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Enhancing Productivity through Integrated Intelligent Methodology in Automated Production Environment

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1. Introduction

The highly competitive globalized market of today has compelled the manufacturers to enhance not only the quality of their products but also to reduce production costs. The production costs reduction (minimization of the use of resources) together with best technological exploitation has become the biggest challenge for them to enhance their productivity. This has emerged a new setup wherein increased customization, product proliferation, heterogeneous markets, shorter product life cycle and development time, responsiveness, and other factors are increasingly taking centre stage (Bollinger, 1998). Up to now, the classical meaning of productivity in the production environment is more to minimize or efficient resource utilization but global competition has drastically changed the meaning of this term. Now manufacturers are striving hard to focus their attention towards best technological exploitation of resources to achieve effectiveness. Effectiveness can be defined as the way in which the industry meets the dynamic needs and expectations of customers. The exploitation leads to systematic planning, quick and robust decision making, precise process modelling and above all the intelligent process monitoring and production control through precise and real time information exchange among different agents of the production system. But resources and technologies cannot be fully exploited due to the complexity of the production system and diversified and highly dynamic processes. This in turn also limits the systematic collection, characterization and the effective and efficient exploitation of knowledge for precise system and process adaptation as well as for robust decision making. Productivity is now dependent on the value and the range of the products and services as well as the efficiency with which they are produced and delivered to the system. This is the main aspect of the holistic concept for enhancing productivity. The globalization of the manufacturing industry and the intense competition to lead or survive in the market require a much broader conception of productivity enhancement methodologies either or together employed internally and externally to the industry. A comprehensive picture of these productivity enhancement methodologies in the different

sub domain of the whole production system is illustrated in detail in the form of integrated intelligent methodology.
This chapter provides an integrated intelligent methodology for developing a mechanism among different agents of the production system to enhance productivity indirectly. In order to practically demonstrate the mechanism for enhancing productivity, two different application examples from the complete production domain are selected. This domain covers the manufacturing and assembly processes. In manufacturing domain, it is practically investigated the influence of better structuring of knowledge and effective knowledge exchange for the effective optimization of a process chain to produce compressor parts. In joining area, the widespread and systematic knowledge sharing among different agents of the production plant is formulated and implemented to influence productivity through a concept of intelligent production control for joining car body in white parts. The effective knowledge sharing with the process model, automatically updating the influential process parameters for enhancing precision in the process model and achievement of better quality of knowledge guidance for the assembly floor staff is described with the application example of adhesive bonding of car body parts. The investigations and the results from these two distinct examples are merged together to generate the integrated methodology based on intelligent approach for productivity enhancement.
For structuring, characterization and sharing relevant engineering data generated during manufacturing and assembling processes, a technology data catalogue (TDC) is developed. It is used for updating or influencing governing parameters for effective control in the production system. In manufacturing domain, an innovative methodology for process chain optimization is described. In assembly domain, the role of intelligence through knowledge characterization, precise knowledge acquisition for intelligent updating the process models and its use in an automated production setup configuration, on process parameter adaptation and real time corrections for quality assurance is comprehensively described.

2. Situational Analysis and Problem Identification

Currently, diversified productivity enhancement methodologies are being practised in the industry. In this regard, two case studies have been carried out to investigate productivity improvement potential in the production domain; this domain covers the manufacturing of aero engines components and the automotive assembly.
The actual state of aero engines is the result of considerable progress in materials, manufacturing and surface technologies supporting and completing the improvements achieved in design, aerodynamics and thermodynamics (Steffens and Wilhelm, 2008). One example is the introduction of the titanium-alloys in the early 1960 that enabled the design of large fan blades and the design of fast rotating high pressure compressor rotors. This means that the maturity in the design has been reached to a point where the manufacturers are focussing more on productivity in new engine design and their manufacturing. It includes the minimization of costs by several means; the most significant of them is by reducing the number of components, exploiting new materials in the design and fast manufacturing. It is noteworthy to mention here that high speed milling is the most effective way to produce optimum surface finish and geometric accuracy at high metal removal rates. Highly complex components, e.g. compressor bladed disks (blisks), are milled on 5 or 6-axis machines. The productivity in their manufacturing is being achieved by the effective

interaction of an advanced CNC control, optimum tools and clamping devices and an effective coolant lubricant system. Up to now, an optimized milling strategy is needed to minimize machining times, optimize aerodynamically defined surfaces and reduce machining costs (Steffens and Wilhelm, 2008). Blisks can be termed as the combination of aerodynamically defined surfaces. According to Bußmann, Kraus and Bayer (2005), Blisks (bladed integrated disks) or IBRs (bladed integrated rotors) are some of the most innovative and challenging components in modern gas turbine engines. Some of the advantages using blisks are that they reduce weight by 20% and improve efficiency, compared with the conventional blade assembled disk. The weight saving is a result of lower rim loads, the elimination of blade roots and disks lugs and the compression of more performance in the same design and weight cover. The weight reduction and the consequent material economization is a step towards productivity enhancement. Productivity issue has become very critical in blisks manufacturing due to the significant ramp up of their forecasted demand within the next twelve years in Europe as well as in USA, for civil and military proposes (see Figure 1). The increasing blisk market is pushing the continuous improvement of manufacturing processes, the development of new manufacturing strategies and, furthermore, the development of process chains (Bußmann & Bayer, 2008).

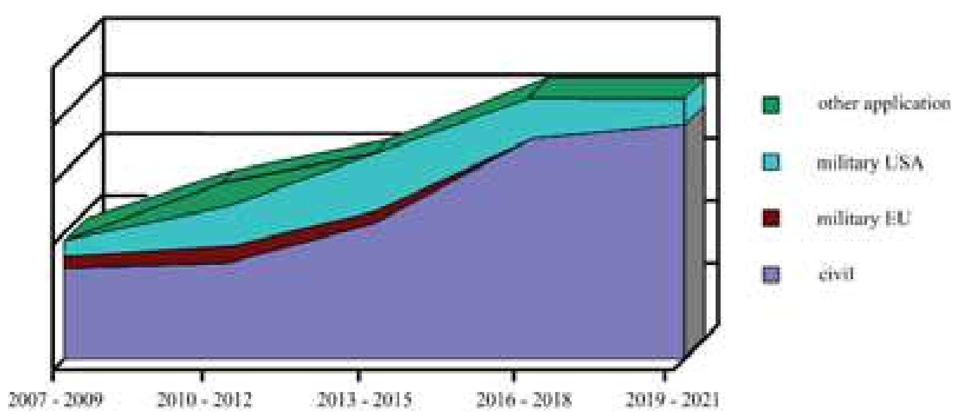

Fig. 1. Blisk Market forecast

The process chain development of a complex geometry is defined by its design features. The engineering activities in design are product design, engineering analysis and the design documentation; while the engineering activities in manufacturing are the process planning, the NC part programming, among several other activities. For the last several years, CAD/CAM is being used for the engineering activities in design and manufacturing, as productive tools. In this context, CAD/CAM is not only meant for automating certain activities of design and manufacturing, but also for automating the transition from design to manufacturing (Nasr & Kamrani, 2007). As part of the process plan, the NC part program is generated automatically by CAD/CAM; the automatically program generation takes place only after the manual introduction of a great number of parameters, such as: the tool, the type of machining, the machining strategies, the process parameters, etc. Most of process parameters, such as feeds and speeds, are initially defined based on information generated by the tool supplier and the process constraints, such as the maximum spindle speed provided by the machine supplier. To achieve a better machining program, these parameters are often modified directly on the machine at the workshop. The changes are based on the experience of the tool machine operator, who along the years has become an expert on the machine tool and the machining process. Although valuable information about the final machining process is stored on the machine, at the end this information is not retrieved in an intelligent way to be used in future machining operations. The biggest disadvantage appears when the operator leaves the company, thus valuable implicit knowledge is gone, costing a great loss for the industry.

Furthermore, in order to create more accurate NC programs and avoid as possible changes at the workshop the CAM-operator should have on-line knowledge about the manufactured products of the company, and well documented information of successful used cases of machined parts (López de Lacalle Marcaide et al., 2004). According to Sharif Ullah and Harib (2006), manufacturing involves knowledge intensive activities, where the knowledge is often extracted from experimental observations.

Like the manufacturing of aero engine components, the automotive assembly system requires data and knowledge for their precise control and on-process quality assurance to enhance productivity further. There are three main factors that are being considered in productivity enhancement. These are time, cost, quality and flexibility in production systems and in their infrastructure; the most significant of them is production monitoring and control. In the past the main emphasis was made on the material and labour productivity which is then diverted towards resource efficiency through many planning strategies, like the material resource planning to influence productivity and the labour productivity enhancement methodologies. In assembly domain, the productivity until now is being improved through many distinct means, particularly virtual assembly techniques to enable fast ramp up and fast programming of the handling and processing equipment. This has given the automotive manufacturers, in particular, a competitive edge in checking the assembly process virtually prior to the actual assembly process. This is one of the areas where automotive industry is investing lot of money to enhance productivity in terms of production ramp up time, production costs and the flexibility in the production setups. This in turn also expanded the role of digital factory in the automotive assembly where the processing, testing and fabrication of assembly lines as well as their visualization are made using interactive digital factory tools (Schenk et al., 2005). In this context, the virtual reality and assembly simulation are combined for better production planning and worker qualification for enhancing productivity in the industry. In the normal production especially in assembly, the generation of unexpected errors which are unforeseen to human experts can be identified prior to the start of the operation on the line. This is due to the fact that many working parameters like dimensional variations of products, fixtures, sensors detection capabilities and robot repeatability are closely coupled with the 3D environment; it is difficult to anticipate all of the error conditions with their likelihood of occurrence and 3-D state in the work-space (Baydar and Saitou, 2001). Through virtual assembly, these errors and deviations can be foreseen and eliminated well in time before the actual assembly or joining takes place. This is in fact provides the manufacturer a large potential for enhancing productivity.

The other technique being employed in automotive industry is AutoID recognition of parts using RFID which fits best even in fast paced complex automotive assembly environments (Gary and Warren, 2008) compared to the conventional low cost bar codes techniques. Bar code has significantly contributed to the productivity for a quite long time but the increasing number of product variety and relevant processing equipment together with advances in database technology has improved the amount, quality, and timeliness of data in the industry (Schuster et al., 2004) in logistics, supply chain management, quality assurance etc. The innovative technologies of today such as Auto-ID and the Electronic Product Code (EPC) with clusters of interactive sensor networks have created larger data streams of greater complexity. It is estimated that the amount of data generated each year is increasing as much as 40% to 60% for many organizations (Park 2004). The above two examples from the assembly domain depict that the manufacturing industry especially the automotive sector is striving hard for the best technological exploitation and resource utilization for enhancing productivity.

These are few but the more actual technologies that have been employed by the automotive manufacturers of today to improve productivity in fragmented form. The state of the art techniques are being used by almost all the automotive manufacturers for productivity enhancement but still the competition is increasing and manufacturers from the automotive industry are striving hard to be highly responsive to differentiated customer demands. By highly responsive means that they should also be highly flexible as well as productive inside so as to meet the individualized demands in an economical way. The area which is not fully explored and where there is still significant untapped potential for productivity enhancement is the intelligent control of production setups. Intelligent control encompasses intelligent selection of resources and parameter settings as well as the exchange of real time data exchange between different actor sensor units as well as the handling systems that play active role in automotive assembly operations. This enables the effective and real time control. For ensuring the real time control in an effective way, smooth flow of comprehensive and precise information throughout the entire process chain is the main key. It offers a solid base for concrete real time decision making as well as online optimization of resources and processes. The up-to-date information enables analysing the current production status of the production system at any definite time. This includes the resources in operations, resources in idle status, material flow and quality assurance for correct planning and control.

3. Methodology

The proposed integrated intelligent methodology (see Figure 2) has an aim to optimize the process chain design in the manufacturing domain and the assembly process control model in the assembly domain through a common knowledge base, the technology data catalogue. Further, the methodology foresees the update of the process model with new process chain parameters and the selection of machine setup, tools and fixtures and other resources.

The intelligent methodology is devised on the following characteristics:

- Highly knowledge driven platform such as technology data catalogue containing the systematic production parameters and functional correlations and coherencies
- Intelligent modelling methods dealing with multi-variant parameter correlations and production control parameters considering their interdependencies
- Highly flexible and applicable control methodology taking all technical specifications and functionalities and capable of fast and smooth ramp up of new technologies, processes and ensure direct and effective on-process quality assurance

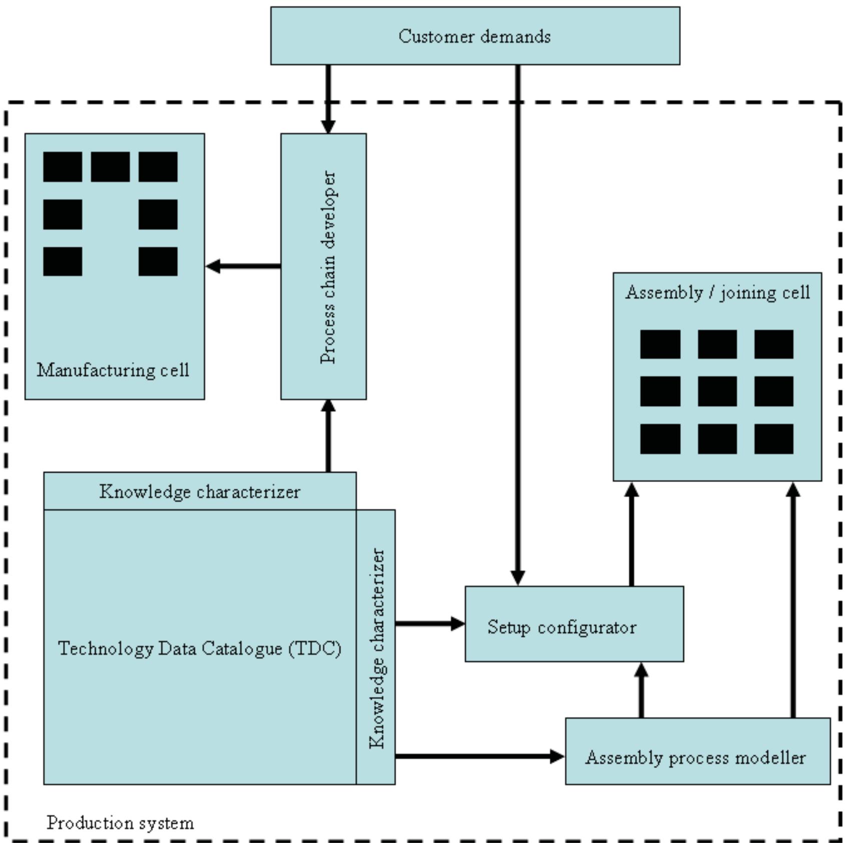

Fig. 2. Schematics for an integrated intelligent methodology

This integrated methodology was practically implemented and demonstrated in two European research projects EU FP6 HYMOULD (http://www.hymould.eu/) and EU FP6 FUTURA (http://www.futura-ip.eu/).
The process chain developer is elaborated further in the case study 1; while the functionalities of the setup configurator and the assembly process modeller are discussed in the case study 2 in the following sections.

3.1 Main component: Technology Data Catalogue

Intensive, precise and effective information exchange plays a vital role in successful running of the processes and activities in the production system. This information can be exchanged formally within the boundaries of defined mechanisms, such as structured methods and formal processes; or informally; and both horizontally, e.g. cross-functional, and vertically within the organization (Perks, 2000; Van der Bij et al., 2003; Calabrese, 1999). Moreover, management can determine knowledge sharing by implementing formal procedures for guiding information flows; moreover, there are mechanisms which can originate such process (Berends et al., 2006). Nevertheless, sharing knowledge among members of a big organization may be a complex activity. And as long as the knowledge is not shared, can not be exploited by the organization (Choo, 1996).

To make this complex activity simpler and enable better exploitation of the knowledge for precise process planning, optimal parameter settings, automatic control program selection and intelligent selection of resources, it is proposed the design and development of a technology data catalogue (TDC) as a main component of the integrated methodology. The main aims of the TDC are collecting, retrieving, structuring, processing and sharing relevant engineering data/information in an intelligent way. The TDC will also provide structured information about the "best-practice" settings of the manufacturing system. Data sources have to be defined and a suitable knowledge representation structure has to be created in order to store the relevant implicit and explicit knowledge generated at the different levels of companies (Minhas et al., 2008).
The TDC constitutes the following:
1) A database with shared terms (concepts, instances, attributes, etc.). The relationship between terms (parameters) will be assured through the axiomatic design theory.
2) Translators will match the conceptual terms coming from different sources ensuring the coherence of the exchange of data between the systems and the TDC. In the literature, translators have already been proposed and successfully tested, e.g. in Goossenaerts and Pelletier (2001).
3) Filters will enable sorting out information that better match the requested technology (Lepratti, 2005; Basson et al., 2004).
4) Characterizer (Berger et al., 2008): required information is selected from different databases and sources, and characterized based on its maturity. Highly mature knowledge is stored in the TDC. The characterization based on maturity considers the standardization, amount of synonyms, visualization, source, etc. (see Figure 3) of the terms and the topics.

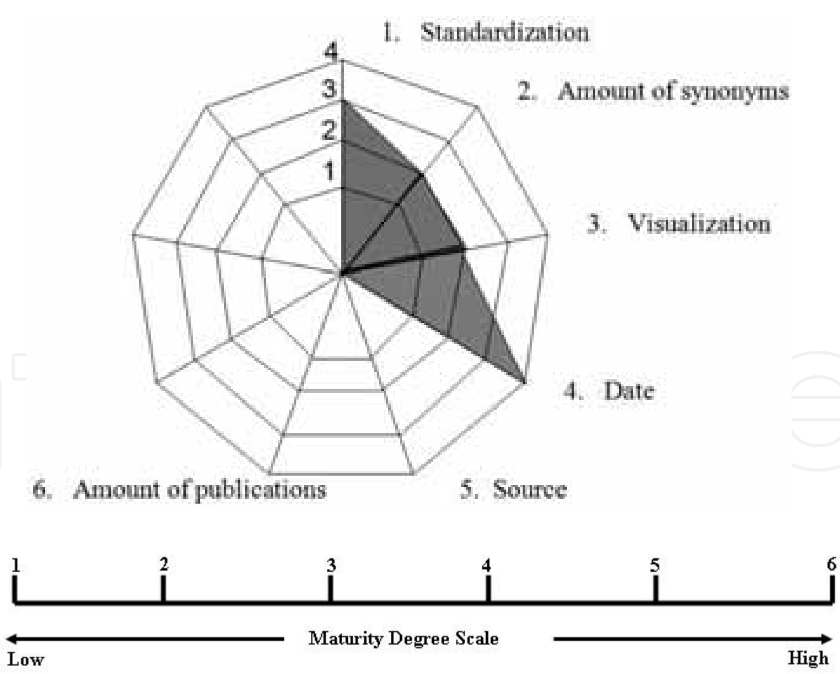

Fig. 3. Characterization criteria and maturity degree scale

For instance, if there is a technical term, which is considered standard then it gets 3 points on a maturity degree scale. If some synonyms for this standardized technical term are available, then the information quality is higher. If the information was originated at recent date then the information gets more points e.g. 4 points: 2007-2006, 3 points: 2005 -2003, 2 points: 2002 – 2000, 1 point: 1999… Sources can come from theory and practice. If theory is proved through practice, this concept meets the criteria to get 4 points. If the knowledge carries visualization and amount of publications, then the knowledge will get more points compared to the one that was merely originated from theory.

3.2 Other Components

The process chain developer is based on the axiomatic design methodology. Axiomatic design presents many advantages compare with other methodologies like TRIZ and the Taguchi Method (Hu et al. 2000). It provides a good structuring and quantitative modelling for coupled, uncoupled and decoupled design. Moreover, through axiomatic design the process chain can be mathematically modelled which assures precision, and the iterative trial and error process can be minimized which saves a significant amount of time, thus gaining higher productivity. The process chain developer communicates with the technology data catalogue through the knowledge characterizer component to gain parameters for the machine setup such as tools, fixtures, coolants and lubricants.

Furthermore, the relevant process parameters which are exchanged between the process chain developer and the knowledge characterizer are the feed rates and cutting speeds for specific features and milling operation; these process parameters are extracted from successful past used cases or projects and stored in the technology data catalogue after being classified by the knowledge characterizer. The precise information exchange is enabled and consequently the time for process chain development and the setup time are minimized.

The main role of assembly modeller is to extract the assembly process parameters and their values from the knowledge characterizer and then finally generate assembly process control programs. This strategy is adopted to ensure high precision in control programs which in turn eliminates the risk of reworking or using the wrong programs and the consequent malfunctioning of the assembly devices as well as the low product quality. The same concept can be mapped to the manufacturing cell, i.e. machining cell where machine programs will be precisely generated through automatic guidance from the knowledge characterizer. As a result, the time for programming and updating will be reduced to a significant level and likewise the implied costs. Precise programs will also influence the process quality outcomes to the greater extent and part/product rejection rates will be lowered eventually.

The assembly process modeller will provide the input to the setup configurator as well as direct control program will be loaded to the assembly cell. The setup configurator after analysing the customer demands configures the assembly cell and set parameters corresponding to the assembly tasks and their control functions being performed in the cell. This enables the configuration/reconfiguration of the cell through software means which enables flexibility. Easy configuration of the cell will enhance productivity in setup time reduction or assembling new components/parts; a step towards fast ramp up. The most salient feature of this integrated methodology is that it simultaneously addresses the time, cost, and quality together with flexible way of adapting production setups and utilizing resources.

4. Case Study 1: Enhancing Productivity in the Manufacturing Domain

The state of the art for productivity enhancement in the manufacturing industry is partly described in the section 2. It was deduced that there is still a need for new manufacturing strategies, as well as, for optimal process chain development. It is necessitated a formal methodology for extracting and then exploiting the useful knowledge from the used cases or projects.
The case study being described here addresses these issues by taking an example of the manufacturing process of bladed integrated disks (blisks). This case study presents a process chain developer able to design an optimized process chain for the production of blisks that will contribute to the enhancement of productivity in the manufacturing domain. The process chain developer is made on the axiomatic design methodology. While the axiomatic design methodology is providing structure to the process chain, the technology data catalogue, main component of the previously described integrated methodology, is providing all data needed for the integrated process chain (see Figure 4). The input data for the process chain developer is coming from the customer needs, i.e. the requested part or design, generally generated as 3D geometry in CAD, and its respective material. The output is the optimized process chain with all process parameters for the manufacturing cell.

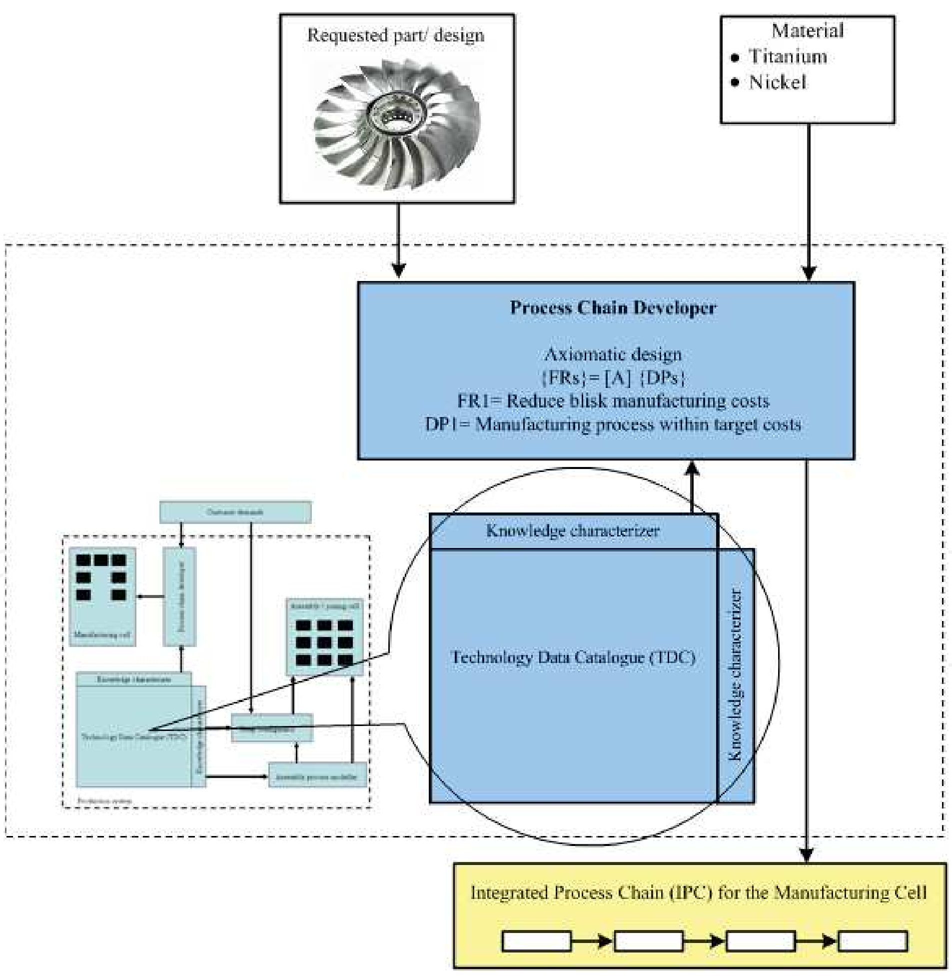

Fig. 4. Interaction between the process chain developer and the TDC

4.1 Production of Blisk Airfoils

Bußmann et al. (2005) affirmed that the optimum blisk manufacturing process, from technical and commercial point of views, depends on material, geometric and aerodynamic parameters; furthermore, they proposed a toolbox-approach that may provide the optimum technology or combination of technologies which may satisfy current and anticipated requirements. Since the disk body involves conventional cutting, surface compactness and finishing, processes where a sufficient amount of experience has been achieved through the production of the conventional blade assembled disk, the toolbox-approach is utilizable specifically for airfoiling.

To produce blisk airfoils, three manufacturing processes are commonly used depending on the airfoil size and the resistance of the material to be machined (Bußmann et al., 2005):

- Milling the entire airfoil from the solid; the gas duct area between the airfoils is also milled. This process is applicable for medium-diameter blisks and medium blade counts, and for titanium blisks in the low pressure compressor (LPC) and in the intermediate pressure compressor (IPC) section.
- Joining blade and disk together by linear friction welding (LFW) or inductive high frequency pressure welding (IHFP) and subsequently using adaptive milling to remove expelled material; the gas duct area between the airfoils is also milled. This process is applicable for large-diameter blisks, hollow-blade blisk, blisk with large chamber volumes, where the process is suitable to save raw material costs, and for blisks with few blades; and primary for titanium blisks in the low pressure compressor (LPC) section
- Removing material through electrochemical machining (ECM) or precise electrochemical machining (PECM). This process is applicable for medium to small-diameter blisks, high number of blades, and for the hotter sections of the high pressure compressor (HPC) of nickel alloys and nickel powder metallic materials or sintered materials.

4.2 Axiomatic System Design Framework

Axiomatic design is a methodology created by N. P. Suh (Suh, 1990) that endows designers with the scientific basis for the design of engineering systems. Additionally, axiomatic design enhances creativity, minimize the iterative trial-and-error process, express the process design mathematically and, moreover, determine the best design. Suh defined design as an activity that "involves interplay between what we want to achieve and how we choose to satisfy the need (the what)" and four domains that delineate four different design activities (Suh, 2001): the customer domain, the functional domain, the physical domain, and the process domain (see Figure 5).

The customer domain is characterized by attributes or the needs that the customer seeks in a product, or a process or a system; in the functional domain the needs are defined based on functional requirements (FRs) and constraints (Cs); in the physical domain the design parameter (DPs) that satisfy the specified FRs are described; finally, in the process domain manufacturing process variables (PVs) are characterized and a process based on the PVs that can produce the DPs is developed. Constraints (Cs) provide the limits on the acceptable design. The difference between Cs and FRs is that Cs do not have to be independent as the FRs.

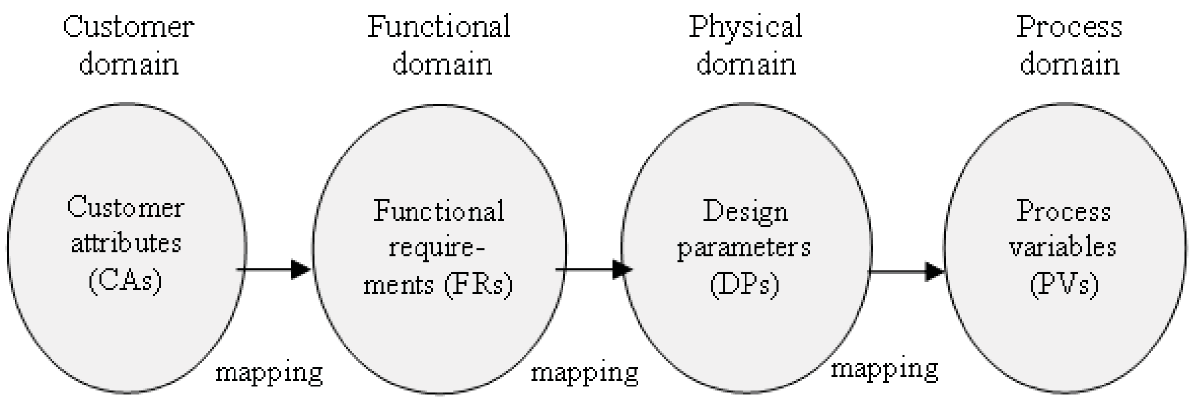

Fig. 5. Axiomatic design domains

The axiomatic design starts by the identification and definition of the customer attributes or needs, and then their translation into functional requirements; this involves a mapping process from the customer domain to the functional domain. Then a mapping process between functional domain and the physical domain follows to satisfy the customer needs; this process is also called zigzagging method. This method allows creating hierarchies for FRs, DPs, and PVs in each domain. During the mapping process, there can be found many possible DPs; the key DPs are selected for the design according to two design axioms. The mapping process can be expressed mathematically in terms of vectors; that is, a vector of FRs can be related to a vector of DPs according to the following equation:

$$\{FR\} = [A]\,\{DP\} \tag{1}$$

where [A] is the design matrix that indicates a relation between a DP and a FR.
The elements of the matrix are represented with a "0" if there is no effect and with an "X" if there is an effect and later on substitute by other values.
Moreover, when all Aij are equal to zero except those where i=j then the design matrix is defined as diagonal and the design is called uncoupled design; where each of the FRs can be satisfied independently by means of one DP. And when the upper triangular elements are equal to zero then the design matrix is defined as a lower triangular and the design is called decoupled design; where the independence of FRs can be assured only if the DPs are defined in the right sequence. In any other case, the design matrix is defined as a full matrix and the design called coupled, which is the most undesired design.

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix} \tag{2}$$

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ X & X & X \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix} \tag{3}$$

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} X & 0 & X \\ X & X & 0 \\ X & X & X \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix} \quad (4)$$

(2) Diagonal matrix/ uncoupled design, (3) triangular matrix/ decoupled design, and (4) full matrix/ coupled design

4.3 Process Chain Developer

Initially, the process chain developer must identify the customer need or attribute (CA) and then translate them into functional requirements which must be fulfilled by design parameters. As it was described in the last section, blisks are not completely accepted by the customers because their manufacturing costs are still higher than the ones for the blade-disk joints (Steffens and Wilhelm, 2008). Thus, the main customer attribute at this point is defined as the minimization of blisk costs. According to this CA, the first level functional requirement (FR) and the respective design parameter (DP) are decomposed as follows:
FR1 Reduce blisk manufacturing costs
DP1 Manufacturing process within target costs
Further, blisk manufacturing costs are split into three main categories (Bußmann, et al., 2005): the material costs, the airfoiling process cost and other manufacturing and quality assurance costs. Thus, the next decomposition is as follows:
FR11 Minimize quality assurance costs
DP11 Steady process to target design specifications
FR12 Minimize airfoiling process costs
DP12 Airfoiling processes optimization
FR13 Minimize material costs
DP13 Optimum material utilization
The design equation representing the interaction between the FRs and DPs is as follows:

$$\begin{Bmatrix} FR11 \\ FR12 \\ FR13 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ X & X & X \end{bmatrix} \begin{Bmatrix} DP11 \\ DP12 \\ DP13 \end{Bmatrix} \quad (5)$$

where [A] is a triangular matrix, thus a decoupled design.
For the further decomposition of functional requirements and design parameters, material and process parameters which may have influence on the cost and delivery time of blisks are analysed. These parameters are summarized in the table 1 (Esslinger and Helm, 2003). The material costs are directly correlated to the blisk costs, as pointed in table 1; although they are external costs that can be minimized only by the material supplier, they are partially considered in the development of the process chain since a better utilization of the resources can enhance some reduction of costs. The other material parameter, the material data quality, is being ensured by the knowledge characterizer of the technology data catalogue.

Material parameters	Cost and time of delivery
Material costs	Relevant
Material data quality	Relevant
Process parameters	Cost and time of delivery
Process stability	Relevant
Number of steps and their duration	Relevant
Availability of process simulation	Relevant

Table 1. Correlation between material and process parameters and customers´ demands

Concerning the process parameters, the process stability is correlated in general to the cost and delivery time of blisks and, in particular to the quality assurance costs since a mature process result in less quality discrepancies. The last process parameter, the availability of process simulation, is guaranteed by the use of CAD/CAM tools, which is considered as a constraint in this process chain development. The decomposition of FR11/DP11 (minimize quality assurance costs/ steady process to target design specifications) is defined as follows:
FR111 Minimize process deviations
DP111 No process adjustments
FR112 Deliver product on time
DP112 Throughout time
FR113 Meet design specifications
DP113 Target surface roughness

$$\begin{Bmatrix} FR111 \\ FR112 \\ FR113 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ X & 0 & X \end{bmatrix} \begin{Bmatrix} DP111 \\ DP112 \\ DP113 \end{Bmatrix} \tag{6}$$

where [A] is a triangular matrix, thus a decoupled design
As it is illustrated in the table 1, the number of steps and their duration are correlated to the blisk costs, thereby an optimized manufacturing process must be designed. Thus the decomposition of FR12/DP12 (minimize airfoiling process costs/ airfoiling processes optimization) is as follows:
FR121 Optimize milling process
DP121 Optimized process chain design
FR122 Optimize joining process
DP122 Optimized joining approach
FR123 Optimize ECM/ PECM process
DP123 Optimized ECM/ PECM approach

$$\begin{Bmatrix} FR121 \\ FR122 \\ FR123 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP121 \\ DP122 \\ DP123 \end{Bmatrix} \tag{7}$$

where [A] is a diagonal matrix, thus an uncoupled design.
As it was pointed out in the previous section, there are three main airfoiling processes for the blisk manufacturing: milling, joining and electrochemical machining (ECM)/precise electrochemical machining (PECM); this case study is focused on the design of an integrated process chain for milling. And because the milling process enhances better results for medium-size range blisks of titanium alloys (Bußmann, et al., 2005) the first constraint is defined as follows:
C1: medium-size blisk made of titanium alloys
Before the milling process can be carried out, a design in CAD is required. Therefore, a second constraint is also defined.
C2: 3D-CAD geometry
The further decomposition of FR13/DP13 (minimize material costs/optimum material utilization) is as follows:
FR131 Increase material data quality
DP131 Precise material data from the knowledge characterizer
FR132 Reduce wasted material during machining
DP132 Minimum number of damaged workpieces/ prototypes

$$\begin{Bmatrix} FR131 \\ FR132 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ X & X \end{bmatrix} \begin{Bmatrix} DP131 \\ DP132 \end{Bmatrix} \tag{8}$$

where [A] is a triangular matrix, thus a decoupled design.
Here, the characteristics of titanium alloys that have an influence on the machinability of the alloy (Janssen, 2003); e.g. the low heat conductivity causes thermal load on the tool cutting edge, while the chemical affinity by high temperatures produces welding between the chip and the tool; are taken in consideration for the process chain design. These material characteristics are relevant for increasing the quality of the material data which will be stored in the technology data catalogue (TDC) after its categorization by the knowledge characterizer. The intelligent gaining of precise material data (DP131) is facilitating the design of the process chain and saving setup times.
A milling approach that integrates a strategy, tools and machines make possible a production time reduction of about 50% (Bußmann et al., 2005), thus the FR121/DP121 (optimize milling process/ optimized process chain design) is decomposed as follows:
FR1211 Define the milling strategy
DP1211 Feature-based design
FR1212 Determine machine and cutting tool
DP1212 Machine and cutting tool selection from the TDC
FR1213 Generate process parameters
DP1213 Feeds and speeds selection from the TDC

$$\begin{Bmatrix} FR1211 \\ FR1212 \\ FR1213 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ X & X & X \end{bmatrix} \begin{Bmatrix} DP1211 \\ DP1212 \\ DP1213 \end{Bmatrix} \tag{9}$$

where [A] is a triangular matrix, thus a decoupled design
One of the advantages of feature-based designing is that the features can be associated to machining processes which are further related to process resources (machines, tools, fixtures and auxiliary materials), process kinematics (tool access direction), process constraints (interference and spindle power), process parameters (feeds and speeds) and other information, such as time and costs. Thus, enabling the creation of, what in the literature is called, a feature-based manufacturing knowledge repository (Nasr and Kamrani, 2007) and what in this chapter was defined as technology data catalogue and further extended with a knowledge characterizer to assure the precision of the data.
The optimized process chain is finally developed taking all relevant process parameters: feed rate and cutting speed for the specific feature and milling operation; these process parameters, stored from successful past used cases or projects, are retrieved from the technology data catalogue (TDC) through the knowledge characterizer. The structuring of knowledge and precise knowledge exchange is enhancing effective optimization of a process chain to produce bladed integrated disks (blisks). This optimal chain development with high precision will eliminate redesigning and the trial and error in the process chain which eventually minimizes time and cost. Consequently, a more productive process chain development is achieved.

5. Case Study 2: Enhancing Productivity in the Assembly Domain

The state of the art strategies for making the assembly systems more productive are discussed in the section 2 in fragmented form. It is concluded that the high mass customization has induced the complexities in terms of efficient and intelligent utilization of resources, precise modelling of assembling processes and reliable and effective quality control.
The case study being described here was made on the assembly process of automotive body in white. In this case, the innovative joining process adhesive bonding of car body parts is taken as an example. Adhesive bonding has a strong potential in the car body assembly which has made the joining of different multifunctional materials possible. The objective of this case study is to investigate the possibility of increasing productivity in assembly process with the following targets

- Efficient resource utilization with the easy and fast ramp up of joining parts in the flexible cell
- Precise modelling of the assembly process and automatic updating with the precise knowledge (experienced knowledge from the used cases)
- Intelligent selection and parameter settings of assembly setups and using the same setup for multipurpose applications (Setup cost and time reduction)

5.1 Adhesive Bonding Process

Taking adhesive bonding as an example, for joining tasks, the process control sequence and the relevant program is generated by the process modeller after extracting accurate process parameters for the joining process parameters, e.g. adhesive dispensing rate, robot application speed, etc.

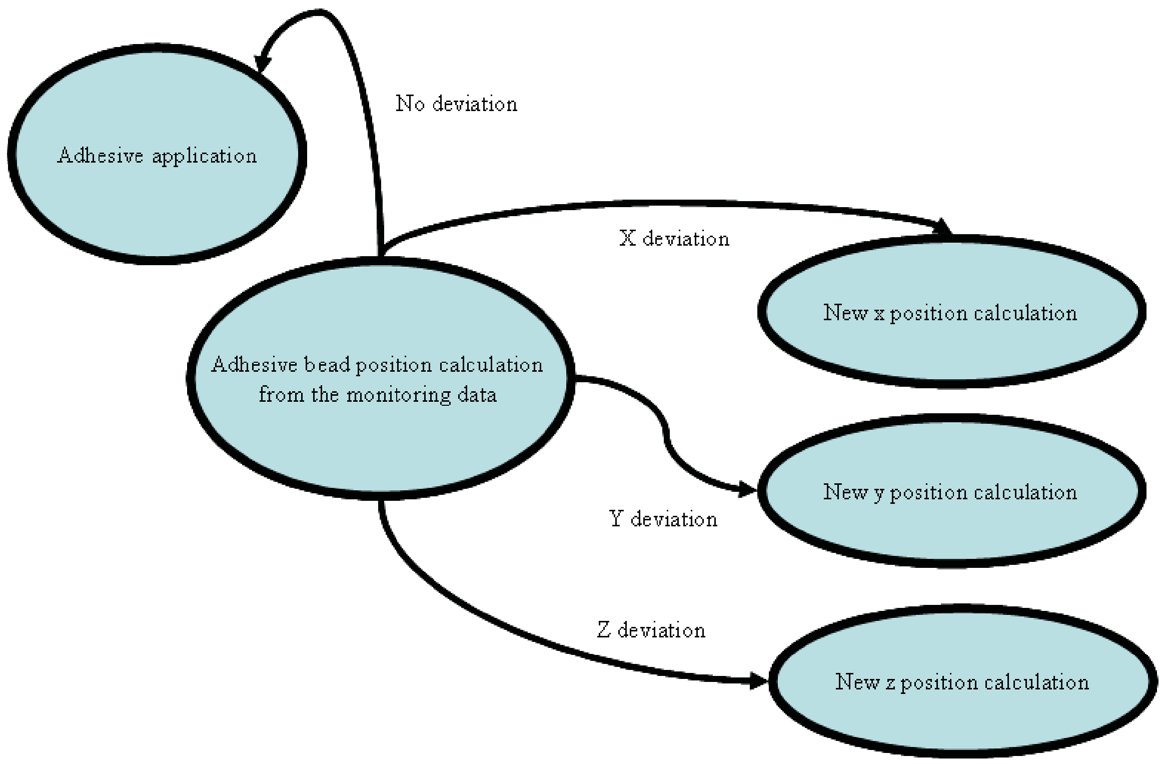

Fig. 6. Computation of adhesive positioning with hybrid automata

Figure 6 shows a part of block program that is modelled using the concept of hybrid automata (Henzinger, 1996; Branicky et al., 1998). The intelligence can play its active role in setting up guard conditions in the modelled program. As an example the information about the guard conditions corresponding to the actual process conditions can be extracted from the knowledge characterizer while switching from the discrete steps to the continuous states for calculations such as the position calculations from the monitoring data coming from the sensors to the process model for the actual quality of adhesive bead, i.e. its form and position. The knowledge characterizer will provide the necessary process parameters i.e. dispensing pressure, temperature, robot speed, nozzle valve actuation frequency and its operating timings. This procedure of modelling though hybrid automata helps in eliminating risks and ensures precise process control that can be used in real time situation at the assembly cell level thereby enhancing process reliability and productivity. The process flow diagram (control program) of adhesive bonding station is shown in the following figure 7. The process flow contains many feedback loops and computations after extracting monitoring data from the sensors. These feedback loops are activated using parameters from the knowledge characterizer and the conditions sett by the TDC.
The significant task of the process modeller is that it is automatically updates the process model through the real time exchange of data with the knowledge characterizer. It saves setting up time in a case where there is significant change of variants in the cell, which are then to be assembled enabling fast automatic adaptation of control programs. It makes the process modelling and programming activity in the assembly more productive in terms of time and cost. Moreover precise process modelling through extensive knowledge exchange with the knowledge characterizer helps in achieving higher quality, thereby making this activity more productive in terms of process reliability.

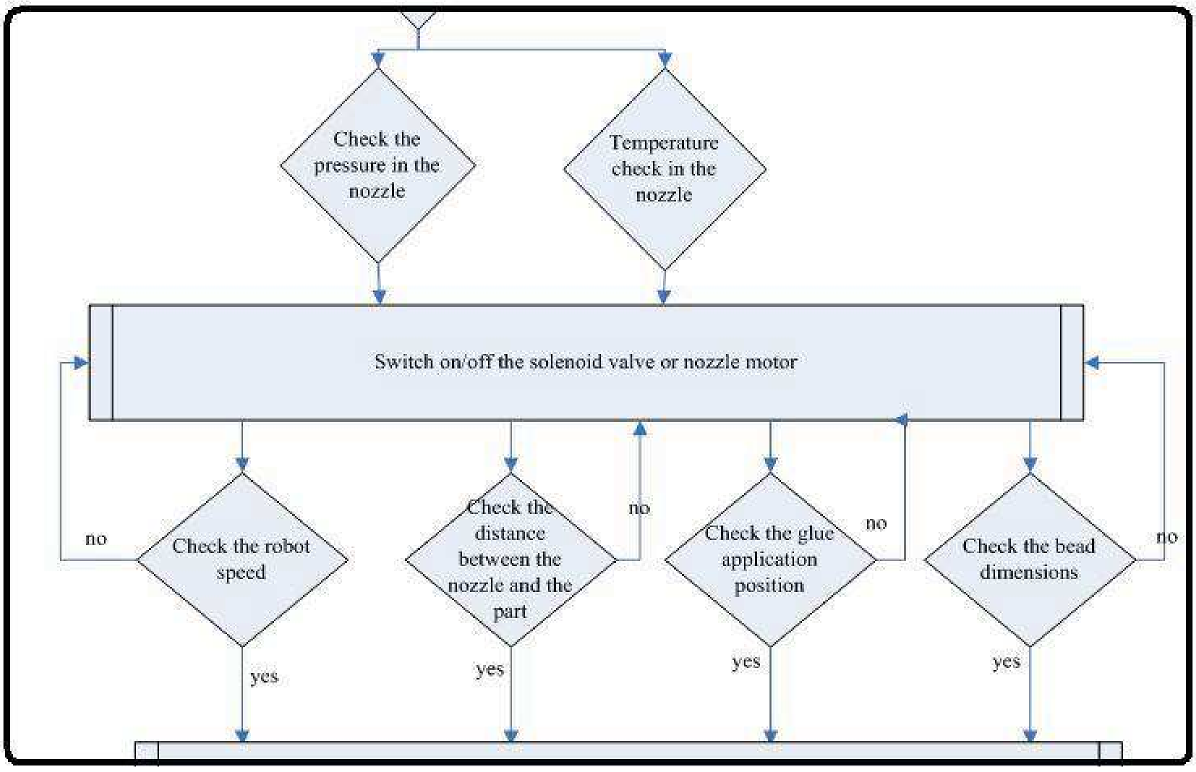

Fig. 7. Process flow diagram (part) for robot guided adhesive bonding application

Flexibility in terms of resource selection and production setup configuration is one of the most influential factors in enhancing productivity. The more is the system flexible, the greater is the system productive, provided the system is subjected to the mass customization. For simplicity, this case study is carried out using the example of multisensory monitoring of adhesive bonding process for demonstrating effective and on-process quality assurance. It enables enhanced process and the resulting product quality.

5.2 Multipurpose Multisensory Setup

The investigation for fast adaptation of production setups is made using the case of adaptation of multisensory setup that can be adaptable for different assembly processes in the assembly cell (see Figure 8).

The sensors are selected in the network relevant to the joining process by the setup configurator and the controller manages the monitoring data exchange with the main controller for real time process control.

The selection of sensors can be made using the following methodologies

1. Cost functions
2. Axiomatic design approach (Houshmand M. & Jamshidnezhad B., 2002; Igata, 1996)
3. Algorithms known from cognitive mapping theory (Zhang et al., 1992)

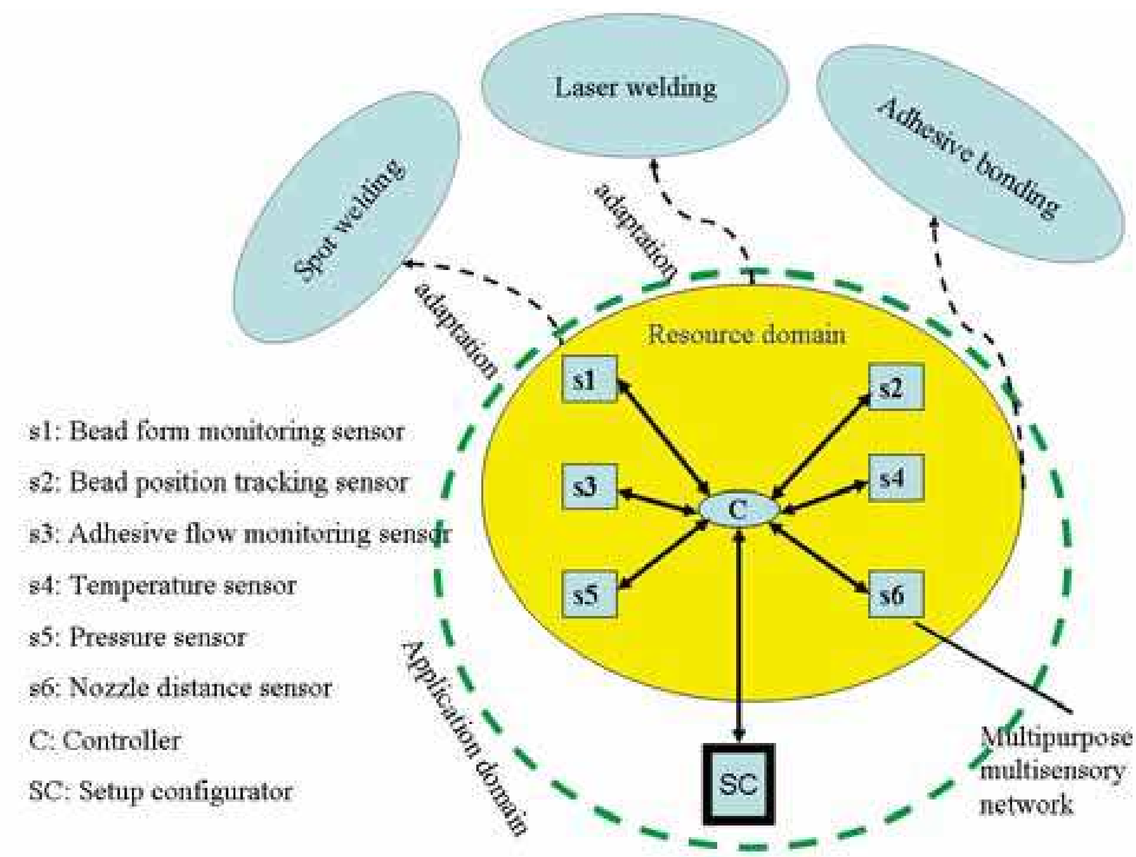

Fig. 8. Schematics of multi-purpose multisensory network

Cost function based evaluation methodology is simpler compared to the other two methodologies, but it has widespread use as it can be employed not only for the static activation of sensors but also for the dynamic activation of sensors in the network. The selection of sensors corresponding to process parameters can be made using the following algebraic equations. From figure 8, if there are n sensors in the networks with n set of characteristics implies:

		Sensor	
S_1,	S_2,	S_3, S_4…………………	S_n
Characteristics	Characteristics		Characteristics
E_1	E_1		E_1
E_2	E_2		E_2
E_3	E_3		E_3
E_4	E_4		E_4
.	.		.
.	.		.
.	.		.
..	.		.
.	..	…………	..
.	.		.
E_n	E_n		E_n

(10)

where S_1, S_2, S_3,…….., S_n are the sensors in the network with the characteristics E_1, E_2, E_3…… E_n respectively and calculation of cost function can be made in the following way:

$$W_1 = w_{e1} + w_{e2} + w_{e3} + \ldots\ldots\ldots\ldots + w_{en} \quad (11)$$
$$W_2 = w_{e1} + w_{e2} + w_{e3} + \ldots\ldots\ldots\ldots + w_{en}$$
$$W_3 = w_{e1} + w_{e2} + w_{e3} + \ldots\ldots\ldots\ldots + w_{en}$$
$$\vdots$$
$$W_n = w_{e1} + w_{e2} + w_{e3} + \ldots\ldots\ldots\ldots + w_{en}$$

where W_1, W_2, W_3,……,W_n are the evaluated weights of S_1, S_2, S_3,…….,S_n respectively based on the weights of their characteristics w_{e1}, w_{e2},w_{e3},…………….,w_{en}.
Finally the sensors are selected after the sensor weights evaluated corresponding to their suitability for process parameter measurement by the following equations:

$$M(P_1) = W_1S_1 + W_2S_2 + W_3S_3 + \ldots\ldots\ldots + W_nS_n \quad (12)$$
$$M(P_2) = W_1S_1 + W_2S_2 + W_3S_3 + \ldots\ldots\ldots + W_nS_n$$
$$M(P_3) = W_1S_1 + W_2S_2 + W_3S_3 + \ldots\ldots\ldots + W_nS_n$$
$$\vdots$$
$$M(P_n) = W_1S_1 + W_2S_2 + W_3S_3 + \ldots\ldots\ldots + W_nS_n$$

where $M(P_1)$, $M(P_2)$,…………., $M(P_n)$ gives the equations of selected sensors suitable for measuring the relevant parameters. The sensors which are not suitable will be given zero weightage, as a result they are automatically eliminated from the equations.
This methodology works well when the mature knowledge about the sensors and their characteristics are available in the TDC. The ramp up of newly developed or the sensors with new technology needs an update in the TDC for reliable selection and their parameter settings.

6. Discussion and conclusions

In this chapter, the intelligent integrated methodology for productivity enhancement has been highlighted. The methodology was discussed using two case studies in the production system. The first one was elaborating the innovative process chain optimization of blisks through axiomatic design approach and the intelligent selection of process parameters from the TDC through the knowledge characterizer; and the second one was discussing the parameter settings and adaptation of assembly process control models of a car body in white parts and finally the configuration/ reconfiguration of the adhesive bonding assembly. Moreover, with this integrated methodology is ensured the effective knowledge sharing with the process model from the knowledge characterizer, automatically updating the influential process parameters for enhancing precision in the process model developed through hybrid automata, achievement of better process and the resulting product quality.
The salient advantage of this integrated methodology is that it addresses all the influential factors of productivity simultaneously. It is noteworthy to mention that this methodology revolves around the technology data catalogue as knowledge base for optimization and

adaptation purposes and this is possible only if the information of the used cases has a high degree of maturity. Furthermore, if the knowledge is not mature or the used cases are not available then the technology data catalogue and the knowledge characterizer can not be so effective and reliable in precise optimization and adaptation. The authors have noticed these limitations and as a next step this integrated methodology will be extended by using concepts and algorithms known from the self learning theory.

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This book, edited by the Intech committee, combines several hotly debated topics in science, engineering, medicine, information technology, environment, economics and management, and provides a scholarly contribution to its further development. In view of the topical importance of, and the great emphasis placed by the emerging needs of the changing world, it was decided to have this special book publication comprise thirty six chapters which focus on multi-disciplinary and inter-disciplinary topics. The inter-disciplinary works were limited in their capacity so a more coherent and constructive alternative was needed. Our expectation is that this book will help fill this gap because it has crossed the disciplinary divide to incorporate contributions from scientists and other specialists. The Intech committee hopes that its book chapters, journal articles, and other activities will help increase knowledge across disciplines and around the world. To that end the committee invites readers to contribute ideas on how best this objective could be accomplished.

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