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Digital Manufacturing Supporting Autonomy and Collaboration of Manufacturing Systems

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1. Introduction

This chapter discusses on the challenges and opportunities of digital manufacturing supporting the decision making in autonomous and collaborative actions of manufacturing companies. The motivation is the change towards more networked collaboration caused by, for example, globally distributed markets and specialization of manufacturing companies to their core competences, their autonomous activities. This situation has led to increasingly complex manufacturing activities in the manufacturing network and the importance of collaboration has become a critical factor. In most cases companies seek to respond to the challenges through cooperation rather than expanding their own operations. The autonomy means that the parties involved in the manufacturing activities do their own tasks by themselves independently from other parties while the collaboration involves the activities that one party cannot do by itself and therefore, co-operation of several parties are required. This kind of situation can be clearly seen in networked manufacturing activities involving several companies, but similarly, inside a company and its one facility, same kind of autonomous and collaborative activities can be recognized. In the discussion, the dimensions of autonomy and collaboration are considered in designing and developing manufacturing systems, as well as in improving the daily operations.

The rest of this Chapter is structured as follows. Section 2 discusses on the main issues behind the research, including Competitive and Sustainable Manufacturing, changeability in manufacturing as well as support from digital manufacturing. In Section 3, a structure for manufacturing systems and entities is proposed, which is the base for the design and development activities of manufacturing systems discussed in Section 4. An academic research environment is introduced in Section 5 describing several of the theoretical aspects discussed before. Section 6 gives a brief conclusion on the topics discussed.

2. Background

The focus of the discussion is on mechanical engineering industry of discrete part manufacturing for business-to-business (B2B) industry, including their part manufacturing and product assemblies. These kinds of products are typically highly customized and tailored to customer needs and requirements with low or medium demand (Lapinleimu, 2001). This type of production usually involves several companies and is formed as a supply network. For example, the production includes a main company, its suppliers and suppliers of suppliers as well as customers and customers of customers. The current manufacturing paradigm, in the above context, has evolved from the early craft manufacturing via mass manufacturing towards mass customization. Typical characteristics that have been recognized include (Andersson, 2007):

- Globally local systems spread over industrial ecosystems and manufacturing networks of their own pros and cons.
- Managing the networked manufacturing, where the importance of procurement and management of knowledge flow increase.
- Specialization to one's core competences and collaborating with others in the manufacturing network.

Early discussions considered whether these characteristics could be fulfilled with developing existing flexible manufacturing systems (FMSs), or to shift to reconfigurable manufacturing systems (RMSs) paradigm. At some point, more ambitious goals were set with the aim to describe a manufacturing system with autonomous entities having the needed level intelligence to be changeable to organize themselves to altered situations, and to identify what new entities will be required. At the same time, a manufacturing system is required to be competitive in order to survive in the markets as well as sustainable to reduce or eliminate unwanted activities and outputs.

2.1 Competitive and sustainable manufacturing

The well-known definition of sustainability is: "The Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development [WCED], 1987), thereafter (WCED, 1987). This political statement is the root cause for today's key global challenges and related problems that call for a drastic change of paradigm from economic to sustainable development. Competitive Sustainable Manufacturing (CSM) is seen as a fundamental enabler of such change (Jovane, 2009).

Sustainable development has been recently increasingly emphasized around the world; in Europe (Factories of Future Strategic Roadmap and the Manufuture initiative), the USA (Lean and Mean), and Japan (Monozukuri and New JIT). The CSM paradigm widens the classical view of sustainability to interact with the Social, Technological, Economical, Environmental, and Political (STEEP) context (AdHoc, 2009). Sustainable manufacturing is a multi-level approach where product development, manufacturing systems and processes as well as enterprise and supply chain levels need to be considered, with metrics identified for each level (Jawahir et al., 2009).

The CSM is one of the strategic research areas within the Department of Production Engineering (TTE) at Tampere University of Technology (TUT). Figure 1 presents the main areas of the CSM approach, consisting of three main pillars, Sustainable, Lean and Agile Manufacturing. Lean manufacturing aims to combine the advantages of craft and mass production, while avoiding the drawbacks such as the high costs of craft production and rigidity of mass production systems (Womack et al., 1990). For example, the Lean Enterprise Institute (2008) defines Lean manufacturing as "a business system for organizing and managing product development, operations, suppliers, and customer relations that requires less human effort, less space, less capital, and less time to make products with fewer defects to precise customer desires, compared with the previous system of mass production."

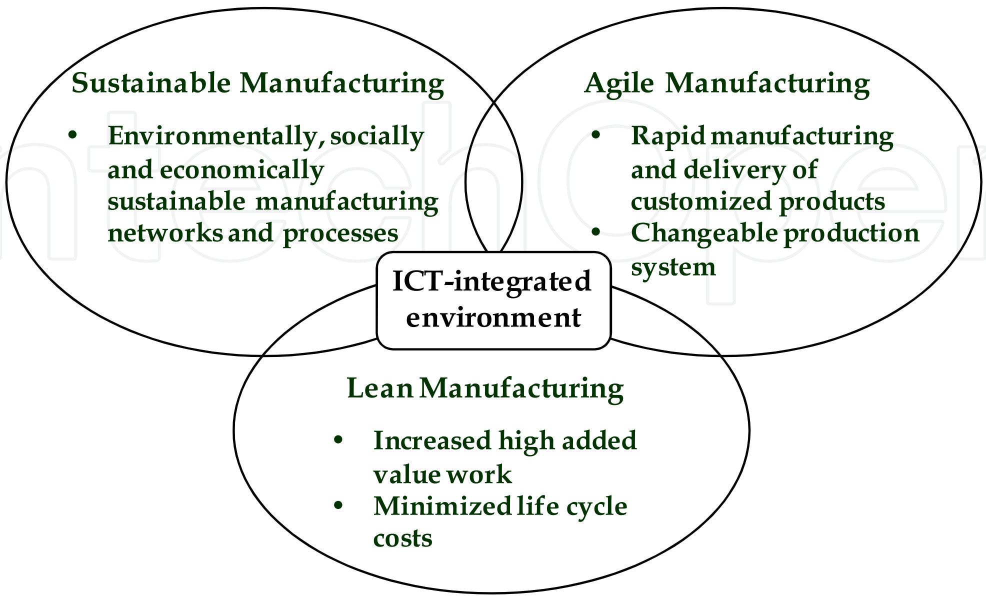

Fig. 1. The cornerstones of the CSM at the Department of Production Engineering (Nylund et al., 2010)

Agile manufacturing can be defined as an enterprise level manufacturing strategy of introducing new products into rapidly changing markets (Nagel & Dove, 1991) and an organizational ability to thrive in a competitive environment characterized by continuous and sometimes unforeseen change (Kidd, 1994). Agile manufacturing highlights the need to adapt to changes in the business environment, and generally agility is defined as ability to react to and take advantage of changes and opportunities, see for example (Sharifi & Zhang, 1999; Gould, 1997).

Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). It consists of three structural pillars namely society, environment, and economy, whilst at the same time it also involves operational aspects such as the consumption of resources, natural environment, economic performance, workers, products, social justice and community development (Jayachandran et al., 2006). When these three pillars of Lean, Agile, and Sustainable are considered as one system, Lean emphasized the stability of a system that can be referred as the autonomy while agility adds the needed capability to change to new situations, therefore focusing more on the collaboration. These two have their main focus on economic issues while sustainability adds the viewpoints of energy and environmentally friendly manufacturing.

2.1.1 Changeability in manufacturing systems

Wiendahl et al. (2007) suggest changeability as an important factor in the competitiveness of manufacturing companies in addition to the classical factors of cost, quality, and time. Changeability is defined on the five structuring levels of an enterprise: changeover ability, reconfigurability, flexibility, transformability and agility. Agility, which was discussed in the context of CSM, is seen from a manufacturing enterprise level and refers to the ability of an enterprise to effect changes in its systems, structure and organization (Gunasekaran & Yusuf, 2002).

Transformability is changeability at a factory level. It includes, for example, facilities, organization and employees. The whole factory is oriented towards the market to offer the right products and services (Wiendahl et al., 2007). Into a detailed level of manufacturing activities the term changeover ability is used. It is related to single workstations that perform manufacturing processes in order to manufacture product features.

Reconfigurability and flexibility are the most widely examined structuring levels of changeability in the context of manufacturing systems. An FMS is configured to deal with part variations within its scope. The functionality and capacity of FMSs are pre-designed, while flexibility is inherent and built-in a priori (ElMaraghy, 2005). Because of the fixed flexibility of FMS, it is not flexible enough for rapid and cost-effective reconfiguration in response to changing markets (Mehrabi et al., 2000). An RMS is composed of general-purpose hardware and software modules that are reused in reconfiguration tasks. Modules are replaced or added only if necessary. An RMS has the ability to change capacity and functionality to bring about the needed flexibility, i.e. to bring about exactly the functionality and capacity needed exactly when needed (Koren, 1999).

2.2 Support from digital manufacturing

The tools and principles of digital manufacturing, factories, and enterprises can offer significant value to all aspects of manufacturing systems during their life cycles. However, there are no commonly used or agreed definitions for those, but they usually share the idea of managing the typically isolated and separate manufacturing activities as a whole by the means of Information and Communications Technology (ICT) (Nylund and Andersson, 2011). Typical examples often found from the definitions, based on literature, are (see, for example: Bracht & Masurat, 2005; Maropoulos, 2003; Souza et al., 2006):

- An integrated approach to develop and improve product and production engineering technologies.
- Computer-aided tools for planning and analysing real manufacturing systems and processes.
- A collection of new technologies, systems, and methods.

Typical tools and principles of digital manufacturing on different structuring levels are, for example (Kühn, 2006):

- Computer-aided technologies, such as computer-aided design (CAD) and computer-aided manufacturing (CAM), e.g. offline programming for virtual tool path generation to detect collisions, analyse material removal and optimise cycle times.
- Visual interaction applications, e.g. virtual environments and 3D-motion simulations that offer realistic 3D graphics and animations to demonstrate different activities.
- Simulation for the reachability and sequences of operations as well as internal work cell layout and material handling design. These include, for example, realistic robotics simulation (RRS) and ergonomics simulation.

- Discrete event simulation (DES) solutions including the need for and the quantity of equipment and personnel as well as evaluation of operational procedures and performance. DES can also be focused on e.g. factories and supply chain or network sales and delivery processes as well as to complex networked manufacturing activities, including logistical accuracy and delivery reliability of increasing product variety.

The above are examples of typical application areas of digital manufacturing. In each case, the activities rely on up-to-date and accurate information and knowledge. The total information and knowledge of a manufacturing system can be explained with explicit and tacit components (Nonaka and Takeuchi, 1995). The explicit part of the knowledge can be described precisely and presented formally in ICT-systems. The skills of humans are explained as the tacit dimension of knowledge, which, presented digitally, may lead to unclear situations and can be wrongly understood. The importance of the transformation from tacit to explicit knowledge has been recognized as one of the key priorities of knowledge presentation (Chryssolouris et al., 2008).

Challenges exist both in the autonomous and collaborative parts of the digitally presented manufacturing entities. The internal part should include only the needed information and knowledge to fully describe the autonomous activities while the collaboration mostly relies on effective sharing of information and knowledge and therefore both the communication language and content should be described formally. Effective knowledge management consists of four essential processes: creation, storage and retrieval, transfer, as well as application, which are dynamic and continuous phenomenon (Alavi and Leidner, 2001). Examples of the application areas of the digital part are:

- Email messages, Internet Relay Chat (IRC), Instant Messaging, message boards and discussion forums.
- More permanent information and knowledge derived from the informal discussions, stored in applications such as Wikipedia.
- Internet search engines and digital, such as dictionaries, databases, as well as electronic books and articles
- Office documents, such as reports, presentations, as well as spreadsheets and database solutions.
- Formally presented information systems, such as Enterprise Resource Planning (ERP), Product Data Management (PDM), and Product Lifecycle Management (PLM).

The importance of the possibilities offered by ICT tools and principles is ever more acknowledged, not only in academia, but also in industry. The Strategic Multi-annual Roadmap, prepared by the Ad-Hoc Industrial Advisory Group for the Factories of the Future Public-Private Partnership (AIAG FoF PPP), lists ICT as one of the key enablers for improving manufacturing systems (AdHoc, 2010). The report describes the role of ICT at three levels; smart, virtual, and digital factories.

- Smart factories involve process automation control, planning, simulation and optimisation technologies, robotics, and tools for competitive and sustainable manufacturing.
- Virtual factories focus on the value creation from global networked operations involving global supply chain management.

- Digital factories aim at a better understanding and the design of manufacturing systems for better product life cycle management involving simulation, modelling and management of knowledge.

Both digitally presented information and knowledge as well as computer tools and principles for modelling, simulation, and analysis offer efficient ways to achieve solutions for design and development activities. General benefits include, for example:

- Experiments in a digital manufacturing system, on a computer model, do not disturb the real manufacturing system, as new policies, operating procedures, methods etc. can be experimented with and evaluated in advance in a virtual environment.
- Solution alternatives and operational rules can be compared within the system constraints. Possible problems can be identified and diagnosed before actions are taken in the real system.
- Modelling and simulation tools offer real-looking 3D models, animations, and visualisations that can be used to demonstrate ideas and plans as well as to train company personnel.
- Being involved in the process of constructing the digital manufacturing system tasks increases individuals' knowledge and understanding of the system. The experts in a manufacturing enterprise acquire a wider outlook compared to their special domain of knowledge as they need to gather information also outside their daily operations and responsibilities.

3. Structure of manufacturing entities and systems

The proposed structure of manufacturing systems consists of manufacturing entities as well as their related domains and activities. An entity, being autonomous, is something that has a distinct existence and can be differentiated from other entities. The term 'entity' has similarities to other terms, such as: object, module, agent, actor, and unit. A domain is an expert area in which two or more entities are collaborating. Domains have certain roles in the system and their own responsibilities and specific objectives. An activity is a set of actions that accomplish a task that is related to the entities and domains, as well as to their context.

3.1 Structure of manufacturing entities

Figure 2 illustrates the general viewpoints of the proposed structure of manufacturing entities. The structure is explained with internal structure of individual manufacturing entities. It is derived from the principles behind the term 'holon' and the concept of Holonic Manufacturing Systems (HMS). The term holon comes from the Greek word 'holos', which is a whole and the suffix '–on', meaning a part. Therefore the term holon means something that is at the same time a whole and a part of some greater whole (Koestler, 1989).

In HMS, holons are autonomous and co-operative building blocks of a manufacturing system, consisting of information processing part and often a physical processing part (Van Brussel et al., 1998). In this approach, the information part is divided into digital and virtual parts differentiating the digitally presented information and knowledge from the computer models representing the existing or future possible real manufacturing entities. The digital part barely exists as clearly consisting separate part. It can be distributed in several information systems both globally and locally and in information rich computer models, the virtual parts of the manufacturing entities.

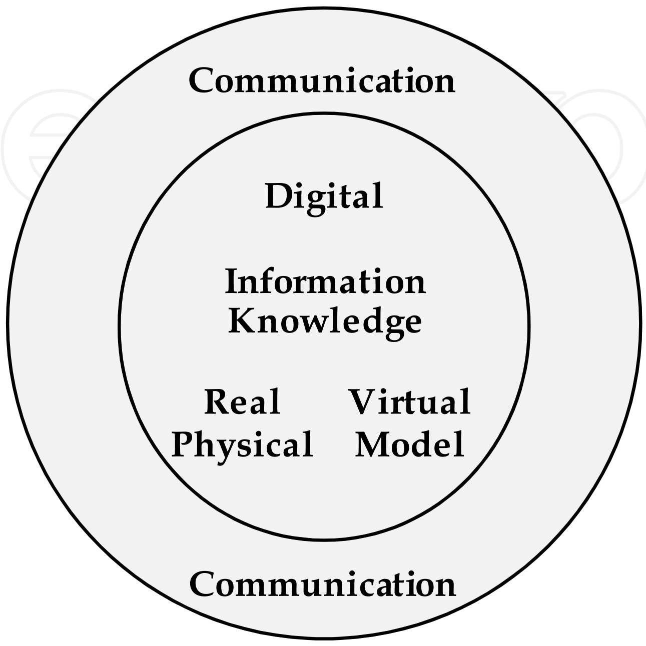

Fig. 2. Internal structure of manufacturing entities

The digital, virtual, and real parts combined present the autonomy of a manufacturing entity. The communication part is responsible of both the language and content of the messages between manufacturing entities. Therefore, it enables the manufacturing entities to collaborate with each other (Nylund & Andersson, 2011). As the autonomous entities exist distributed, independently from each other, they can be developed separately. At the same time, the communication part enables the investigation of the entities in an integrated fashion, and to develop the whole system they form.

The division into digital, virtual, and real is intentionally missing the tacit dimension, as it is intended to be used in decision making processes by humans, based on their skills and knowledge. At the end, the humans are the ones that are making the decisions, or are the ones that are creating the decision making mechanisms.

3.2 Structure of manufacturing systems

A manufacturing system consists of manufacturing entities with different roles as well as their related domains and activities. Figure 3 shows a general presentation of manufacturing entities of products, orders, and resources as well as their connecting domains of process, production, and business. The focus is on the manufacturing activities that are related to the transformation of raw material to finished products and their associated services as well as the flow of information and knowledge that is related to the physical manufacturing of customer orders.

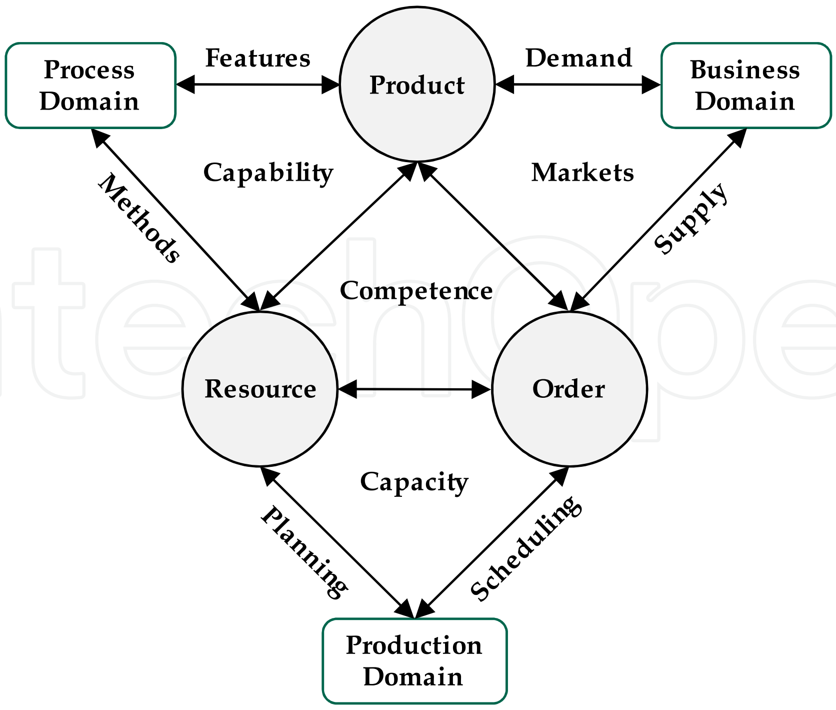

Fig. 3. Structure of manufacturing systems

The proposed structure is loosely based on the HMS reference architecture Product-Resource-Order-Staff Architecture (PROSA) (Van Brussel et al., 1998). The PROSA explains the relations between the entities with the information and knowledge they exchange while in this approach the relations are explained with activities occurring between the entities. Brief descriptions of the entities and domains are:

- *Products* represent what the manufacturing system offers to its customers. The characteristics of the products specify the requirements for the manufacturing system, i.e. what the system should be able to do.
- *Resources* embody what is available to manufacture the products. The characteristics of the resources determine what kinds of products can be manufactured.
- *Orders* represent instances of products that are ordered by customers. They define the volume and variation requirements of the products ordered, as well as the capacity and scalability requirements for the manufacturing system.
- *The process domain* represents the capabilities that are needed to manufacture the products. It connects the development activities of products and resources.
- *The production domain* defines the capacity and scalability to manufacture changing volumes and variations in customer orders. It handles the material and information flow of the manufacturing system.
- *The business domain* is responsible for markets, i.e. for the right products being available for the customers to gain enough orders.

3.3 Structuring levels in manufacturing

A fractal is an independently acting manufacturing entity that can be precisely described (Warnecke, 1993). Fractals are structured bottom-up, building fractals of a higher order.

Entities at the higher levels always assume only those responsibilities in the processes which cannot be fulfilled in lower order (Strauss & Hummel, 1995). This is similar to holons and holarchies, as at every fractal level of holons the level above is the holarchy of the holons at a lower level. Similarly, the autonomy of the holons is not considered in the holarchy, but instead dealing with and organizing the co-operation of the holons is the responsibility of the holarchy.

In Figure 4, four different structuring levels, manufacturing units, stages, plants, and networks, are distinguished.Manufacturing units correspond to individual machine tools that have certain manufacturing methods. The units are designated to manufacture the features of work pieces that have similarities in, for example, size and shape as well as tolerances and material properties. Typical areas are computer-aided design (CAD) and computer-aided manufacturing (CAM), e.g. offline programming for virtual tool path generation to detect collisions, analyse material removal and optimise cycle times (Kühn, 2006).

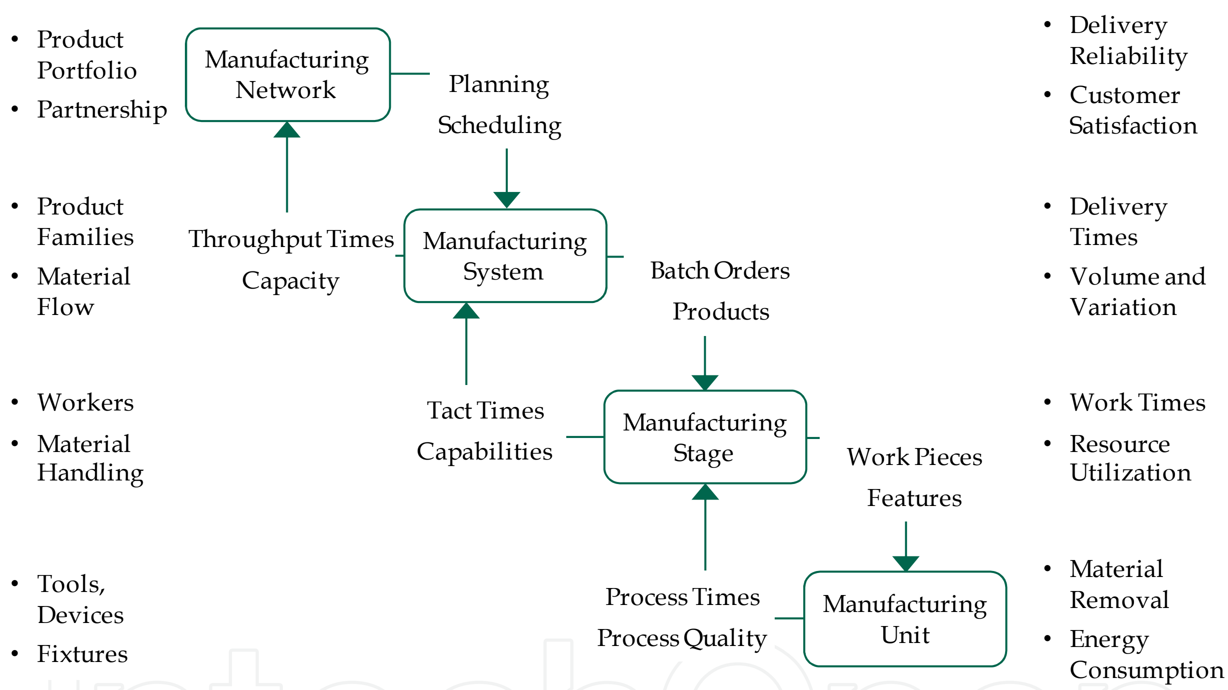

Fig. 4. Examples of structuring levels of manufacturing and their connections

Manufacturing stages are physical or logical manufacturing areas, e.g. manufacturing cells, consisting of one or more manufacturing units and their co-operation. Additionally, the manufacturing stages include internal material handling in moving the work pieces between the manufacturing units as well as buffers and stocks to hold batches of the work pieces. In manufacturing stages the focus can be on simulation for the reachability and sequences of operations as well as internal work cell layout and material handling (Kühn, 2006).

Manufacturing plants are composed of manufacturing stages, warehouses for storing the products as well as internal logistics to transfer material between the stages and material storing areas. They typically correspond to factories and have customers who can be other companies or internal customers, such as an assembly plant. Typical simulation issues concern the layout design and material flow analysis as well as planning and controlling the manufacturing activities. Simulation studies on a manufacturing plant level are usually conducted using discrete event simulation (DES) including the need for and the quantity of equipment and personnel as well as evaluation of operational procedures and performance. Manufacturing networks consist of factory units, which can exist globally. One of the key differences between plants and networks is that entities in the network often belong to different companies that may have contradictory goals in their strategies. Simulation can be focused on traditional supply chain sales and delivery processes as well as to complex networked manufacturing activities, including logistical accuracy and delivery reliability of increasing product variety.

4. Digital manufacturing support for manufacturing activities

A digitally presented manufacturing system contains the information and knowledge of manufacturing entities and activities that it is reasonable to represent in a digital form. This, at its best, makes possible efficient collaboration between all the manufacturing activities and related parties. The discussion on digital manufacturing support is based on a previously developed framework for extended digital manufacturing systems (EDMS). An EDMS can briefly be defined as follows (Nylund and Andersson, 2011):

- an integrated and collaborative environment for humans, machines, and information systems to act and interact;
- to enhance the research, development and management activities of products, production systems, and business processes,
- supporting knowledge-intensive decision-making in the entirety of their lifecycles.

4.1 From ideas to innovative solutions

Figure 5 represents a process from ideas and the need for change to innovative solutions. It consists of a chain of activities where the results evolve towards more precise solutions. Each phase has its enablers as inputs and the activity creates results as outputs. The results affect the enablers in the following phases of the process. The process is also iterative as it is possible to go back to previous phases in order to change or refine them. The need for change can arise, for example, from social, technological, economic, environmental, and political aspects.

The changes can also derive from voluntary ideas that are seen to improve the competence of the system. If the process has not been developed previously, the current system has to be analysed to create the digital information and knowledge of what currently exists. The synthesis of the existing system and possible changes form the new requirements for the future system. The combination of feasible new possibilities and existing capabilities forms the solution principles. The results are digital entities and abstract and conceptual descriptions, including the objectives and preliminary properties of the future system.

When the descriptions evolve towards a more detailed level, possible technologies can be investigated, resulting in alternative solutions. The solution alternatives can be modelled as virtual entities that include, in addition to their digital description, for example, 3D models with their own operating rules, motion, and behaviour. Combining the existing and new virtual entities forms a rough simulation model. The solution that is implemented has to be verified to make sure that the behaviour and co-operation of the entities in the system are modelled correctly. The verified simulation model can be used to run test experiments. By analysing the results from the simulation model and comparing them with known or predicted outcomes, the behaviour of the simulation model can be validated. When the simulation model is verified and validated, it can be used for manufacturing experiments. The experiments are used to analyse the behaviour of the system, and can lead towards innovative solutions.

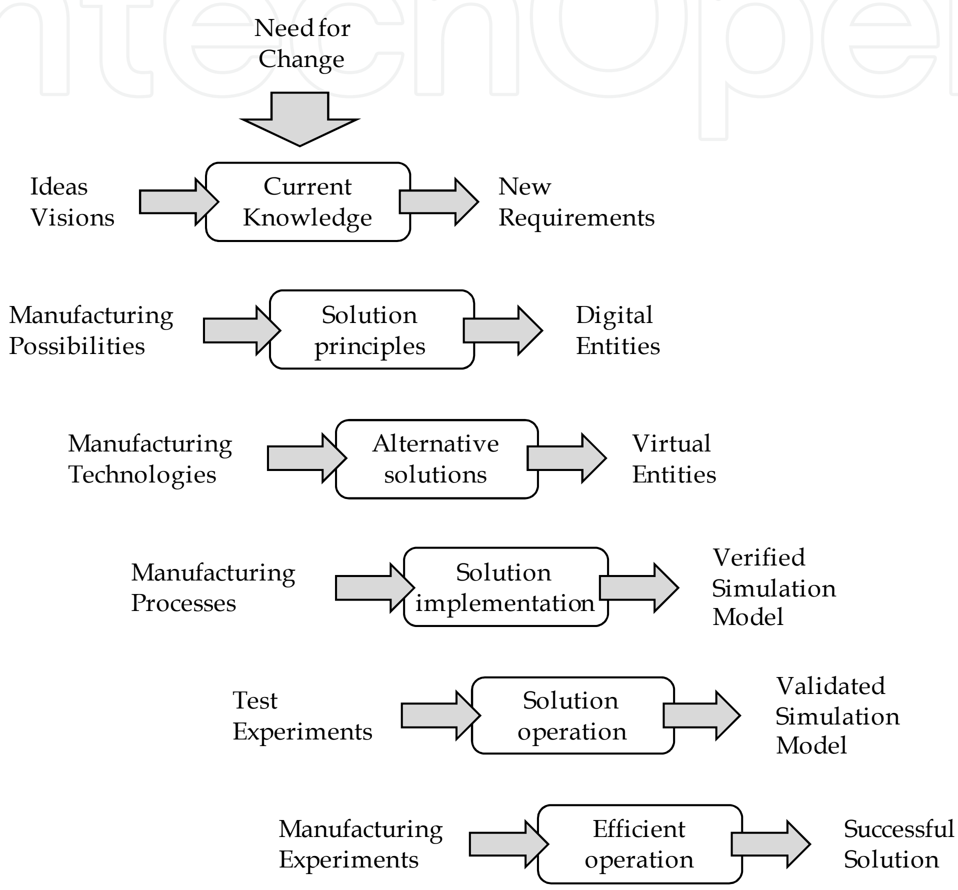

Fig. 5. The process from ideas to innovative solutions

4.2 Manufacturing process and flow development

Figure 6 shows a theoretical example of process and flow development. The manufacturing process part corresponds to the process domain, presented in Figure 3, where the capabilities for a manufacturing network are developed. The part of the manufacturing flow presents the production domain in Figure 3, aiming for the right capacity and scalability of the manufacturing network to meet the customer demands. The existing capabilities are combined with new possibilities, requirements, and constraints in the production network creating the synthesis of existing and what new capabilities will be required. These derive from, for example, new possible markets, customers, and competition i.e. what is important in the future that the current capabilities cannot fulfil. The new possible capabilities are tested virtually using computer-aided technologies in connection with the digitally presented information and knowledge.

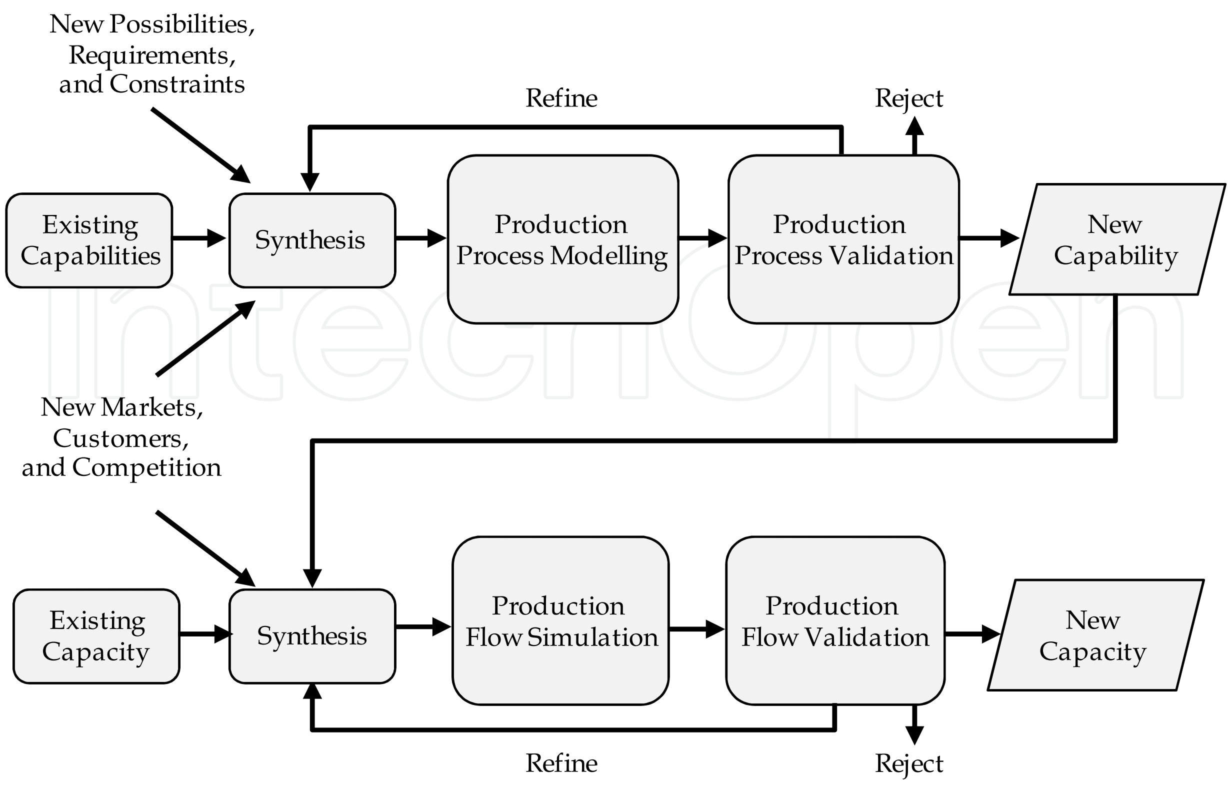

Fig. 6. Production process modelling and production flow simulation.

The resulted new capability is validated both to ensure that it does what it is supposed to do and that it meets the performance requirements, such as cost, quality, and time efficiency as well as the social and environmental issues. The production flow simulation in Figure 6 follows the same idea as the production process modelling. The new capability can add to the total capabilities of the network if something new is implemented, or change the existing capabilities if something already existing is reconfigured. It is not enough that all the needed capabilities exist.

The production flow simulation aims to define how much capabilities are required to produce the changing volume and variation of customer orders at the right time. Typical areas are the controlling, planning and scheduling of the activities. To investigate the production process modelling in more detail, five categories between product requirements and resource capabilities can be recognized, see Figure 7:

- Existing capability: The capabilities exist for all of the product requirements without any need for changes to the system. The products can be manufactured as the service requests have service providers.
- Possible existing capability: At least some of the product requirements need further investigation as to whether the capabilities exist or not. The requirements are close to the existing capabilities and, using modelling and simulation, the capabilities can be verified.
- Capability after reconfiguration: There is no existing capability but it may be possible to reconfigure the system so that it has the capabilities. By modelling the reconfigured system the possibility can be verified.

- Capability after implementation: The system does not have the needed capability. It may be possible if new capabilities are added to the system. Again this can be verified using modelling and simulation.
- No capability: The result may also be that there are no capabilities and they cannot be implemented either. This leads to the need for an alternative solution, which leads to a result that fits into one of the first four categories.

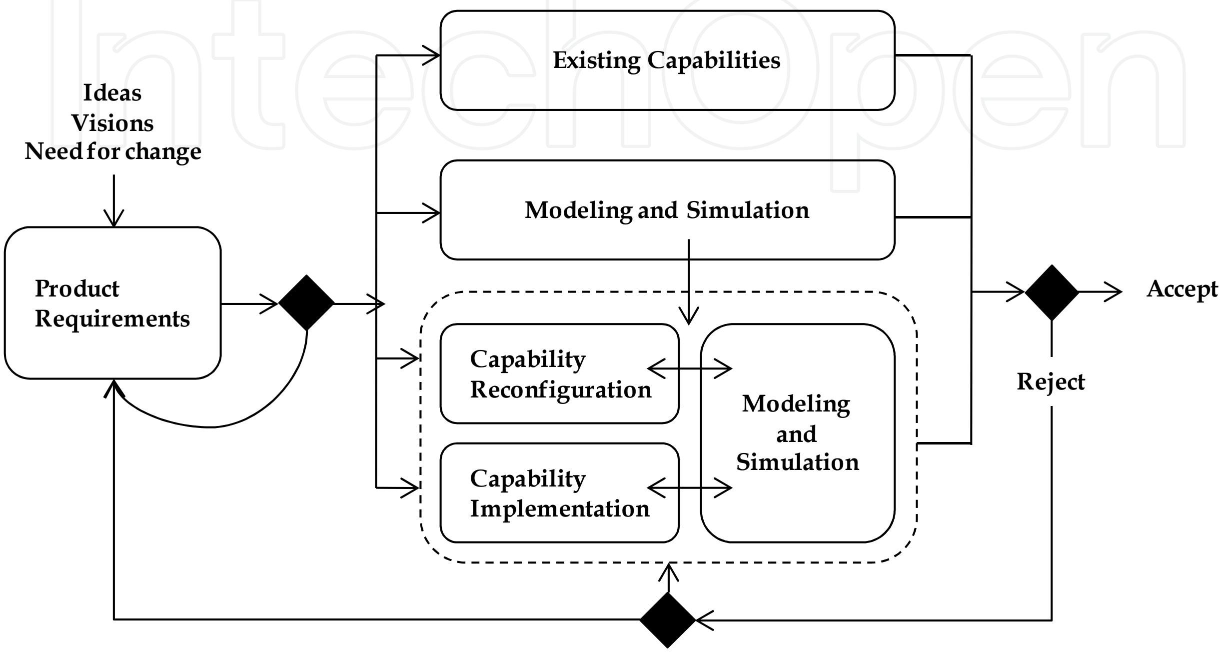

Fig. 7. Alternative outcomes of capability modelling and simulation

When it is known that the capabilities exist for all the product requirements, the efficiency of the capabilities still needs to be evaluated against factors such as cost, quality, and time. It has to be decided if the solution alternative is good enough. It can be further investigated in the capacity loop or it can be rejected and sent back to the capability loop. If all the needed capabilities exist, the capacity of the system has to be checked. The same five categories can be used in capacity evaluation. If it is known that there is enough capacity, nothing else has to be done. Modelling and simulation can be used to verify that there is enough capacity. It can also be used in capacity reconfiguration and implementation issues. Modelling and simulation of capacity has the same constraints as in the case of capabilities. The capacity for existing volume and variation still has to exist when new products are considered as an addition to existing products. In the capacity loop, the solution can be accepted or rejected, as in the capability loop. If the solution is rejected, it can be sent back to the capability loop or further back into the design requirements loop.

4.3 Manufacturing system operation

Operation of a manufacturing system can be viewed from the time dimensions of past, present, and future. The past represents what has happened i.e. it can be said to be the digital memory of the system. The time dimension of the present, what is happening now, is used to operate the current system by monitoring the state of the system and comparing it to the desired state. The future dimension makes it possible to plan future manufacturing activities ahead and to compare different changes in strategies. Figure 8 shows the connection of the time dimensions into the operation of manufacturing systems.

The past presents the data collected from the system activities when they happened. It can be used to analyse previous manufacturing activities in order to find out what happened and the reasons why it happened. In finding the root causes for phenomena, the system can learn from its past and prevent unwanted situations in the future. Rules for the autonomy of the manufacturing entities, as well as for their collaboration, can be enhanced and new rules can be created. The present here means the near future, where no major changes are planned.

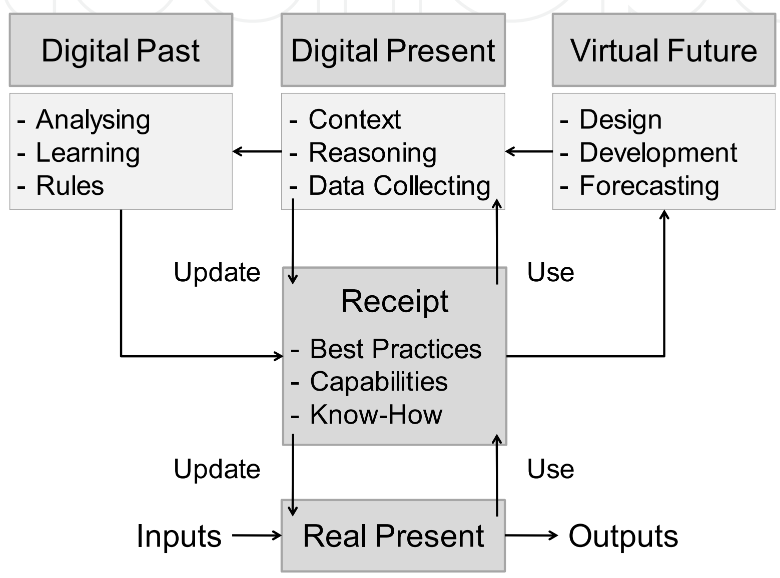

Fig. 8. Digitally co-existing past, present, and future time dimensions

It is, for example, the use of existing resources and the planning and scheduling of customer orders that have already been placed. In the present the digital and real existences co-exist. As the system operates the activities are logged, creating new history data to be analysed and to aid decision-making. The state of the real manufacturing system can be seen in the digital manufacturing system and actions can be taken with the state of the system as a starting point.

The dimension of the future relies on the information and knowledge gathered from the system previously. Future design and development decisions are syntheses of existing capabilities and requirements combined with future goals and possibilities. The viewpoint of the future can be divided into tactical decisions and visions. Tactical decisions consider the near future into which the manufacturing system is heading. Future visions are similar to tactical decisions, the difference being the time horizon.

The outcome of future visions is more obscure but there are more possibilities to be investigated. The information and knowledge from analysing the past, collecting data from the present, and forecasting the future is stored in the form of receipts. A receipt holds the capabilities of a system, constantly updating and refining the best practices in conjunction with human skills and know-how. The receipts are the basis of the operations in the real present, the only time dimension in the real world.

4.4 Continuous analysis and improvement

A manufacturing system can be seen as multiple autonomous manufacturing entities interacting and co-operating in a complex network of manufacturing activities. The activities are explained as services, which hold the information and knowledge needed to explain the manufacturing activities. It is required that the activities are known exactly, in that they are understood by all related parties.

Describing the activities as services in a digital format creates a formal way to present the services. This makes possible efficient collaboration in a digital manufacturing system between entities that can be humans, machines, or information systems. The information and knowledge is kept as the autonomous property of the manufacturing entities and the communication between the entities includes only the information that is needed to fully describe the collaboration activity.

The communication between the manufacturing entities is loosely based on service-oriented architecture (SOA), which consists of self-describing components that support the composition of distributed applications (Papazoglou & Georgakopoulos, 2003) enabling the autonomous manufacturing entities to negotiate and share their information and knowledge. The basic conceptual model of the SOA architecture consists of service providers, service requesters, and service brokers (Gottschalk, 2000). The roles of manufacturing entities in a digital manufacturing system based on SOA are briefly explained as follows:

- Service requesters are typically product entities when they are realized as order entities. The order entities call on the services they require to be manufactured.
- Service providers include the manufacturing resource entities which have the capabilities needed to provide the services that are requested.
- Service broker plays a role of an actor that contains the rules and logics of using the services. Its function is to find service providers for the requesters on the basis of criteria such as cost, quality, and time.

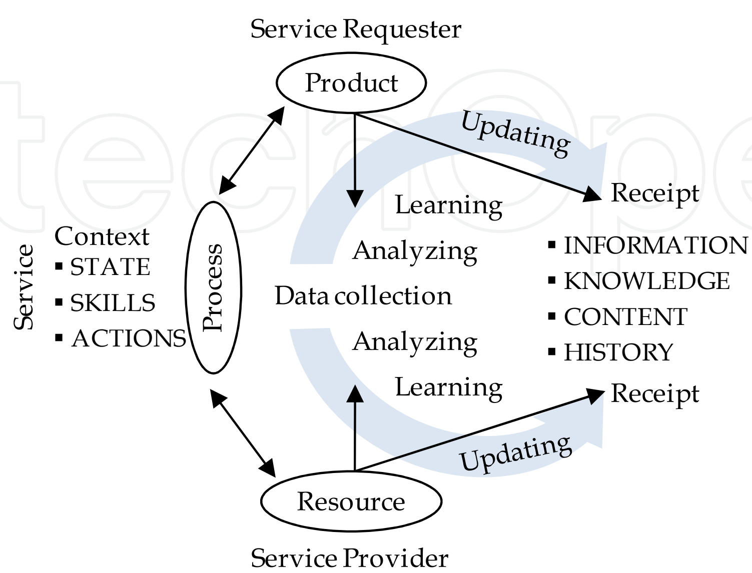

Fig. 9. An example of a service between a service provider and a service requester

Figure 9 shows an example of a service occurring in the process domain between products and resources. A service consists of two different entities, i.e. the product and resource entities having the roles of service requesters and providers. The actual service, being the manufacturing activity, is twofold, consisting of a context and receipt. The context is the environment, real or virtual, where the service takes place, whilst the receipt is the digital description of the service. The product entity requests a service, which is provided by the resource entity. The service, whether it is happening in a virtual or real environment, has a certain context that is in a certain state. The state is a basis for the actions happening during the service, and the result is based on the skills of the service provider. During the service data are collected from the process. The collected data are analyzed, forming information that is the basis for learning from the service. When something is learned, it is used to update the receipt, which will be the basis for future services.

When a certain product entity uses a service provided by a certain resource entity, the data collection, analysis, learning, and updating phases include adding the same data and information to the knowledge of both entities. The knowledge of a resource entity is updated with several product entities using the services it provides. In a similar fashion, the knowledge of a product entity consists of all the services it requests. A service can be seen as a hierarchy in which a service on the upmost level divides iteratively into multiple sub-services until the level on which the individual part features are requested. This means that an entity requesting a service gets information about the possible service provider entities, but it does not know how the service request is fulfilled. For example, a service request for the manufacturing of a product is a request on the macro level. The macro level service request is divided into multiple sub-services on the meso level and the meso-level service makes similar requests on the micro level. The upper level only needs the information about whether the service request can be fulfilled or not. The hierarchy of the services may be limited by the service requester as it may state special requirements for the service that limit the selection of possible providers. For example, a customer may require certain parts of ordered products to be manufactured in a specific manufacturing plant.

5. Academic research environment

Several of the theoretical issues discussed in this chapter have been implemented into an academic research environment of which real machinery exists in the TTE heavy laboratory, see Figure 10. The digital part of the environment has been constructed as a modular ICT architecture and the virtual part exists as simulation and calculation models. The aim of the environment is to offer a research platform that can be utilised in:

- Designing, developing and testing current and future research topics.
- Prototyping possible solutions for industrial partners in ongoing research projects.
- Utilizing it as an educational environment for university students and company personnel to introduce the latest results in the area of intelligent manufacturing.

The initial version of the environment was introduced during the Tampere Manufacturing Summit seminar, which was held in Tampere, Finland, in June 2009. Since then the environment has been discussed in scientific research papers as well as in seminar and conferences.

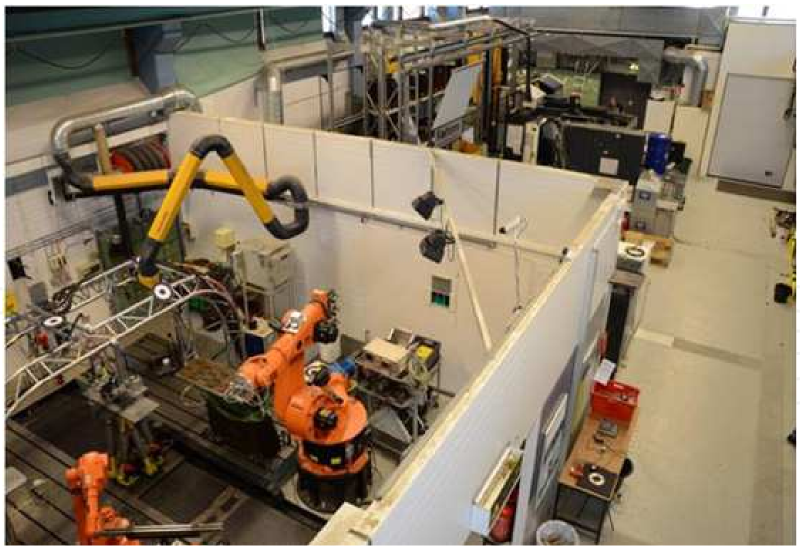

Fig. 10. The research environment in TTE heavy laboratory

5.1 General description of the research environment

The research environment consists of typical manufacturing resources and work pieces as physical entities. The resources of the research environment, offering different manufacturing capabilities are, see Figure 11:

- Machine tools (a lathe and a machining centre) for machining operations.
- Robots for material handling and robotized machining operations.
- Laser devices for e.g. machining and surface treatment.
- A punch press, existing only virtually, for the punching of sheet metal parts. The real punch press is located at a factory of an industrial project partner company.

Fig. 11. The machine tools and devices of the research environment

The work pieces, which can be manufactured in the environment, are fairly simple cubical, cylindrical, and flat parts in shape. They have several parameterized features that can be varied within certain limits, e.g. dimensions (width, length, and depth), number of holes, internal corner radiuses, and sheet thickness. The main reasons for the parameterization are, firstly, that the number of different parts can be increased with the variation without having a large number of different types of parts. Secondly, the parameters can be set in a way where changing the parameters also requires capabilities of different kind i.e. different manufacturing resources are required. This gives more opportunities to compare alternative ways to manufacture the work pieces based on selected criteria, such as the cheapest or fastest way to manufacture a work piece.

5.2 Viewpoints of the environment

The research environment can be seen from the digital, virtual, and real viewpoints. Figure 12 shows the digital, virtual, and real views of the whole research environment. The environment can be viewed from three different structuring levels; the whole environment, machining and robot cells, as well as the individual machine tools and robots. The real part of the environment exists in a heavy laboratory and is divided into two main areas, one including the robots and laser devices, and the second consisting of the machine tools. The real manufacturing entities on each structuring level have their corresponding computer models and simulation environments as their virtual parts.

The information and knowledge of the environment is stored in local databases of the manufacturing entities as well as in a common Knowledge Base (KB) for the whole environment, those presenting the digital part of the environment. The actual connection is enabled by and executed via the KB, see (Lanz et al., 2008), as all communication activities use or update it. The KB is the base for the ICT-related research and development activities of the research environment. It is a system where the data of the environment can be stored and retrieved for and by different applications existing in the environment.

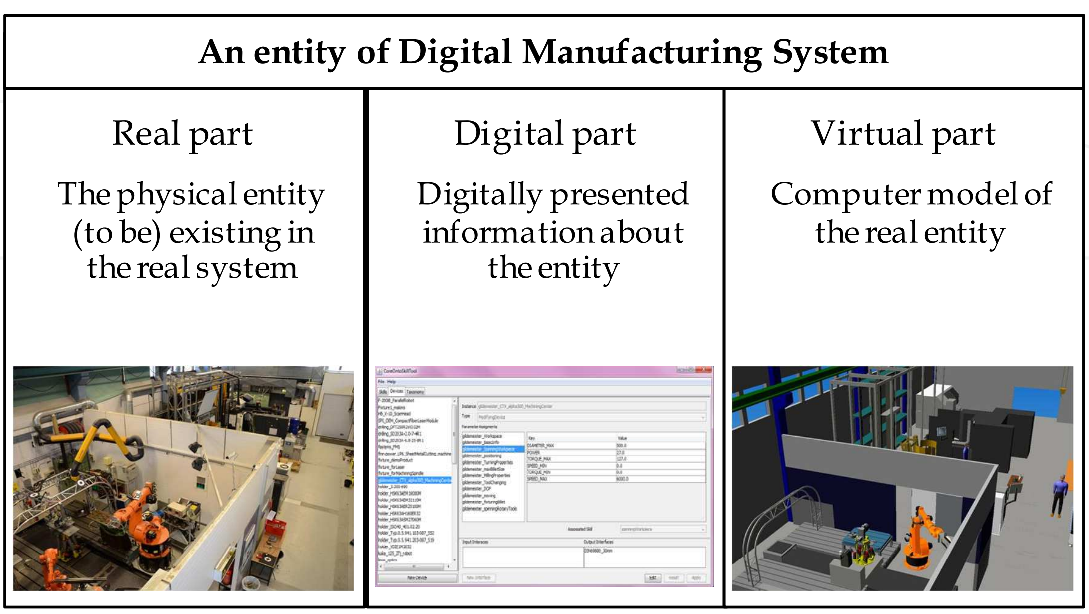

Fig. 12. Digital, virtual, and real viewpoints of the research environment

5.3 Scenarios for manufacturing tests

Figure 13 presents an overall view of the process of digital, virtual and real manufacturing tests that can be performed using the research environment. The product and manufacturing information and knowledge holds what is known about the manufacturing resources of the environment and products that have been manufactured in the environment. The manufacturing methods of the resources are described as capabilities of the research environment i.e. what is known that can be manufactured within the environment. The product requirements are described similarly including all manufacturing features of products that have been previously manufactured. When the ability to manufacture a new product will be examined, firstly a CAD model of the product is required. The CAD model will be analyzed using a feature recognition property of the research environment. For each product feature, a service request is created. The request is sent to the process planning part of the environment to compare the requirements of the new request to existing capabilities of the environment. If a suitable service exists i.e. there exists a process plan for the product feature, the result will be an existing service and no further examination is required. Otherwise, the new service request will be tested for its manufacturability.

The manufacturing tests can roughly be divided into three categories being digital, virtual and real test manufacturing. The digital test manufacturing is basically comparing a set of parameterized values of the service request to the formally described capabilities of the manufacturing resources. The process is quite rapid as it is happening in a computer and no visualization or animation is required. It is the most favourable choice if time is limited.

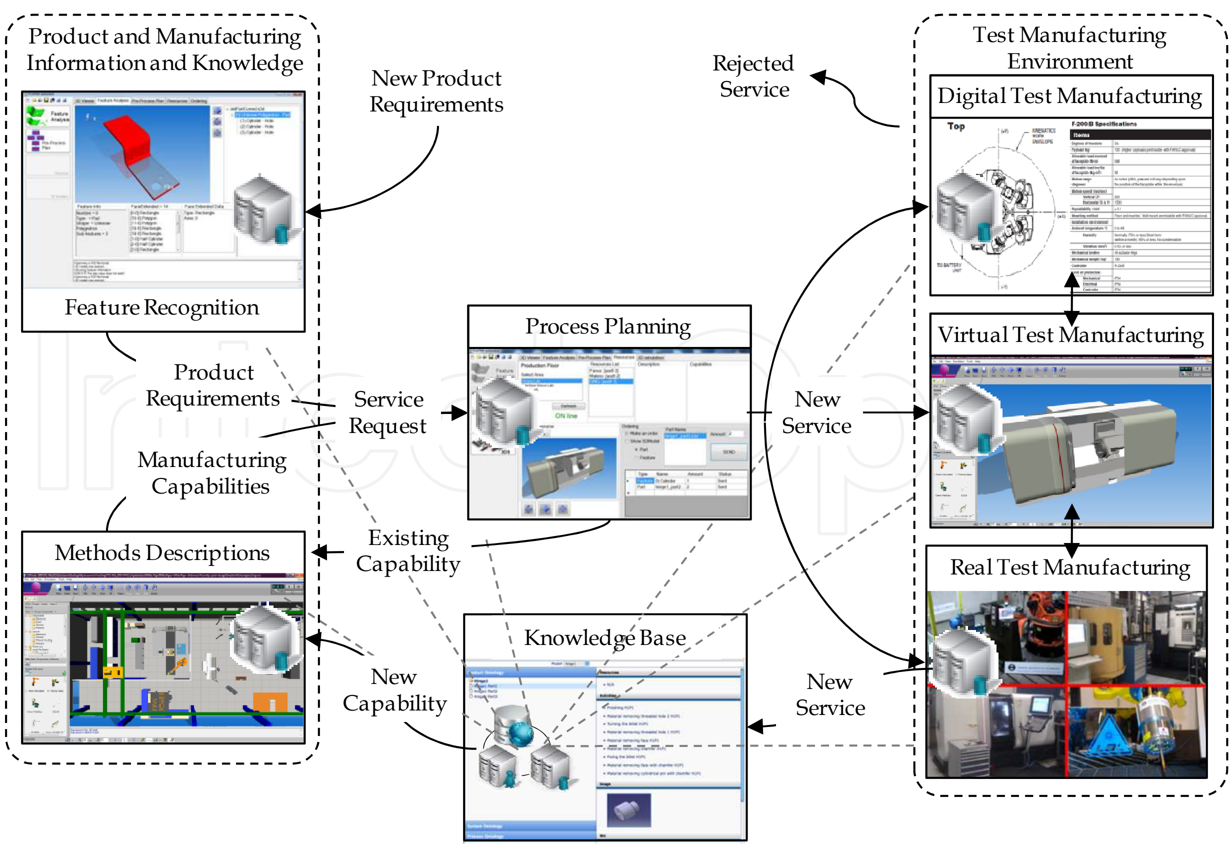

Fig. 13. An overall view of the manufacturing tests of the research environment.

The second choice would be a virtual test manufacturing i.e. typically modelling and simulation. It requires more time as human interaction is required during the process. The time required is dependent if existing simulation models can be used or new simulation models need to be constructed. In the case, where the existing simulation models cannot be used, new ones are required to be built. The creation of a new simulation model may be to reconfigure the existing virtual system to meet the new requirements, or implementing something new into the system if the system does not have all the required capabilities or manufacturing resources. In these alternatives, the test manufacturing is still carried out with computers i.e. it does not interrupt the use of the real manufacturing resources.

The real test manufacturing will be the choice if the digital or virtual manufacturing tests are not accurate enough to fully trust or understand the results gathered from the test. The real test manufacturing requires the physical resources and the time used will reduce the time for daily operations to manufacture customer orders. In some cases it is also reasonable to conduct additional tests with real manufacturing resources to reduce the risk of implementing fault processes. The responsibility of selecting, whether digital or virtual test manufacturing would be enough, is to be determined by humans, based on their skills and knowledge of the matter in hand, and has to be evaluated separately for each time a decision needs to be made. After the manufacturing tests have been conducted, the alternative is either a rejected or accepted new service. The result of rejected service could happen if the product feature cannot be manufactured within the system, or even if it could be manufactured, it is e.g. too expensive, uses too much time or does not output desired quality. In these cases, the results can be fed back to the product development to consider it the feature can be redesigned. In the case where the new service is accepted, it is added as a new capability of the environment and new process plan will be created. This will increase the known capabilities of the environment as each test manufacturing test adds new information and knowledge to the digital part of the environment, which will be available for the future test manufacturing cases.

5.4 Performance metrics

The measurements of the manufacturing environment can be divided into direct and indirect measures. The direct measurements are achieved using the sensors and measurement devices in the environment, and the metrics can be calculated immediately. Examples of the direct measurements are:

- Process quality assurance, a real time measurement using force, acceleration, and acoustic emission (AE) sensors.
- Process stability monitoring following the electricity variation of the robot servomotor caused by the cutting forces.
- Energy consumption monitoring using a Carlo Gavazzi EM21 72D energy meter.

In the case of the indirect measurements the logged data are stored in the history section of the KR. The data can be analyzed and to create the desired performance metrics. Table 1 summarizes the performance metrics from the viewpoints of manufacturing operation, production supervising, and business management.

Performance metric	Manufacturing Operator	Production Supervisor	Business Management
Cost	Continuous improvement to reduce the cost per part	Using the most cost-efficient production choices	The gain more profit and offer cheaper products to customers
Quality	To assure the manufacturing process efficiency and stability	Delivery reliability and Just-In-Time manufacturing	Improved customer satisfaction and decreased reclaims
Material consumption	To use near-net shape blank material	To reduce waste, material and energy use to meet the sustainability requirements	Meeting the requirements of legislation and expectations of the society by reducing the unwanted effects
Waste			
Energy consumption	To have real energy consumption results		
Production load and time metrics	To reduce the time per part and to update any changes in the manufacturing process times	To efficiently plan and schedule production to utilize the capacity of the system	To know how much customer orders can be placed and to give more precise delivery dates
Resource utilization			

Table 1. Different views to utilize the performance metrics

6. Conclusion

This Chapter discussed on the possibilities of digital manufacturing to support efficient activities of designing, developing and operating manufacturing systems. A structure of individual manufacturing entities and whole systems was proposed. Describing entities of a manufacturing system as independent, yet closely related existences of digital, virtual and real enables more efficient and effective manufacturing activities from early conceptual ideas to successful solutions. Even when describing the manufacturing entities independently, they are required to be closely integrated with each other and that can be done via domains of manufacturing related activities of products, resources, and business. Again, when the entities and domains are combined, the integrated fashion should also be invested separately in different structuring levels of manufacturing, yet again closely integrated between the structuring levels

By keeping the entities the same during their whole lifecycle reduces the loss of information and knowledge and enables more efficient manufacturing activities. These we discussed from several aspects i.e. a path from early ideas and needs to efficient solutions, development of manufacturing processes and flow, as well as how a system can learn from its daily operations by collecting and analysing data from the activities that can help in learning thus improving the way to do things in future.

An academic research environment was discussed on how these theoretical aspects can be implemented into a manufacturing environment. As the environment is constantly developed, some of the issues have been fully implemented while some other areas remain as a future of the environment. This is due to the fact that the current and future research topics lead the development of the environment.

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8. References

Ad-hoc Industrial Advisory Group. (2010). Factories of the Future PPP - Strategic Multi-annual Roadmap.

Alavi, M. & Leidner, D.E. (2001). Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research issues. *MIS Quarterly*, Vol. 25, pp. 107-136, ISSN: 0276-7783

Andersson, P.H. (2007). FMS in 2010 and beyond. *Tampere Manufacturing Summit 2007*, Tampere, Finland, June 2007

Bracht, U. & Masurat, T. (2005). The Digital Factory between vision and reality. *Computers in Industry*, Vol. 56, pp. 325-333, ISSN: 0166-3615

Chryssolouris, G., Mavrikios, D., Papakostas, N., Mourtzis, D., Michalos, G. & Georgoulias K. (2008). Digital manufacturing: history, perspectives, and outlook. *Proceedings of the Institution of Mechanical Engineers Part B: Journal of Engineering Manufacture*, Vol. 222, No. 5, pp. 451-462, ISSN (printed): 0954-4054. ISSN (electronic): 2041-2975

ElMaraghy, H.A. (2005): Flexible and reconfigurable manufacturing systems paradigms. *International Journal of Flexible Manufacturing Systems, Special Issue on Reconfigurable Manufacturing Systems*, Vol. 17, pp. 261-276, ISSN (printed): 0920-6299. ISSN (electronic): 1572-9370

Gottschalk, K. (2000). Web Services architecture overview. IBM developerWorks, Whitepaper

Gould, P. (1997). What is agility?. *Manufacturing Engineer*, Vol. 76, No. 1, pp. 28-31, ISSN

Gunasekaran, A. & Yusuf, Y.Y. (2002). Agile manufacturing: a taxonomy of strategic and technological imperatives. *International Journal of Production Research*, Vol. 40, No. 6, pp. 1357-1385, ISSN (printed): 0020-7543. ISSN (electronic): 1366-588X

Jawahir, I.S., Badurdeen, F., Goldsby, T., Iyengar, D., Gupta, A., Metta, H., Stovall, C. & Ladd. C. (2009). Assessment of Product and Process Sustainability: Towards Developing Metrics for Sustainable Manufacturing. *NIST Workshop on Sustainable Manufacturing*, Gaithersburg, MD, USA, October 2009

Jayachandran, R., Singh, R., Goodyer, J. & Popplewell, K. (2006). The design of a sustainable manufacturing system: A case study of its importance to product variety manufacturing. *Intelligent production machines and systems, 2nd I*PROMS virtual international conference*, ISBN 13: 978-0-08-045157-2, Pham, D.T., Eldukhri, E.E. & Soroka A.J. (eds.), pp.650-656

Jovane, F. (2009). The Manufuture Road towards Competitive and Sustainable HAV Manufacturing, *Tampere Manufacturing Summit*, Tampere, Finland, June 2009

Kidd, T. (1994). *Agile Manufacturing: Forging new frontiers*. Addison-Wesley Reading, 1st edition, ISBN-13: 978-0201631630, Boston, MA.

Koestler, A. (1989). *The Ghost in the Machine*. Arkana Books, ISBN-13: 978-0140191929, London, UK

Koren, Y., Heisel, U., Jovane, F., Moriwaki, T. Pritschow, G., Ulsoy, G. and Van Brussel H. (1999). Reconfigurable manufacturing systems. *CIRP Annals*, Vol. 48, No. 2, pp. 527–540, ISSN: 0007-8506

Kühn, W. (2006). Digital Factory - Integration of simulation enhancing the product and production process towards operative control and optimization. *International Journal of Simulation Modelling*, Vol. 7, No. 7, pp 27-39, ISSN: 1726-4529

Lanz, M., Kallela, T., Velez, G. & Tuokko, R. (2008). Product, Process and System Ontologies and Knowledge Base for Managing Knowledge between Different Clients. *Proceedings of the 2008 IEEE International Conference on Distributed Human-Machine Systems*, pp. 608-513, ISSN: 1094-6977

Lapinleimu, I. (2001). Ideal Factory, Theory of Factory Planning, Produceability and Ideality. Doctoral dissertation, Tampere University of technology, Finland, Publications 328

Lean Enterprise Institute. (2008). *Capsule Summaries of Key Lean Concepts*. accessed September 15, 2011, Available from: http://www.lean.org/WhoWeAre/NewsArticleDocuments/key_lean_definitions.html

Maropoulos, P.G. (2003). Digital enterprise technology-defining perspectives and research priorities. *International Journal of Computer Integrated Manufacturing*, Vol. 16, Nos. 7-8, pp. 467-478, ISSN (printed): 0951-192X. ISSN (electronic): 1362-3052

Mehrabi, M.G., Ulsoy A.G. & Koren, Y. (2000). Reconfigurable manufacturing systems: Key to future manufacturing. *Journal of Intelligent Manufacturing*, Vol. 11, pp. 403–419, ISSN (printed): 0956-5515. ISSN (electronic): 1572-8145

Nagel, P. and Dove, R. (1991). 21st century manufacturing enterprise strategy. Iacocca institute, ISBN-13: 978-0962486630, Bethlehem, PA.

Nonaka, I. & Takeuchi, H. (1995). The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation. Oxford University Press, ISBN-13: 978-0195092691, Oxford, USA

Nylund, H., Koho, M. & Torvinen, S. (2010). Framework and toolset for developing and realizing competitive and sustainable production systems. *Proceedings of the 20th International Conference on Flexible Automation and Intelligent Manufacturing*, July 2010, Oakland, CA, USA, pp. 294-301.

Nylund, H. & Andersson, P.H. (2011). Framework for extended digital manufacturing systems. *International Journal of Computer Integrated Manufacturing*, Vol. 24, No. 5, pp. 446 – 456, ISSN (printed): 0951-192X. ISSN (electronic): 1362-3052

Papazoglou M.P. & Georgakopoulos, D. (2003). Service Oriented Computing. *Communications of the ACM*, Vol. 46, No. 10, pp .25-28, ISSN: 0001-0782

Sharifi, H. & Zhang, Z. (1999). A methodology for achieving agility in manufacturing organizations: An introduction. *International Journal of Production Economics*, Vol. 62, No. 1-2, pp.7-22, ISSN: 0925-5273

Souza, M.C.F., Sacco, M. & Porto A.J.V. (2006). Virtual manufacturing as a way for the factory of the future. *Journal of Intelligent Manufacturing*, Vol. 17, pp. 725-735, ISSN (printed): 0956-5515. ISSN (electronic): 1572-8145

Strauss, R.E. & Hummel, T. (1995). The new industrial engineering revisited - information technology, business process reengineering, and lean management in the self-organizing “fractal company”. *Proceedings of 1995 IEEE Annual International Engineering Management Conference*, Singapore, June 1995, pp. 287-292.

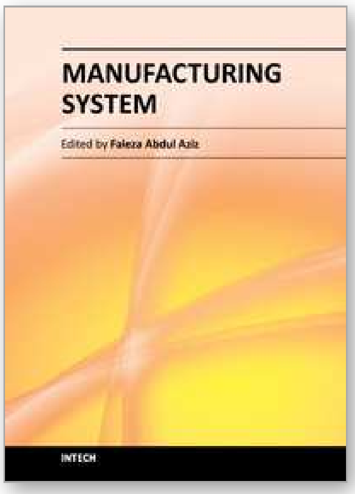
Van Brussel, H., Wyns, J., Valckenaers, P., Bongaerts, L. & Peeters, P. (1998). Reference architecture for holonic manufacturing systems: PROSA. *Computers in Industry*, Vol. 37, pp. 255-274, ISSN: 0166-3615

Warnecke, H.J. (1993). The Fractal Company: A Revolution in Corporate Culture, Springer-Verlag, ISBN-13: 978-3540565376, Berlin, Germany.

WCED (1987) Our Common Future. World Commission on Environment and Development (Brundtland Commission), Oxford University Press, ISBN-13: 978-0192820808, Oxford.

Wiendahl, H.-P., ElMaraghy, H.A., Nyhuis, P., Zäh, M.F. & Wiendahl H.-H. (2007). Changeable Manufacturing - Classification, Design and Operation. *CIRP Annals*, Vol. 56, No. 2, pp.783-809, ISSN: 0007-8506

Womack, J.P., Jones, D.T. & Roos, D. (1990). The machine that changed the world, Rawson, ISBN-13: 978-0060974176



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