

Smart Equipment and Virtual Resources trigger Network Principles in Manufacturing

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Abstract. Computing miniaturization and smart devices rapidly change manufacturing. Decentralization and atomisation of resources uncover novel manufacturing behaviour. Virtual representations of units, processes and resources enforce unaccustomed network principles with strategic impact and irrefutable implications on manufacturing. Eventually manufacturing in total might have to be reconsidered. Distributed manufacturing, largely engaging interacting intelligent manufacturing units and decentralized planning, may be regarded as the manufacturing future. Gradually evolving decision procedures clearly illustrate important effects of irreversible shifts of focus towards units' collaboration and interoperability.

1. Introduction

In manufacturing, newly available technologies offer so far unseen opportunities. Technologies for information processing and communication are about to embrace all important manufacturing areas. Real production increasingly melts with the digital production world. With novel information technology, smarter equipment and networked units, many factories gradually turn into large computing units sending data across and outside companies. Numerous approaches for computerising manufacturing units and processes propagate powerful and fascinating services, ready for implementation. The appearance of novel devices, able to be positioned, to be tracked, to be identified on one hand, also capable to communicate, to act, to negotiate and even to decide on the other is gaining influence on everything that concerns manufacturing. As manufacturing increasingly supports the processes by means of virtualized smart resources, distributed manufacturing (DM) [17] irreversibly extends from automated factory floors onto manufacturing enterprises in total. Advances on the fields of embedded systems, and cyber physical systems additionally accelerate this shift. Important developments are also telecommunication driven and discussed under different chapters, as Internet of things, Ubiquitous Computing, Cyber Physical Systems, Smart Objects or comparable terminology. Decentralisation and atomisation of processes, units and procedures and their virtualisations are in trend. Some principles that had been found for DM now reappear for manufacturing in total, so most upcoming set ups can be mirrored to the DM experiences and respective findings.

As various communities from different disciplines outside of manufacturing are intensively working on new services and novel devices, the most important developments, relevant for manufacturing, are sketched. On the respective fields, the literature, most frequently referred to, as well as pioneer papers with coining terminology are cited; recent developments in manufacturing are



introduced in accordance with international, governmental or industrial institutions. The proposed virtualisations are largely based on information models, so a structured overview on frequently used models in manufacturing is recalled. To obtain closed and coherent descriptions of networks, topological spaces are introduced as a base for further discussions. The space construct, as outlined, reduces down to the essentials on one hand; on the other hand it is powerful enough to capture all relevant aspects of networked manufacturing. The possibility of smoothly attaching model worlds to the nodes of the space literally imposes interpretations of cyber physical production and smart objects. The resulting set of loosely coupled, autonomously acting manufacturing units are evidently subject to principles and modes of complex structures that are known from advanced mechatronic systems and DM set ups [18] already. In this context, procedures for controlling the behaviour of units and the generalized principle of encapsulation are outlined for generalisation. The final section is devoted to technical and managerial implications.

The paper aims at offering a more comprehensive theory base for virtualizing manufacturing which helps to anticipate an emerging “smart age” of manufacturing. Practitioners should be provided with some trajectories on these rapid developments and expected impacts as inputs for their decisions and to verify their gut feelings for the next steps in organising manufacturing network processes.

2. ICT Breakthroughs with Disruptive Impact

Intensive research and development in the fields of telecommunications, computer science and engineering shows vast progresses. Miniaturised, smart and multi-functional electronic devices with enormous computation capabilities and with high mobile, ubiquitous, uninterrupted, and embedded capabilities are already in use in daily life [1]. In consequence, ICT changes the working environment in manufacturing as well. Some important IT developments provoked intensive actions and reactions in the manufacturing world, not only on company levels but on national and international levels [28] as well. Considering the fact that telecommunication, software and computer industries involve biggest players with enormous research capacities on this field, more brilliant innovations will be ahead with radical and disruptive consequences throughout manufacturing. Their potential cannot be ignored by manufacturing companies as the use of these novel ICT achievements are expected to be comfortable and efficient on various other sectors; undoubtedly they will irreversibly and broadly find their ways into the manufacturing world.

2.1. Cyber Physical Systems

Some years ago, an object virtualization method has emerged, known as Cyber-Physical System (CPS, also DCPS if distributed) [26], [32], [36], meaning the integration of computing systems with physical processes and physical environments. Major motivation behind the notion of CPS is the need to design and produce reliable and sustainable computing systems that work in harmony with their surroundings [30]. Components are networked at every scale and computing is deeply embedded into every physical component, possibly even into materials [33], [7]. Exploiting CPS for manufacturing has brought up the terminology of Cyber Physical Production Systems (CPPS), which is strongly propagated in the national funding scheme Industry 4.0 in Germany. The introduction of CPS into automation is expected to break up the monolithic functional automation pyramid into virtualized distributed networked nodes that are more difficult to handle; therefore machine toolmakers claim urgent need for joint actions. When using CPS [35], components could adapt themselves automatically to the other components, which inevitably changes the way in which these CPS-enabled components are designed and manufactured. Therefore manufacturers see reasons for totally rethinking industry and industrial production when establishing CPPS to take full advantage of the introduction of CPS, [35].

2.2. Internet of Things (IoT), Pervasive Computing and Smart Object (SO)

Some text Parallel to CPS (US), computer scientist had come up with the Internet of Things (IoT) in the context of ERA (EU). CPS and IoT cannot be clearly differentiated, since both concepts have been driven forward in parallel, although they have always been closely related [5]. The IoT is considered a

part of the future internet and could be defined as a dynamic global network infrastructure with self-configuring capabilities, with physical and virtual objects carrying own identities and specific attributes like virtual personalities; they use intelligent interfaces and are online connected the information network. IoT is of interest to manufacturing. In industry, the “thing” may typically be the product itself, the equipment, the transportation means, etc. It is obvious that these developments, too, accelerate the integration of Smart Objects in the Internet. Additionally pervasive computing has migrated from desktops to mobile phones, and computing is increasingly included into a variety of objects.

By adding more data to objects, we are witnessing the upcoming of a large IoT, where every object has his proper identity (e.g. [8]). We shall experience smart worlds full of smart objects [14]. A Smart Object (SO) is an autonomous physical/digital object augmented with sensing, processing, and network capabilities. RFID technology is closely linked to SOs. In contrast to RFID tags, SOs carry chunks of application logic that let them make sense of their local situation and interact with human users. Coupled with software agent technology however, RFID can transform everyday objects into smart objects as well [6]. Therefore smart objects and all the developments around are widely considered as of highest relevance for manufacturing, because RFIDs are applied in manufacturing as solution components since years already.

2.3. Ubiquitous Computing (UC), Cloud Computing, Cloud Manufacturing (CM), Grid Manufacturing, Cloud Based Distributed Manufacturing and Hybrid Clouds

UC, too, has contributed to upgrade objects to become smart objects, which can provide new services that could not have been imagined before, because of the steady connection between the real-world objects and the intelligence of information systems. UC denotes another vision of a future world of smart objects, physical items with physical shape and function being extended into virtuality [20]. Miniaturizations of computer technology will result in smallest processors and sensors for integration into more and more everyday objects, outdating accustomed computing equipment. Instead, people will be able to communicate directly with their clothes, or watches, or pens, and these objects will communicate with each other and with other people’s items [10]. UC cannot be considered a proper technology or classified as a new functionality, rather as a set of functions which as a sum creates novel computing [31].

Cloud architecture may provide users with computing resource options of configurable, virtual manufacturing networks, based on models like federated factories or software service applications [24]. Cloud computing is a novel model for enabling ubiquitous on-demand network access to a network of computing resources that can be instantly accessed and released with little effort or third party interaction [26]. A cloud is parallel and distributed computing net, composed of a set of interconnected computers, presented as one unified computing resource that is available according to service-level agreements [3]. Virtualisations of resources and fast interconnections open up companies in general and manufacturing areas in particular to new services and services’ architecture i.e., cloud hardware-as-a-service (HaaS), cloud software-as-a-service (SaaS), cloud platform-as-a-service (PaaS), cloud infrastructure-as-a-service (IaaS). Virtualized computing resources allow big data storage and rprocessing, cloud ERPs and Cloud CRMs are already available, online monitoring and positioning of all products and resources enable tracking and fixing issues in real time, allowing companies to instantly improve all attributes of their manufacturing process.”

A number of researchers already propagate to specify Cloud Computing into Cloud Manufacturing CM (e.g. [40]). CM is anticipated as a new mode of networked intelligent manufacturing which is service-oriented, highly efficient and advocates immediate implementations of the concept of Cloud Computing in manufacturing. CM may, indeed, become a networked manufacturing mode with quickest responses to market demand, enhanced competitiveness and facilitated collaborative manufacturing [41]. Furthermore Resource Cloud Encapsulation RCE of soft and hard manufacturing resources with resource sharing is projected as services for further resource virtualization in CM [25].

In IoT and CPS, information technologies are used to access and to connect manufacturing resources. In RCE, moreover, all physical manufacturing resources are seen as transferred into logical services; based on complete resource virtualization, RCE technology constructs large-scale virtual manufacturing resource pools that can be used for interacting and feedback control of manufacturing. RCE is supposed to largely reduce the coupling between physical resource and manufacturing application by the transferring physical resources into logical resources and virtual CM services with instant utilization, high agility, high security and high reliability. In addition, resource pooling and virtualization might enable even more sophisticated solutions under Cloud-Based Design and Manufacturing (CBDM). This is a type of parallel and distributed system consisting of a collection of inter-connected physical and virtualized service pools of design and manufacturing resources [38] possibly triggering new perceptions of product design and manufacturing.

All cloud solutions enable to dynamically adapt in order to satisfy unpredictable or unexpected demand. Such manufacturing clouds support scalability to a certain level, e.g. manufacturing units, general purpose equipment, and standard components for machining. Given that the cloud is a huge shared service pool of design and manufacturing resources, it may also be possible for cloud service consumers to find some dedicated tools and equipment for some specific products available in the manufacturing cloud that can satisfy their requirements [37].

Public clouds are handled by external providers, and the data of various clients may be mixed in factories, servers or CPUs of the cloud. End users do not know, if other clients' orders are executed, too, in a factory, not even in one and the same manufacturing unit. Private clouds are a good choice for companies that feel the need for high data protection. Hybrid clouds that combine the models of public and private clouds may be the key to achieving an external supply in scale form and under demand, but these clouds add the complexity of determining how to allocate tasks and processes across these different environments [23].

3. Model World of Manufacturing and ICT trajectories

Whenever we talk about interacting, negotiating and communicating objects, we always talk about respective models of these objects performing such activities. Also planning, decision and execution in manufacturing does obviously not regard the units themselves but certain models and attributes of these units that configure and are put into relations. Each step may make use of a number of models interacting, raising the question of how their dependencies and simultaneous actions influence choices, highlight attributes or require certain levels of detail of these models to be involved. The manufacturing network units' interaction structure must be envisioned as an interrelations' structure of specific models, representing these units. Envisioned like this, manufacturing does not just consist of simple units but of objects that encapsulate rich model structures, able to unfold numerous attributes and properties into the attached realm of models.

Manufacturing networks may then be interpreted as specific Hausdorff spaces. The topological nature of Hausdorff spaces allows identifying network units (nodes) and to attach tangent spaces to each one [19]. The set-up is rich enough to capture a vast majority of configurations and decision situations occurring in manufacturing networks. This is accomplished by "attaching" tangent spaces carrying adequate models, attributes, relations and aspects assigned to the manufacturing networks' nodes (Fig. 1). Moreover, these virtualizations of manufacturing objects, also called mappings, capture e.g. encapsulations of behaviour, fold and unfold properties, on-off modes of self-organization. Configurations may be mapped and monitored as well by models, indicators and attributes, and the views are expressed by composite attached models, the reason why all mappings are assumed to be homeomorphous.

In practical terms, the homomorphism postulate stands for compatibility of models of different units. Models of tasks of different units can form a process flow model only and models of machines of different units compose a useful layout only, if the respective units' models are compatible. To be able to do this easily, all involved virtualizations of the units will have to be standardised in some way, so a collection of units represented by attached models is instantly able to link, to interact and to

execute important procedures e.g. for manufacturing planning, structuring, operating, linking, improving and deciding.

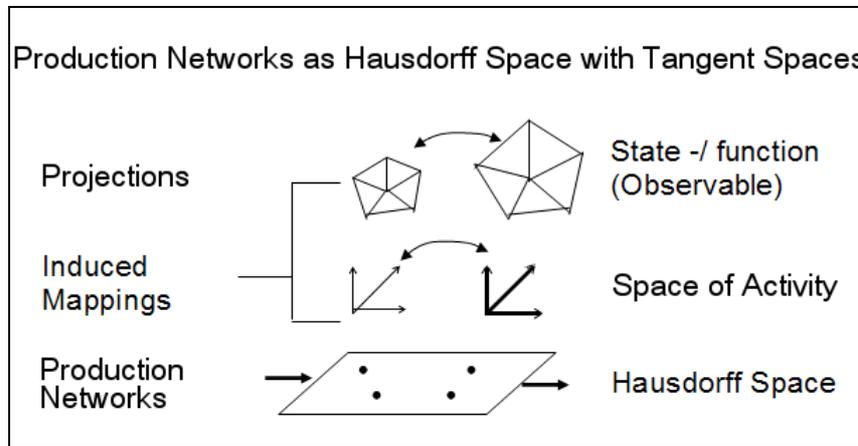


Figure 1. Production Networks’ units with attached tangent spaces (models) as mappings of Hausdorff Space nodes according to [16]

3.1. Models for manufacturing management and -planning

To answer the question about which models are to be attached for manufacturing applications, which properties and attributes ought to be mapped, the chapters of manufacturing systems planning and control history may be recalled.

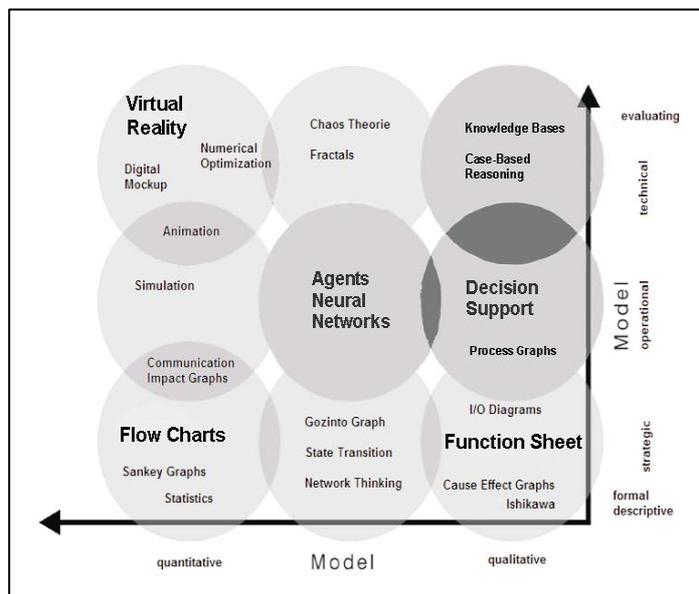


Figure 2. Portfolio of generally used information models for manufacturing planning and decisions, attachable to the network units according to [18]

With the sophistication of manufacturing, important abstractions and experiences have been consolidated into a collection of generally recognised models, instruments and tools. With the introduction of computers in manufacturing, many of these models and instruments (or derivatives thereof) have been successfully incorporated in standard software e.g. ERP, Cave, DSS or facilities’ planners (Figure 2). Manufacturing management generally makes intensive use of these models and model systems for specific problem solving, routine decisions and planning support, for instance for shopfloor planning, adequate models are flow charts, Sankey graphs, DMU/VR based on geometry

data of buildings and machines. A structured approach to display important sets of models for manufacturing has been made in the context of concurrent enterprising and collaborative distributed planning, which could be considered as a base for virtualizing manufacturing networks.

3.2. ICT use and Manufacturing Models' availabilities

Of course, the application of the models, as described above, depends on the availability of computing power and respective software. Even for the near future it is foreseeable that most smart units in manufacturing will have enough computing power to carry these as an encapsulation. Just to trigger some ideas, the progress in decentralized ICT support with availability of these models for manufacturing processes may be illustrated over the time line and the data volumes involved (Figure 3).

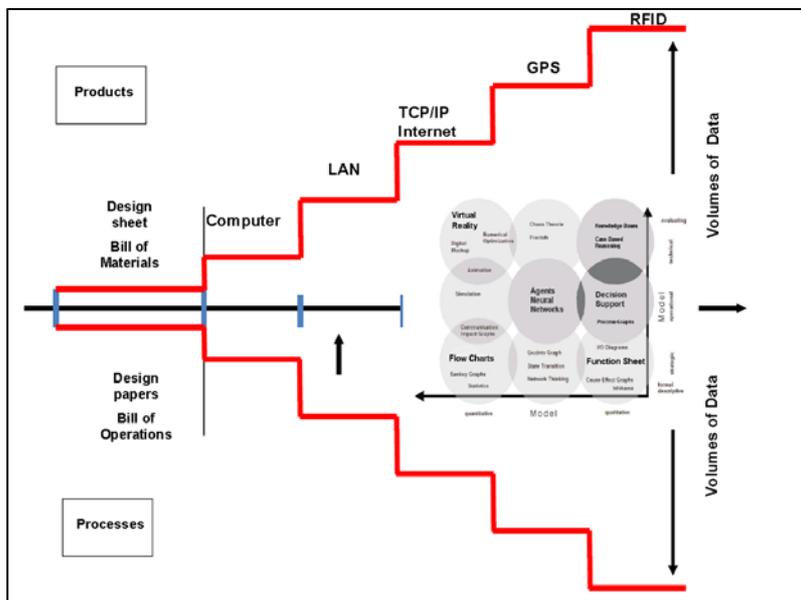


Figure 3. ICT devices and corresponding data volumes and respective model worlds to be implemented, arrayed on a timescale.

As one trajectory for future manufacturing it may be kept in mind, that manufacturing units may be imagined as carrying all the models discussed above ready for application to link, to compose, to negotiate and to decide, processed by own computing power or remote. Manufacturing then appears as a set of loosely coupled autonomous smart units, spontaneously forming networks and executing processes; concurrent and evolving planning; negotiating decisions, all by interrelating models. This appearing set up seems to be quite different from what we are accustomed to when describing manufacturing and manufacturing management. Therefore it may be considered worthwhile to take a closer look at this emerging world of smart manufacturing units and the rules of the game there and to search for characteristics and principles.

4. Principles, Properties and Modes

On a smaller scale, many of the phenomena stated have already been encountered with configurations of distributed manufacturing [17]. Seeing all the similarities, the attempt to generalise and widen up important principles that have been identified for loosely coupled manufacturing systems, to the manufacturing networks' level, appears most promising. For start, a list of properties for smart units in manufacturing may be given that support compounding manufacturing processes of networked elements. Most of the capabilities, which smart objects for general use include already, are suitable for manufacturing process set ups, therefore their adaptation is less a question of requirements fulfilment, and it seems to be more a specification matter.

4.1. *Smart Units' Properties and Requirements*

4.1.1. *Modularity.* For increasing flexibility of operations as well as the ability to be easily reconfigured due to changing conditions, typically modularity is introduced into manufacturing operations and equipment design. Modularity is generally followed by distribution of functionalities, frequently accompanied by physical or/and geographical distribution. The principle of modularity is known and widely used in manufacturing and organisation already.

4.1.2. *Heterogeneity.* Due to the variety of devices and units engaged, the manufacturing networks are intrinsically heterogeneous. Heterogeneity can occur on various levels and for a number of reasons; on the technical level, heterogeneity originates from different hardware platforms, operating systems, database management or programming languages; on the conceptual level, heterogeneity originates from differences in understanding and modelling the same real-world phenomena.

4.1.3. *Time Synchronisation.* Timekeeping technologies, e.g. from positioning system satellites and the Network Time Protocol provide real-time approximation of Coordinated Universal Time (UTC, world time standard) are used.

4.1.4. *Interoperability.* Technologies for realizing smart devices have already been around for years, standardized by the IETF. Interoperability is the ability of two or more systems or components to exchange information and to use the information that has been exchanged [12], [15]. In distributed manufacturing, interoperation abilities are aimed at on all levels, people resources, between enterprises and enterprise units.

4.1.5. *Scalability.* The capability to extend resources in a way that no major changes in structure or application are necessary is generally referred to as scalability. Due to stronger links between cyber objects and real manufacturing units, the term of scalability becomes relevant for manufacturing systems too. For example, the cloud system allows the cloud service consumers to quickly search for and fully utilize resources, such as idle machines, in a different company to upscale manufacturing capacities.

4.2. *Concurrency Modes and Mechanisms*

Recognizing these potentials is surely not exaggerated to postulate the necessity of a complete re-thinking of manufacturing and a thorough revision of every well established and habitually used, so far proven and uncontested, manufacturing setup. It's not only the fact that all solutions have been set up without employing such options and technical possibilities, it is no longer possible to establish factory centred solutions on the base of pure systems thinking, widely ignoring the network nature of manufacturing. Most prominent examples are deeply rooted for example the term of process and supply chain in manufacturing; in reality we work on the base of process and transformation stage networks, which expose process chains ex post as planning and decision results.

4.2.1. *Behaviour.* Behaviour is the range of actions made by systems, or abstract units, in interaction with other units and the environment. A unit shows its state in indicators (variables, data) and exposes its behaviour through methods (functions) that react to certain events. Process parameters present the behaviour of a unit and its interactions with other objects. Monitoring tools enable the users to specify and to process-level events such as inter process communication, as long as these events are at the correct level of abstraction of the network units, as successfully applied in DM [17]. As a representation of the units' behaviour, Spaces of Activity (SoA) may be described by the units' objectives, the resources and constraints. In consequence, the SoA volume may be identified as the unit's decision space i.e. admitted zone for the units' state (Figure 4). The unit's behaviour, e.g. expressed by corresponding indicators, gives input for decisions on maintaining the unit's self-

organization mode or reducing autonomy and calling for external interference. In cases of a unit's inability to cope with the objectives or the changes in the environment, network "order parameters" may gain influence on the units' activities ((self) reproduction, (self) destruction, (self) structuring).

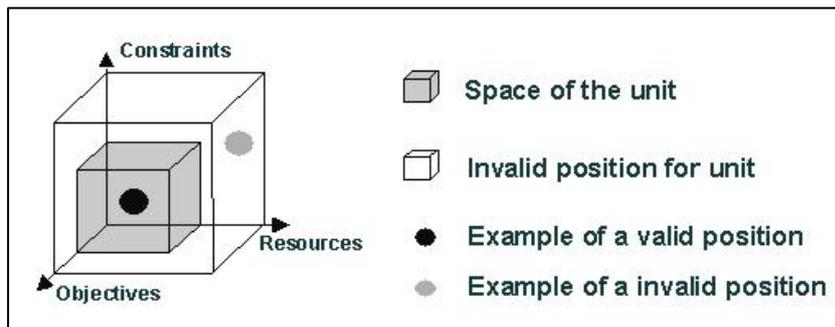


Figure 4. The Space of Activity (SoA), a model mapping of network nodes, monitoring the behaviour of the unit by relevant indicators and observable.

This "biologically" [34] as well as "fractal geometric" [xx] inspired manufacturing model approach addresses challenges in complex (unpredictable) manufacturing environments linked to self-organization, restructuring and adaptation. It makes easily adaptable to changes in manufacturing environments, and coins the global behaviour by the effects of interaction between units [2]. Applied for manufacturing network decisions, such behaviour thinking supports the often encountered "levelled" manufacturing network adaptation procedures.

4.2.2. Parallelism. An optimum base for collaborating using least resources and time is to do substantial steps towards parallelism of all actions and operations. Parallelism aims at reducing execution time or improving throughput. Adding parallelism to an event driven view requires reasoning about all possible chains of transitions to determine events that might interfere with others.

Parallelism for mobile applications uses operation time and requires sophisticated algorithms since it is not sufficient to run just a few services in parallel. Mobile systems are power constrained but improved wireless connectivity enables shifting computations to servers or the cloud. Leading experts state that, generally, parallel systems can be expected supporting task parallelism and data parallelism, both essential for decentralised and distributed manufacturing applications. Eventually each node of a task can have multiple implementations that target different architecture [4]. For manufacturing applications this allows taking full advantage of the task parallelism on one hand and running independent operations in parallel on the other. Parallelism will revise process planning, for example, by building sequences from independent sub-sequences. For parallelism of operations in manufacturing, industrial networks will strongly rely upon dynamic forms of communication and coordination that handle non-predictable situations by self-adaptiveness and self organization.

4.2.3. Iteration. Developing configuration options and decide about favourable configurations is a highly iterative process and not a straight-line journey. Loops back are possible, as factory and network capabilities identified and may not fit or others may give rise to potential new business opportunities. The 'Iteration' mode emphasises the fact that there is an inherent, evolving nature to structuring. Iteration results in changes that must propagate through the structure's stages, requiring continuous process rework. Within simple settings of collocated operations, the challenge of managing can still be achieved by conventional planning systems and respective intra-organisational decision mechanisms. For networks, management becomes much more complicated, as the involved units and their roles are not stable, but evolve dynamically. However precisely these properties enormously increase a companies' adaptabilities and strongly amplify differentiations and uniqueness. This means continuous restructurings and adaptations for manufacturing networks as well. For the decisions on structuring, re-linking, or breaking up connections in manufacturing networks, iterative procedures

develop both system structure models and map behaviours onto structures vice versa, ensure the manufacturing networks robustness, their stability against uncertainties, operator mistakes, or imperfections in physical and/or cyber components. Since integration into processes must be orchestrated in order to achieve suitable performance behaviours, it is necessary to ensure the expected alignment with respect to the fit degrees, similar KPI or (estimated values of) key alignment indicators (KAI) [29].

4.2.4. Encapsulation. In general, encapsulation is the inclusion of one thing within another thing so the included thing is not apparent. In DM, encapsulation is concerned with the possible encapsulations of abstractions of units (e.g. models or task descriptions) and transformations (e.g. processes) [17]. The Encapsulation mode enables to build networks and processes by combining elements for creating new processes and units or for atomising units to obtain elements. Self-similarity and compositionality of a unit or a process is a direct consequence of unit- or task encapsulation and provides the basis for constructing networks from components [21] [xx]. The models of a unit are accessible through interactions at the interfaces supported by the models. The model element may be seen as based on connectors (links) to construct and compose units. In the tangent space projection, there are two kinds of elements. (I) unit models, and (II) connectors.

The units are loosely coupled and their control is originated and encapsulated by connectors, which is used to define and coordinate the control for a set of components (element or composite). Indeed, the hierarchical nature of the connectors means that composite units are self-similar to their sub-components; this property also provides the basis for hierarchical composition. Each unit model may additionally encapsulate more models and methods.

In a composite, encapsulations in the sub- units are preserved. As a result, encapsulation is propagated in compositions of newly constructed components (units are self-similar) and is also closely related to components' reuse.

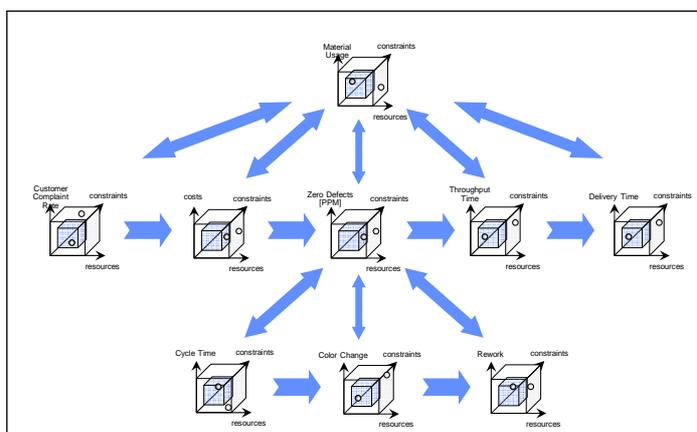


Figure 5. Breakdown (unfolding) of encapsulated behaviour into desired Levels of Detail.

Encapsulated models of units and connectors, may arbitrarily be compressed/broken down resp. fold/unfold (Figure 5). For instance a critical behaviour of a unit on a lower level may have to be compensated on a more aggregated network level or even at the configuration level of the total manufacturing network. Arising criticalities are to be negotiated and harmonized with other units' objectives and resources. A unit's behaviour may generally result in decisions on maintaining the self-organization mode, reducing or removing the autonomy and calling for network interference along the subsequent decision cycle.

Strategy and Objectives.

The network gets vision, mission and network draft which will later be detailed in order to generate the design and the operation parameters. The network strategy has to support the idea that in order to

truly align the structure with business requirements, units must be free to negotiate and to choose the solutions that best meet their unique needs.

Monitoring and Analysis.

This stage tracks the execution of the manufacturing processes. It executes by detecting/ sensing the current state of the business and operational manufacturing environment, by monitoring the manufacturing-related business processes for determining if the manufacturing units' behaviours are acceptable (e.g., concerning economic performance), for capturing (unexpected) events and continuously informing on the current situation (e.g., desired, undesired and unexpected events). Activities that constantly update the units' potentials, capabilities or availabilities or that check the network for underperforming units and that notify the network in cases of outages or other alarms, recognised by units' criticalities. Structures, mechanisms and outputs are studied, compared and rated. These analyses may be driven down to sub or sub-sub levels where resource configurations and their contributions to the objectives as well as the SoAs structures (incl. the criticality settings) are broken down. In cases of less severe criticalities, improvements or objectives' alignments are initiated. Severe criticalities will provoke networks' adaptations or reconfigurations.

Network design.

The network is be configured to meet customer requirements best. Partners, units and other actors are identified and linked to a network structure. Processes have to be linked and assigned to responsibilities.

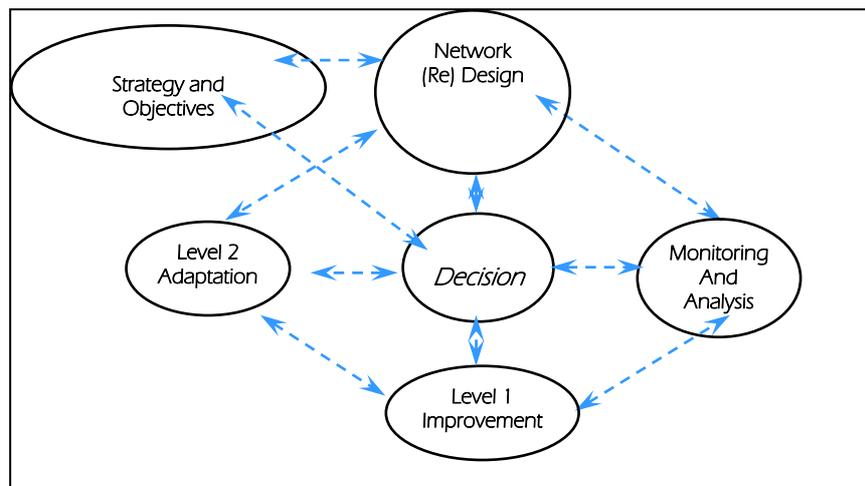


Figure 6. Revolving decision cycle procedure of levelled interventions in manufacturing for gradual continuous configuration.

The strategy elements may be broken down to the decisive factors and the respective indicators that cover all key areas of the networks. They may result in relations of sub objectives and/or aggregated objectives' systems.

Decision.

The decision phase marks the point where the necessary initiatives are taken in order to support the networks evolution into the intended direction. All decisions of importance may be taken, revised, improved or repeatedly cancelled within this cyclic procedure (Fig. 6) i.e. previous program strategy, network configuration, make/buy decision, site decision, process/technology/equipment decisions, etc. are revisited regularly. History and time (complexity attributes) might hinder to execute the resulting

decisions immediately. Structures might exist that cannot be instantly eliminated or the building of new competencies will take some time. For the modelling of the network it is therefore recommended to maintain other models (structure simulator) beside the model of the given actual network. These models should provide for “what if” evaluations and simulated comparisons of indicators that make visible, to what extent the actual configuration shows “suboptimal” effects on the results.

Figure 7 illustrates the self-similarity of composite components in a decision network involving the decision cycle as described. Most importantly, every composite component is similar to all sub-components. This means that composition is done in a hierarchical manner. Furthermore, each composition preserves encapsulation. The topological nature ensures that the hierarchical structure of the encapsulation enforces additional rules to ensure the overall process optimum.

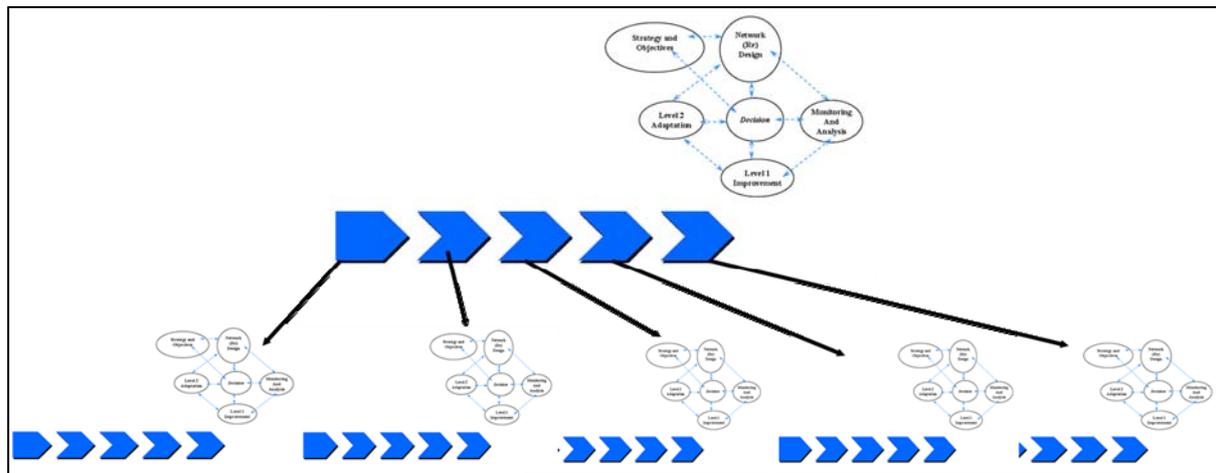


Figure 7. Meshed decision cycles including encapsulated models and instruments to negotiate and decide on manufacturing networks' process fulfilment on several levels of detail according to distributed manufacturing/properties.

A unit component encapsulates all necessary models and procedures. A composite component also encapsulates computation and control [21]. For decentralized decision making based on network business models special logics, algorithms and methods for integration and management seem to be necessary. This concerns the matching of partners as well as the temporary collocation of operations in manufacturing networks. On this basis, all units' behaviour as well as all interrelations may be optimised and planning procedures and logic for the meshed control of configurations, containing processes and resources in networked manufacturing structures, may be established.

4.2.5. Emergence. Emergence focuses on the arising of new patterns, structures and characteristics of networks that are neither really predictable nor fully deductible from antecedent states, events or conditions. DM configurations are ideally envisioned as emergent. Generally, emerging set-ups are characterised as dynamical, meaning they arise over time, as coherent, meaning they show somehow enduring integration and occasionally as ostensive, meaning they appear during a set up evolves. In the smart world as outlined, manufacturing processes may therefore be seen as emergent items as well, corresponding to the term emergence precisely in this sense. Complexity science has means to express links and dynamics of interconnectivity, or what in complexity discourse is traditionally termed “emergence”; arising of unforeseen new structures with unexpected new properties e.g.[11].

Example.

In automotive car body shop the model as well as the decision structure was implemented in order to optimize a buffer system and to make the shop more flexible. The objective is to optimise the processes and outcome within a storage area by using adequate commissioning strategies. All objects

regularly interact (Iteration) and can simultaneously (Parallelism) be addressed. Every part, every box and also the equipment and the human agents are represented as a Space of Activity (SoA) (Behaviour) and have possible process models available (Encapsulation).

The storage area operates on the basis of commissioning parts. Availability parameters as well as performance indicators are monitored and analysed. Criticalities concerning the spaces of activity activate the decision cycle. The revolving logic switches to the improvement step trying out three options 1 Commissioning of parts, 2 Commissioning of boxes containing respective parts, 3 Manual commissioning depending upon their feasibility. For the cases if commissioning of boxes is sufficient, the system operates on this mode, as long the indicators for the parts commissioning are not more favourable. If the commissioning of boxes runs out of feasibility, it is switch to manual commissioning. The last resort of restructuring would mean a long term investments decision which is done on a more aggregated level. If all of these options fail, the decisions on the supply of material are given to a higher order decision instance, having in either total process/manufacturing network.

The decision cycle will firstly assumes the commission to box as to be supplied to the area, as this is not always possible the option offered different boxes containing their respective parts for picking is chosen, leaving the commissioning to the assembler if this is not possible for as improvement the commissioning is to be manually done by the workers.

The total setup represents a network of mechatronic systems with meshed controlled elements. The above features of the system appear as encapsulating these coupled elements and the networked system. Information processing uses different terminology for control levels. Higher levels are in charge, as soon as the regular process, its improvements and additional efforts are unsuccessful to meet the objectives. The cyclic nature of the decision process was not fully implemented in the practical example (automotive supplier), as the procedure contradicts the time sliced linear overall planning logics in the network (ERP logic) on the more aggregated system levels.

In Figure 7, the process chain emerges as a result of the interactions between units. There is no ultimate configuration solution to be found beyond continuous adaptation and restructuring. To state that process chains emerge, however, does not mean to abandon overall planning. Rather than deriving outcomes by rigid adherence to preconceived strategies, the key for ensuring good solutions is to focus on creating effective rules for interactions. These rules ensure alignments among participants that increase the likelihood of favourable emergent network configuration leading to the objectives fulfilments aimed at.

5. Conclusions and Outlook

What definitely follows for industrial practice is that non-hierarchical views of manufacturing will fully establish. Iterative concepts of planning and control will replace central, sequential, rhythmic and time sliced procedures by event-driven parallel distributed evolving logics. Manufacturing will introduce and apply new types of methods and tools, supporting linkage and reconfiguration as well as high level plug & produce, plug & participate and concurrent work skills.

Any decisions on implementation of smart units in manufacturing as well as virtual resources as services are elements of a company's core strategy and cannot be delegated to IT experts or service providers. The services required by manufacturing differ from general services. The main points, which highlight manufacturing, are interaction ability; powerful functionality (manufacturers will want to streamline business processes and to optimize inventory), real-time ability and Multi Corporation set up.

More standards on all levels will be defined, most likely on international level and done by institutions outside of manufacturing. For implementation decisions, it's rather a matter of choosing and evaluating than developing own standards or engaging in standardisation organisations. It is always worthwhile to keep an eye on rapidly spreading devices of telecommunication and respective freeware for general use that could eventually establish irresistible quasi- or de facto standards.

Manufacturing near associations ought to provide recommendations which existing or upcoming standards should be considered.

Many virtualization instruments address manufacturing main processes, hence key productivity issues. The use of resources along these models will translate into lower costs for all involved units. Early adopters of such novel distributed manufacturing options might immediately set so far unseen KPI benchmarks and cause competition pressure. Specialization of manufacturers using complex and expensive machinery or factories to develop certain products or sub-products for other manufacturers is facilitated.

Moreover these systems might instantly demonstrate drastic changes in the forms of manufacturing or manufactured products and, especially, could initiate novel business models synthesising new services and new products. Business model development should focus on the research questions [37]. Why would those involved in this business model choose a smart operating environment over a traditional manufacturing environment? How will equity be assured when value is delivered as a result of shared-interest, multiple-party work? How should IP be handled in collaborative environments?

Especially, Cloud Manufacturing allows easy integration of applications and processes both within an organization and between different organizations that wish to collaborate. However, some of the greatest concerns are security problems, loss of control (infrastructure, services, and management), technology, difficulty in migrating to other platforms, and loss of reliability. Companies may feel most attracted to the hybrid cloud, an option that might be reserved for applications, which do not require any synchronization or highly specialized or expensive equipment. Initially, hybrid solutions with large portions of proper company implementations are expected.

The development will challenge HR policies. If comparisons to mechatronics and distributed manufacturing hold, there will be mainly high/ICT skilled experts around in these virtualized manufacturing areas. General use of smart services should be sensitive to potential cultural and organizational differences in users' motivation to participate. Collaboration is not always considered appropriate and reasonable across cultures. Control beliefs should be encountered by informing and enabling users. An abort function or a similar type of "emergency feature" to cut off the provider from the user's smart object can easily be installed. Another major finding is that companies should train and provide the entire staffs, not just the "front-line employees, in order to improve their social interaction skills in this technology-mediated service setting. It is important to understand that the introduction of smart interactive services substantially changes the way providers, manufacturers and customers interact [39].

Apart from the possible criticism for its novelty, there is an open controversy with this kind of manufacturing virtualization and all similar approaches, in which IT has a starring role. However, the actual virtualization wave in manufacturing is, despite of obvious gaps and high risks, unstoppable, because the advantages of these technologies are evident and their benefits are indispensable for manufacturing. Mechatronics and distributed manufacturing are intensively working with intelligent devices and units that are networked, so these fields have provided substantial work to incorporate network principles in processes and process control. Advanced implementations from these fields may be seen as the manufacturing of tomorrow in the nutshell where managements don't take but rather game their decisions. Generalising important chapters of this work could bring multiple advantages when consequently expanded into the manufacturing world in total.

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