge information has to be handled and exchanged along the process planning phase (Berger et al. 2008). At the resource layout level, Smart Robot Tooling concept (see Figure-7) is introduced in this paper which takes into account the machining using the cost efficient resources like robots. The employment of robot for machining operations requires different machining strategies, parameters, applications and settings compared to a CNC machine. As a plug-and-produce solution, the industrial robot machining cell is not limited to any specific manufacturing technology. It can be reconfigured for assembly and joining applications as well as transportation of materials and workpiece in its working area possibly by crossing or linking with other cells. The configuration or reconfiguration of machining cells based on industrial robots is less challenging than rearranging of CNC machines in machining centres or machining parks. The limitations that hinders the industrial robot to be used for machining application is the lack of its absolute pose accuracy, the discrepancy between offline robot programming and the actual path followed by robots to accomplish any task.

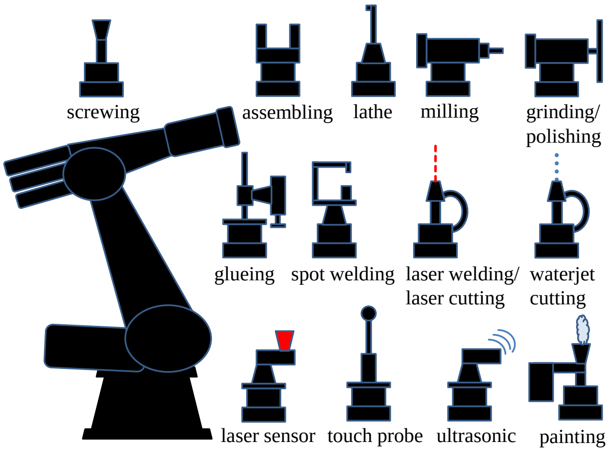

Figure 7 – Smart Robot Tooling Concept

Additionally, the huge cloud of program points is generated for machining operations. The robot stability problems generates process forces and the slow processing time of measured data and feedback loops in high speed robotic motions (Wang et al., 2009). The introduced Smart Robot Tooling concept envisaged to reconfigure the robot for new applications and help reducing high changeover and development costs associated with the reconfiguration process. The quick reconfiguration of robot requires a hybrid concept. This hybrid concept incorporates the model based and sensor base solutions. The model based solution handles each single robot as a single entity. It can be achieved by first measuring the robot characteristics (e. g. tolerances and accuracy) and its behaviour (e. g. process forces) to be stored in a database. It is particularly useful in a situation when the robots are exchanged or replaced to transform or scale production setups. All the necessary information is taken from the database to ensure accuracy in the reconfiguration process. The sensor based compensation will eliminate differences between the desired and actual position of robot. Positioning errors below the robot physically accuracy due to the created non-static process forces by the milling tool, should also be compensated to achieve the same level of machining quality as CNC machine delivers. These desired high speed movements for compensating the described errors require a high speed dynamic and stiffness piezo actuated platform.

4. CONCLUSIONS

The distributed manufacturing systems have emerged as the solution for enhancing agility and responsivity in production systems. Furthermore, the distributed production as well as the customized product specifications, corresponding pool of new materials and processes and time constraints to bring innovations in a shortest possible time demands configuration of the production system at distributed network level based on cost, time and environmental impact of production processes. At the resource level, plug and produce approach should be employed to make the resources quickly ready for customized production. Moreover, resources can be reusable for new applications. The increasing material and process variety will lead OEMs to open up their current body shop production strategy from centralized to a distributed network. This distributed network will be constituted by suppliers and OEMs to develop customized body-in-white in a modularized way. This distributed production network will push manufacturers to make more concrete and effective planning to achieve future strategic goals. Therefore, the configuration of distributed production network must be based on cost, time and potential environment impact of production process at suppliers, OEMs as well as the associated supply chains. Additionally, the use of cost efficient and versatile resources is envisaged to reduce development and setup costs. Furthermore, at resource level, the incorporation of cost efficient resources and their configuration is necessary to achieve productivity in customized production.

5. ACKNOWLEDGMENTS

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