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Concept of Virtual Manufacturing

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Abstract

Virtual Manufacturing system is a computer system which is utilised to generate the same information about manufacturing system's structure, states and behaviours as we can observe in real manufacturing systems. Virtual reality and virtual manufacturing often concentrate on an interface between VR technology, manufacturing, production theory and practice. It is our belief that the direction of evolution of manufacturing theory and practice will become clearer in the future once the role of VR technology is understood better in developing this interface. Virtual Manufacturing will have a similar effect on the manufacturing phase thanks to the modelling, simulation and optimisation of the product and the processes involved in its fabrication. After a description of Virtual Manufacturing (definitions and scope), we present some socio-economic factors of VM and finally some "hot topics" for the future are proposed.
Keywords- Virtual Reality, Virtual Manufacturing, VR Technologies

I. Introduction

Manufacturing is an indispensable part of the economy and is the central activity that encompasses product, process, resources and plant. Nowadays products are more and more complex, processes are highly-sophisticated and use micro-technology and Mechatronic, the market demand (lot sizes) evolves rapidly so that we need a flexible and agile production. Moreover manufacturing enterprises may be widely distributed geographically and linked conceptually in terms of dependencies and material, information and knowledge flows.

In this complex and evaluative environment, industrialists must know about their processes before trying them in order to get it right the first time. To achieve this goal, the use of a virtual manufacturing environment will provide a computer-based environment to simulate individual manufacturing processes and the total manufacturing enterprise. Virtual Manufacturing systems enable early optimization of cost, quality and time drivers, achieve integrated product, process and resource design and finally achieve early consideration of producibility and affordability. The aim of this paper is to present an updated vision of Virtual Manufacturing (VM) through different aspects. As, since 10 years, several projects and workshops have dealt with the Virtual Manufacturing thematic, we will first define the objectives and the scope of VM and the domains that are concerned. The expected technological benefits of VM will also been presented. In a second part, we will present the socio-economic aspects of VM. This study will take into account the market penetration of several tools with respect to their maturity, the difference in term of effort and level of detail between industrial tools and academic research. Finally the expected economic benefits of VM will be presented. The last part will describe the trends and exploitable results in machine tool industry (research and development towards the 'Virtual Machine Tool'), automotive (Digital Product Creation Process to design the product and the manufacturing process) and aerospace.

II. The Concept of Virtual Manufacturing and its Development

A. *Definition of Virtual Manufacturing*

Virtual Manufacturing is defined as a computer system which is capable of generating information about the structure, states, and behavior of a manufacturing system as can be observed in a real manufacturing environment. In other words, a VM system produce no output such as materials and physical products , but it can produce information about them VM is an integrated computer-based model which represents the physical and logical schema and the behavior of a real manufacturing system.

The manufacturing activities and process are modeled before and sometimes in parallel with the real manufacturing operations in the real world. Always comparison of models with reality and various model maintenance operations are necessary. An interaction between the virtual and real worlds is accomplished by continuous monitoring of the performance of the VM system. In such circumstances as realized by VM it becomes possible to adopt various methods to organize engineering activities from product design to production management.

The term Virtual Manufacturing is now widespread in literature but several definitions are attached to these words. First we have to define the objects that are studied. Virtual manufacturing concepts originate from machining operations and evolve in this manufacturing area. However one can now find a lot of applications in different fields such as casting, forging, sheet metalworking and robotics (mechanisms). The general idea one can find behind most definitions is that "Virtual Manufacturing is nothing but manufacturing in the computer". This short definition comprises two important notions: the process (manufacturing) and the environment (computer). In VM is defined as "manufacture of virtual products defined as an aggregation of computer-based information that provide a representation of the properties and behaviors of an actualized product". Some researchers present VM with respect to virtual reality (VR). On one hand, in VM is represented as a virtual world for manufacturing, on the other hand, one can consider virtual reality as a tool which offers visualization for VM.

Virtual Manufacturing is defined as "an integrated, synthetic manufacturing environment exercised to enhance all levels of decision and control" (Fig 2.1.1)

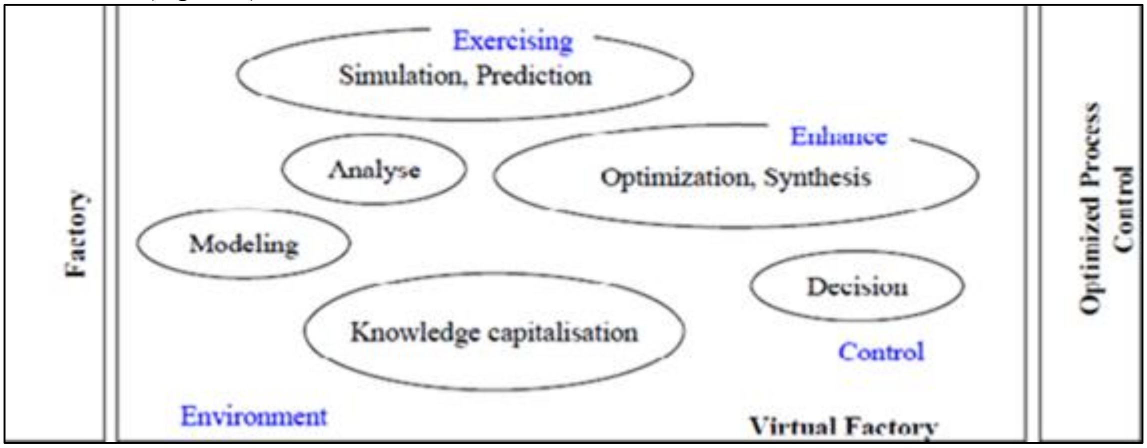

Fig. 2.1.1: Virtual Manufacturing

- Environment: supports the construction, provides tools, models, equipment, methodologies and organizational principles.
- Exercising: constructing and executing specific manufacturing simulations using the environment which can be composed of real and simulated objects, activities and processes.
- Enhance: increase the value, accuracy, validity.
- Levels: from product concept to disposal, from factory equipment to the enterprise and beyond, from material transformation to knowledge transformation.
- Decision: understand the impact of change (visualize, organize, and identify alternatives).

A similar definition has been proposed in: "Virtual Manufacturing is a system, in which the abstract prototypes of manufacturing objects, processes, activities, and principles evolve in a computer-based environment to enhance one or more attributes of the manufacturing process." One can also define VM focusing on available methods and tools that allow a continuous, experimental depiction of production processes and equipment using digital models. Areas that are concerned are

1) Product and process design,
2) Process and production planning,
3) Machine tools, robots and manufacturing system and virtual reality applications in manufacturing.

B. Significance and Application of Virtual Manufacturing

The attractive applications of VM include analysis of the manufacturability of a part and a product, evaluating and validating the feasibility of the production and process plans; optimization of the production process and the performance of the manufacturing system. Since a VM model is established based on real manufacturing facilities and processes, it does not only provide realistic information about the product and its manufacturing processes but also allows for the evaluation and the validation of them. Much iteration can be carried out to arrive at an optimum solution. The modeling and simulation technologies in VM enhance the production flexibility and reduce the fixed costs since no physical conversion of material to product is involved. Apart from these, VM can be used to reliably predict the business risks and this will support the management in decision making and strategic management of an enterprise. Some typical applications of VM are as follows:

- VM can be used in the evaluation of the feasibility of a product design, validation of a production plan, and optimization of the product design and processes. These reduce the cost in product life cycle.
- VM can be used to test and validate the accuracy of the product and process designs. For example, the outlook of a product design, dynamic characteristics analysis, checking for the tool path during machining process, NC program validation, checking for the collision problems in machining and assembly etc.
- With the use of VM on the internet, it is possible to conduct training under a distributed virtual environment for the operations, technicians and management people on the use of manufacturing facilities. The costs of training and production can thus be reduced.
- As a knowledge acquisition vehicle, VM can be used to acquire continuously the manufacturing know-how, traditional manufacturing process, production data etc. This can help to upgrade the level of intelligence of a manufacturing system.

The Benefits derived from VM are as follows:

1) Enhancing the Capability of the Risk Measures and Control

VM can be used to predict the cost of product development and production as well as provide the information related to the production process and the process capability. The information is useful for improving the accuracy of the decisions made by the designer and the management. The problems in product development and manufacturing process can also be predicted and resolved prior to the actual production.

2) Shrinking the product Development Cycle

VM will allow more computer-based product models to be developed and prototyped upstream in the product development process. This will reduce the need for the number of downstream physical prototype traditionally made to validate the product models and new designs. Thus the company can reduce its product development time.

3) Enhancing the Competitive Edge of an Enterprise in the Market

VM can reduce the cycle time and costs in product development. With the virtual environment provided by VM, the customers can take part in the product development process. The design engineers can response more quickly to the customers' queries and hence provide the optimal solution to the customers. The Competitive edge of an enterprise in the market can thus be enhanced.

III. CLASSIFICATION OF VIRTUAL MANUFACTURING

A. Classification Based on Type of System Integration

According to the deifications proposed by Onosato and Iwata, every manufacturing system can be decomposed into two different sub-system: a real and physical system (RPS); and a real informational system (RIS). An RPS is composed of substantial entities such as materials, parts and machines that exist in the real world. An RIS involves the activities of information processing and decision making. A Computer system that simulates the responses of the RPS is called a "virtual physical system" (VPS), whereas that simulates a RIS and generates control commands for the RPS is called "Virtual-informational system" (VIS).

B. Classification Based on Types of Product and Process Design

According to the product design and process design functions, VM can be sub-divided into product design centered VM, production-centered VM and control-centered VM. Product design -centered VM makes use of different virtual designs to produce the production prototype. The related information of a new product (eg product features, tooling, etc) is provided to the designer and the manufacturing system designers for supporting the decision making in the product design process.

Production-centered VM simulates the activities in process development and alternative process plans. It aims at the rapid evolution of a product plan, the operational status of a manufacturing system and even the objectives of the design of the physical system.

Control-centered VM makes use of the VM technology on the dynamic control of the production processes. It aims at the optimization of the production cycles based on the dynamic control of the process parameters.

C. Classification Based on Functional Usage

VM is used in the interactive simulation of various manufacturing process such as virtual prototyping, virtual machining, virtual inspection, virtual assembly and virtual operational system etc.

1) Virtual prototyping (VP) mainly deals with the process, tooling and equipment in casting, blanking, extrusion, injection moulding, etc . VP makes use of modeling and simulation techniques to analyses the factors affecting the process, product quality and hence the material properties, processing time and manufacturing costs. The virtue of VP lies not only in the reduction of the fabrication of physical prototype shortening the product design and presentation through qualitative simulation and analysis. These facilitate the discussion, manipulation and modification of the product data model directly among personnel with different technical backgrounds.
2) Virtual machining mainly deals with cutting processes such as turning, milling, drilling and grinding etc. The VM technology is used to study the factors affecting the quality, machining time and costs based on modeling and simulation of the material removal process as well as the relative motion between the tool and the work piece. It can be used to evaluate the feasibility of a part design and the selection of processing equipment, etc.
3) Virtual inspection makes use of the VM technology to model and simulate the inspection process, and the physical and mechanical properties of the inspection equipment. This aims at studying the inspection methodologies, collision check, inspection plan, factors affecting the accuracy of the inspection process etc.
4) In assembly work VM is mainly used to investigate the assembly process, the mechanical and physical characteristics of the equipment and tooling the inter relationship among different parts and the factors affecting the quality based on modeling and simulation. It can also be used to predict the quality of an assembly, product cycle and costs as well as to evaluate the feasibility of the assembly process plan and the selection of assembly equipment, etc.
5) Virtual operational control makes use of VM technology to investigate the material flow and information flow as well as the factors affecting the operation of a manufacturing system. It can be used to evaluate the design and operational performance of the material flow and information flow system.

IV. THE SCOPE OF VIRTUAL MANUFACTURING

The scope of VM can be to define the product, processes and resources within cost, weight, investment, timing and quality constraints in the context of the plant in a collaborative environment. Three paradigms are proposed in:

A. Design-centered VM

Provides manufacturing information to the designer during the design phase. In this case VM is the use of manufacturing-based simulations to optimize the design of product and processes for a specific manufacturing goal (DFA, quality, flexibility) or the use of simulations of processes to evaluate many production scenario at many levels of fidelity and scope to inform design and production decisions.

B. Production-centered VM

Uses the simulation capability to modelize manufacturing processes with the purpose of allowing inexpensive, fast evaluation of many processing alternatives. From this point of view VM is the production based converse of Integrated Product Process Development (IPPD) which optimizes manufacturing processes and adds analytical production simulation to other integration and analysis.

C. Control-centered VM

Is the addition of simulations to control models and actual processes allowing for seamless simulation for optimization during the actual production cycle. The activities in manufacturing include design, material selection, planning, production, quality assurance, management, and marketing. If the scope takes into account all these activities, we can consider this system as a Virtual Production System. A VM System includes only the part of the activities which leads to a change of the product attributes (geometrical or physical characteristics, mechanical properties,) and/or processes attributes (quality, cost, agility). Then, the scope is viewed in two directions: a horizontal scope along the manufacturing cycle, which involves two phases, design and production phases, and a vertical scope across the enterprise hierarchy. Within the manufacturing cycle, the design includes the part and process design and, the production phase include part production and assembly.

We choose to define the objectives, scope and the domains concerned by the Virtual Manufacturing thanks to the 3D matrix represented in Fig 4.1. Which has been proposed by IWB, Munich.

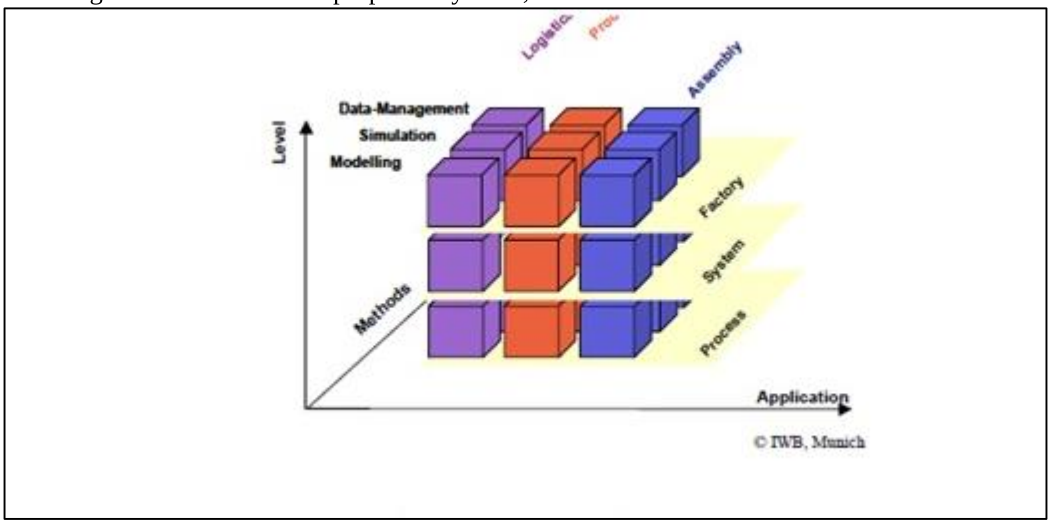

Fig. 4.1: Virtual manufacturing objectives, scopes and domain

The vertical plans represent the three main aspects of manufacturing today: Logistics, Productions and Assembly, which cover all aspects directly related to the manufacturing of industrial goods. The horizontal planes represent the different levels within the factory. At the lowest level (microscopic level), VM has to deal with unit operations, which include the behavior and properties of material, the models of machine tool – cutting tool – workpiece-fixture system. These models are then encapsulated to become VM cells inheriting the characteristics of the lower level plus some extra characteristics from new objects such as a virtual robot. Finally, the macroscopic level (factory level) is derived from all relevant sub-systems. The last axis deals with the methods we can use to achieve VM systems.

V. The Current And Prospective Research Areas

A. Key Technologies Involved in VM

The development of VM demands multi-disciplinary knowledge and technologies related to the hardware and software of the computer, information technology, microelectronics, manufacturing and mathematical computation. Some of these technologies are comparatively mature. However most of them have to be further developed to form an integrated VM platform.

B. Establishment of Virtual Physical Units

The establishment of a virtual physical unit (e.g. a material processing unit , machining unit, inspection unit assembly unit, robot and material delivery devices etc. which mimics the operation of a real physical unit, forms the crucial bases for development of a VM system. The performance of a VM system could be seriously affected by the accuracy, precision and reliability of the information outputs from an individual virtual physical unit.

The establishment of the virtual physical unit includes the integration and management of 3D solid models and models for the simulation of motion and the mechanical properties of the virtual physical units. 3D geometrical solid models and simulation are comparatively mature. There is a number CAD/CAM software and object-oriented programming languages, and image processing software that are available for performing the tasks.

C. Virtual Product Model and Representation

A product model is a generic model used to representing all types of artifacts that appear in the course of manufacturing. It represents target products, their materials and intermediate products, tools and machines and any other manufacturing resources and environmental objects. Those objects have many aspects or views. Due to the rapid development and application of CAD/ CAM technologies and object - oriented computer programming languages the technologies for product modeling, computer representation, product data management (PDM) and engineering data management (EDM) have advanced rapidly. The success of these technologies allows their applications in virtual product modeling, computer representation and virtual PDM.

However, the traditional product modeling and representation methods cannot meet the needs for quantitative analysis of VM process design. For example, non-manifold boundary representation, constructive solid geometry (CSG), state space, feature model, Nerbis synthetic curved surface are widely adopted in model simulation. Even under the consideration of the manufacturing tolerance, they make use of ideal surfaces, regular curved surfaces, and synthetic curved surfaces to represent the product surfaces. These representation methods do not take into consideration the surface roughness of the machined surfaces. Since there are various errors introduced by machine, the surfaces of the actual workpiece are not similar to flat surfaces, regular curved surface or synthetic surface during design. In order to mimic the machining errors and surface quality of the workpiece, there is a need for developing geometrical reorientation methods which are capable of representing the machining errors and surface roughness of the workpiece and deliver this information to CAE and virtual assembly system.

D. Performance Evaluation Technologies for VM

Product design validation is vital to the verification of the functional, reliability, and durability requirements of a given design, whereas processes can best meet the cost and quality goals of a given design. The evaluation of a kind of VM system can be divided into two main streams which are the evaluation of performance of the system and the validation of the related information generated by the VM system for particular product development.

The former determines the functional capability of the VM system. This include the validation of the accuracy of the models , system architecture and the quality of users interfaces, etc The latter evaluates the standard of the product design , manufacturability and associated investment risks during the course of product development by the user. The evaluation methods developed so far mainly included: product manufacturability validation, manufacturing quality analysis, analyses for production cycle, production costs and business risks, etc.

Now a days, most of the research has been found to be limited to a single process. The whole manufacturing system is taken into consideration including integrated analysis of the product life cycle and costs, the difficulties will be large. The current methods might not be mature enough since numerous factors are present in the processes.

The manufacturability of a product includes the feasibility of processing as well as the feasibility of the assembling of the part and product assemblies. It is not only a difficult problem for VM but also for real manufacturing (RM). Although extensive research work has been devoted to investigating this issue, the problems have not yet resolved satisfactorily. Up to the present , most of the proposed methodologies of manufacturability evaluation include the logical determination method for manufacturability or non- manufacturability , the grading method based on the level of difficulties of various process, manufacturing cycle and costing methods, as well as the integrated method based on the manufacturing costs , manufacturing cycle and difficulties of the processes etc. Most of these methods focus on a single process or a specific product. However, VM demands the development of common methods which are appropriate for the evaluation of the whole manufacturing process.

The modelling and simulation techniques for production quality analysis and business risk analysis also form a crucial part in the development of evaluation technologies for VM. Although some successful research studies have been found in these areas, the development is still far from perfect to meet future demands.

VI. EXPECTED BENEFITS

As small modifications in manufacturing can have important effects in terms of cost and quality, Virtual Manufacturing will provide manufacturers with the confidence of knowing that they can deliver quality products to market on time and within the initial budget. The expected benefits of VM are from the product point of view it will reduce time-to-market, reduce the number of physical prototype models, improve quality, in the design phase, VM adds manufacturing information in order to allow simulation of many manufacturing alternatives: one can optimize the design of product and processes for a specific goal (assembly, lean operations) or evaluate many production scenarios at different levels of fidelity, from the production point of view it will reduce material waste, reduce cost of tooling, improve the confidence in the process, lower manufacturing cost in the production phase, VM optimizes manufacturing processes including the physics level and can add analytical production simulation to other integration and analysis technologies to allow high confidence validation of new processes or paradigms. In terms of control, VM can simulate the behavior of the machine tool including the tool and part interaction (geometric and physical analysis), the NC controller (motion analysis, look-ahead). If we consider flow simulation, object-oriented discrete events simulations allow to efficiently model, experiment and analyze facility layout and process flow. They are an aid for the determination of optimal layout and the optimization of production lines in order to accommodate different order sizes and product mixes.

The existence of graphical-3D kinematics simulation are used for the design, evaluation and off-line programming of work-cells with the simulation of true controller of robot and allows mixed environment composed of virtual and real machines.

The finite element analysis tool is widespread and as a powerful engineering design tool it enables companies to simulate all kind of fabrication and to test them in a realistic manner. In combination with optimization tool, it can be used for decision-making. It allows reducing the number of prototypes as virtual prototype as cheaper than building physical models. It reduces the cost of tooling and improves the quality, VM and simulation change the procedure of product and process development. Prototyping will change to virtual prototyping so that the first real prototype will be nearly ready for production. This is intended to reduce time and cost for any industrial product. Virtual manufacturing will contribute to the following benefits.

1) Quality: Design For Manufacturing and higher quality of the tools and work instructions available to support production.
2) Shorter cycle time: increase the ability to go directly into production without false starts.
3) Producibility: Optimize the design of the manufacturing system in coordination with the product design; first article production that is trouble-free, high quality, involves no reworks and meets requirements.
4) Flexibility: Execute product changeovers rapidly, mix production of different products, return to producing previously shelved products;
5) Responsiveness: respond to customer “what-ifs” about the impact of various funding profiles and delivery schedule with improved accuracy and timeless.
6) Customer relations: improved relations through the increased participation of the customer in the Integrated Product Process Development process.

A. Economic Aspects

It is important to understand the difference between academic research and industrial tools in term of economic aspects. The shape of the face in the diagram presented is defined by two curves: – “effort against level of detail” where “level of detail” refers to the accuracy of the model of simulation (the number of elements in the mesh of a FEM model or the fact if only static forces are taken into account for a simulation “effort against development in time” is a type of time axis and refers to future progress and technological developments (e.g. more powerful computers or improved VR equipment). Universities develop new technologies focusing on technology itself. Researchers do not care how long the simulation will need to calculate the results and they not only develop the simulation but they need to develop the tools and methods to evaluate whether the simulation is working fine and whether the results are exact. On the other hand, industrial users focus on reliability of the technology, maturity economic aspects (referring to the effort axis) and on the integration of these techniques within existing information technology systems of the companies (e.g. existing CAD CAM systems). To our mind, Virtual Manufacturing is, for a part of its scope, still an academic topic. But in the future, it will become easier to use these technologies and it will move in the area of industrial application and then investments will pay off. For example in the automotive and aerospace companies in the late 60’s, CAD was struggling for acceptance. Now 3-D geometry is the basis of the design process. It took 35 years for CAD-CAM to evolve from a novel approach used by pioneers to an established way of doing things. During this period, hardware, software, operating systems have evolved as well as education and organizations within the enterprise in order to support these new tools. Today, some techniques are daily used in industry, some are mature but their uses are not widespread and some are still under development.

VII. PRACTICAL APPLICATION OF VM

A. Machine-Tool

The trend in the machine tool manufacturers sector concerning Virtual Manufacturing is research and development towards the “Virtual Machine Tool”.

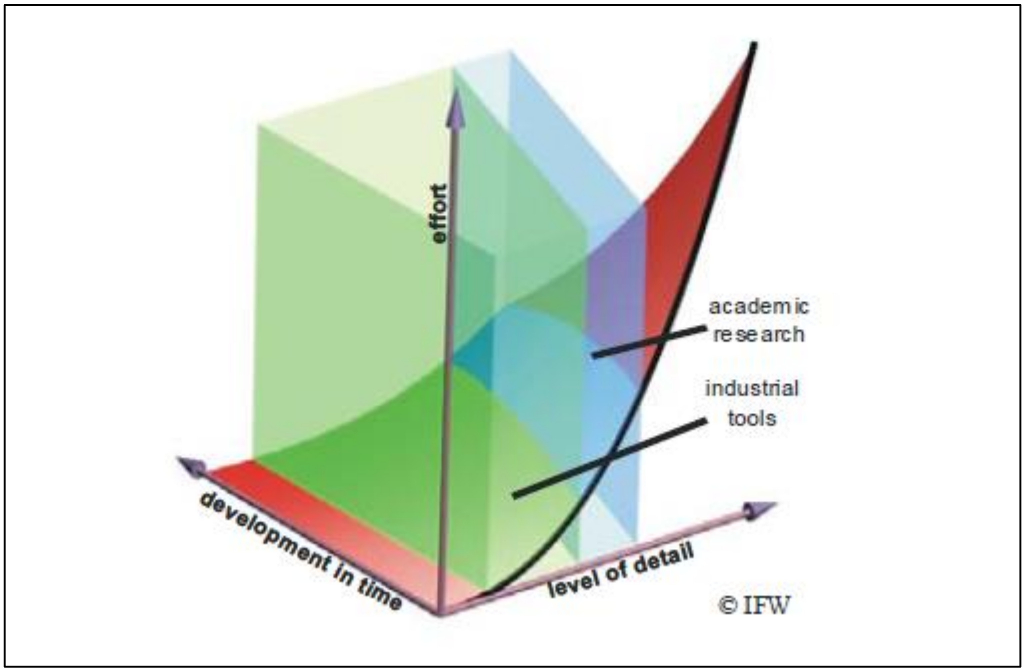

Fig. 7.1: academic Research vs Industrial Tool

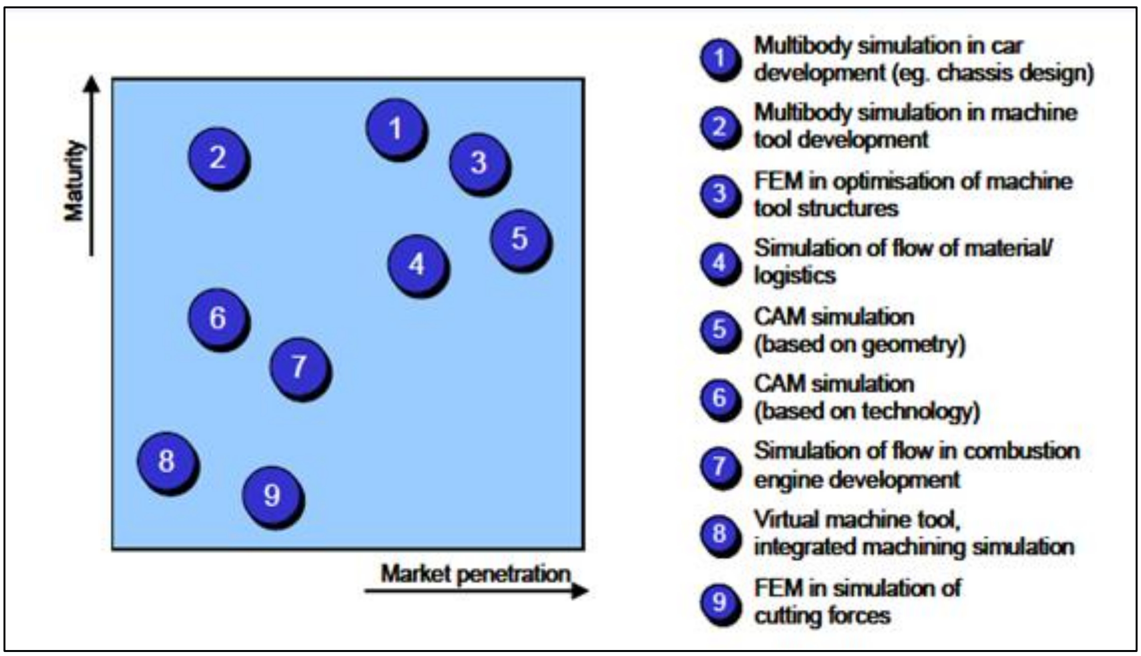

Fig. 7.2: Maturity of Techniques vs Market Penetration

The goal of the Virtual Machine Tool is to reduce time and cost for the developing of new machine tools by introducing virtual prototypes that are characterized by a comprehensive digital geometrical design, and by the simulation of

1) The stationary behavior of the machine structure,
2) The dynamic behavior of moving parts,
3) The changing of signals and state variables in electronic circuits and
4) By the simulation of the manufacturing process itself.

Nowadays, the simulation activities are isolated from each other. Current research is combining different types of simulation to reflect various interdependencies, like e.g. elaborating the frequency response with FEA and combining this with a bloc simulation of the machine. The process simulation of forming processes is almost state-ofthe- art in industry, whereas the simulation of cutting processes is an item for international research (this excludes the pure NC-program simulation, whichis widely used in industry, but which does not reflect the realistic behavior of the interaction of machine tool, tool and work piece during cutting operations).

B. Automotive

In the automotive industry, the objective of the Digital Product Creation Process is to design the product and the manufacturing process digitally with full visualization and simulation for the three domains: product, process and resources. The product domain covers the design of individual part of the vehicle (including all the data throughout the product life cycle), the process domain covers the detailed planning of the manufacturing process (from the assignment of resources and optimization of workflow to process simulation). Flow simulation of factories and ware houses, 3D-kinematics simulation of manufacturing systems and robots, simulation of assembly processes with models of human operators, and FEA of parts of the automobiles are state-of-the-art.

New trends are focusing on the application of Virtual and Augmented Reality technologies. Virtual Reality technologies, like e.g. stereoscopic visualization via CAVE and Powerwall, are standard in product design. New developments adapt these technologies to manufacturing issues, like painting with robots. Developments in Augmented Reality focus on co-operative telework, where developers located in distributed sites manipulate a virtual work piece, which is visualized by Head Mounted Displays.

C. Aerospace

Virtual Manufacturing in aerospace industry is used in FEA to design and optimise parts, e.g. reduce the weight of frames by integral construction, in 3D-kinematics simulation to program automatic riveting machines and some works dealing with augmented reality to support complex assembly and service tasks (the worker sees needed information within his glasses). The simulation of human tasks with precautions allows the definition of useful virtual environment for assembly, maintenance and training activities.

VIII. CONCLUSION

As a conclusion of this paper, we can say that we have now reached a point where everyone can use VM. It appears that VM will stimulate the need to design both for manufacturability and manufacturing efficiency. Nowadays, even if there is a lot of work to do, all the pieces are in place for Virtual Manufacturing to become a standard tool for the design to manufacturing process: computer technology is widely used and accepted, the concept of virtual prototyping is widely accepted, companies need faster solutions for cost / time saving, for more accurate simulations, leading companies are already demonstrating the successful use of virtual manufacturing techniques. Nevertheless, we have to note that there are still some drawbacks to overcome for a complete integration of VM techniques, data integrity, training, system integration. Moreover if large manufacturing enterprises have developed and applied with success VM technologies (aerospace, automotive).VM is a capital intensive technology and a lot of SMEs do not have the wherewithal to integrate them.

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