Asian Journal of Information and Communications 2017, Vol. 9, No. 2, 144-156

KISDI KOREA INFORMATION SOCIETY DEVELOPMENT INSTITUTE Asian Journal of Information and Communications

Smart manufacturing – expanding the systems approach onto complex networks

Hermann Kühnle*
Otto-von-Guericke-University of Magdeburg

Hessamedin Bayanifar**
Otto-von-Guericke-University of Magdeburg

Abstract

Smart properties of manufacturing units inevitably introduce novel network driven concurrency principles to manufacturing networks. Playing this game will unravel the full list of advantages of the network compared to the systems, especially under time pressure or facing frequent and major modifications. The actual value chain, an object passes, is only known ex-post. Specifically, designed checks and verifications, negotiations and dependability mechanisms will optimize operation units' behavior and all communication links.

Keywords: networked manufacturing, inter-disciplinarity, concurrency principles, hybrid decisions, dependability

1. Introduction

Recent developments in manufacturing science and management have been advancing fast. Many approaches already went beyond the limits of the systems' thinking as the restrictions there appeared critical. Meanwhile it is a commonly accepted fact that other backgrounds, such as network theories or complexity thinking, are seen to be most adequate to cover recent developments in manufacturing and management than the widespread general systems thinking pattern. Moreover, shifts in perceptions of manufacturing are regularly inducing paradigmatic debates often pointing at social -, resources'- or ICT etc. dimensions to be included stronger and hence demanding for widening the scope. On the other hand, neither established production and manufacturing technology nor do management sciences seriously deny that their body of knowledge clearly hits limits and loudly encourage further incorporating extra-disciplinary approaches and novel dimensions, achieved by other disciplines. Consequently, considerable work in the manufacturing networks' area and the corporate network domain has already been done at intersections to other disciplines and extern fields that calls for solid scientific grounding or at least a more theoretic foundation. Among the eligible disciplines that make worthy contributions we may enumerate theory from Complex Adaptive Systems, Decision Sciences, Evolutionary Biology, Game Theory, Organisational Theory and Sociology, alongside more traditional approaches from Network Management. Concepts from Data Exchange, of course, are seen as relevant to structured communication protocols. From all these disciplines and fields contributions have been made to

* Corresponding author: hermann.kuehnle@ovgu.de
** hessamedin.bayanifar@ovgu.de

investigate and to describe phenomena of manufacturing networks and related changes that are taking place in industrial entities. By better embedding of practical achievements into theory, key problems in manufacturing networks eventually become more effectively tractable within established research fields.

As all smart units, manufacturing units too, may be seen as specifications of the IoT and CPS (Cyber-Physical System) (Kawsar and Nakajima, 2009; Möller, 2016), along with CPS and IoT, cloud manufacturing too has been presented as representative technologies enabling smart manufacturing systems (Kang, Lee et al., 2016), as the convergence of cyber world and physical world in manufacturing area through intensive collaboration of computer science and information and communication technology with manufacturing science and techniques is leading to the 4th industrial revolution (Monostori, Kádár et al., 2016). Manufacturing will increasingly appear as equipped by physical or/and digital objects, upgraded with sensing, processing, actuating and networking capabilities (ZVEI, 2016). Additional abilities, as environment-awareness or self-logging and self-reporting features further augment these objects and allow carrying many data about themselves as well as their activity domains. Such vast global connectivity and exposure to cyber space also brings dependability and security of these systems into further concerns (Bitkom, VDMA and ZVE, 2016; Marwedel and Engel, 2016). Moreover, smart units may make emerge network structures, e.g. as results from their collaborative processes executed by manufacturing units striving for incentives (attractors). Smart manufacturing networks are being composed of self-optimising, self-orienting entities, managed as well as formed by defined rules. Network management establishes proper and genuine processes or initiates interactions, where units float within network configurations or collaborate and communicate on all levels of detail. Some configurations seem more favourable than others in some respect, so continuous monitoring has to evaluate for gradual and stepwise decisions or configuration alternatives; main issues are linking or detaching. In Smart Manufacturing, business opportunities represent such governing "attractors", giving inputs to drive, to operate and restructure manufacturing networks to build up and to optimize versatile collaborative process nets. Within such structures, taking into account the smartness of the participating units, even huge numbers of peer to peer interactions are quicker and cheaper than comprehensive hierarchical planning and control.

This paper aims at developing a theory base for smart manufacturing systems' principles and properties, and dependability mechanism.

2. Methods

2.1 Theory extension approach

"Philosophy of Science is about as useful to scientists as ornithology is to birds."

Richard Feynman (1918-88), Physicist

All developments in manufacturing went on revealing more and more the network nature as a clear result of the manufacturing processes being in the core and, of course, networks and the local distribution of manufacturing processes, too, instantly leads to areas beyond state of the art. Particularly, for manufacturing networks, which may be very generally considered as human-governed and systematic combinations of means of technological and conceptual procedures in order to transform inputs into outputs in the sense of marketable products, the phenomena as well have to be described in technological, socio-economical, social, process or strategic perspectives. Consequently, efforts on the domain of Smart Manufacturing networks should be aimed at intersections with other disciplines and fields, mainly in two directions.

First, the extension of the validity of constructs should be driven forward resulting from the application to aspects from the complex nature of Manufacturing Networks. Such extensions of validity, however, are confined to the prevailing notions and applications; e.g. the common modus operandi of high-frequency adapted traditional planning reacting to the non-foreseeable market movements which can only be coped with by immediate restructurings.

Second, there should, indeed, be efforts of further theorising and to engage disciplines that have already been active in research on Manufacturing Networks more intensively, such as social sciences, information sciences (network's software agents, telecommunication) and management science together with mathematical fields. Comprehensive theory work for manufacturing should preferably take into account distinct disciplines, such as network theories or complexity thinking that already proved to be valuable for addressing smart manufacturing challenges; more holistic and more comprehensive views are demanded, and open for adaptation of disciplines' borders and for lending from other domains of knowledge. We argue with that focusing on the intersection of disciplines offers important opportunities to trespass boundaries, to redefine core issues to foster further theory building. Developing skills at intersections gives rise to issues of legitimacy, paradigm convergence, interdisciplinary communication, as well as fresh answers to complex phenomena.

There are three modes that researchers can employ with varying levels of impact – ranging from (1) the mere borrowing of concepts, (2) the extension of original theories with the more ambitious redefining boundaries to (3) the transforming of the core of parent fields and disciplines by new domains (Zahra and Newey, 2009).

Because theory building is likely to generate the richest insights, transforms core disciplines by defining and consolidating domains, as Smart Manufacturing constitutes, our choice has to be for this Mode 3, as it offers solid theory construction opportunities.

For smart manufacturing and manufacturing networks a set up would be adequate, when it allows addressing and assigning attributes and indicators for all relevant manufacturing objects. Moreover, full unit descriptions, capabilities' models and objectives and bundles should be assignable, and communication and decision capabilities should be incorporated. Following the principles of engineering, any set up may be accepted as theory, if it addresses most problems, and if it is currently describing and solving problems at the highest rate, who advocates that theory can be seen along a continuum, from lists (categories), to typologies (comprehensive lists), to impressions of relationships among factors, to causations between and patterns among these relationships and to fully explanatory models. Consolidation work on scientific theory may be achieved by:

1. Improving congruence of observations and predictions,
2. Defining quantitative or phenomenological laws,
3. Outlining master examples for the solution of scientific problems including the incorporation of new discovered phenomena (Kühnle and Dekkers, 2012).

A construct may definitely be envisioned as theory, if designs for the description of contexts and a comprehensive frame are melting substantial interdisciplinary contributions tightly together. Since mathematical tools represent a common language, facilitating communication among and between disciplines, mathematical set ups are generally given "natural" superiority in interdisciplinary contexts (Kühnle and Bitsch, 2015).

In order to demonstrate the interaction mechanisms, hybrid control decision making – for assembly line may be taken as an example. Achievements of decision theory, social sciences, strategic management and information technology, especially artificial intelligence are taken in. Key components of such hybrid decisions are set ups of decision-making, composed of manual semiautomatic and automated decisions and human interventions. Decisions may be taken, based on smart components, dependent on the maturity of the smart control, the degree of automation as well as the structures' configurations.

It is not only the improvement of technical functions by more interrelation, but mainly the intelligent linking that will reduce complexity revealing new qualities of problem solutions. This may happen on the base of autonomous self-organising units being supported by software agents, where agents display proactive and reactive, robust, adaptive, cognitive and social properties. Especially, self-organisation and the involvement of smart objects point into the direction of artificial intelligence, jeopardising the traditional role of humans in the decision processes, e.g. by eventually executing tasks as simple servants. Resource monitoring, goal assigned capacities, external objectives as delivery service, flexibility limits, load maximising are considered as input. Long-term customer orders and stock orders are the planning base, the short-term customer orders on top are unpredictable and even more parameters as qualifications for assembly line, limited human resources, vacancies or individual working schedules are in play.

Decisions are made cyclic in stages. The given restrictions are inputs for mathematical algorithms, linear optimising and worker assignment logic, date, individual time schedule, assignment to assembly line. More influences may be played in by simulation i.e. lots, changes in numbers, changes in schedule and so on. All scenarios will be automatically checked for requirements fulfilment; social criteria will be checked leading to asymmetric assignment of working timeslots per worker, enabling to exploit his daily or weekly time buffer, whereas others might be reduced to minimum flexibility. Volatility is mostly smoothened out by controlled assignment of standards orders resulting in more compatible plans. For frequently critical situations, Level I Improvement is sufficient; more severe coordination measures will be taken for the assembly unit as for the qualification or restructuring of the assignments, by engaging Level II Adaptation. Iteration eventually results in plans for e.g. assembly lines, including assignments of objective bundles and necessary changes of lot size, or schedule, which will be passed on automatically to the respective units. Proactive planning may be applied, reactive pattern be used, or on demand procedures for unplanned events as volatility in order volumes. The example proves that unidirectional cost effects are not always adequate for intelligent decision preparation. It is not appropriate to derive capacity loads directly from demands or, vice versa, to define the schedules and loads by existing resource profiles. The responsible person now may make use of option for modifying input attributes and for checking by simulation runs. Lot sizes of orders and due dates may be changed, after the respective preconditions, as availabilities of resources have been checked automatically. Social criteria for smooth individual work schedules come in, and adaptations may be done by varying loads of standard orders. Not only control decisions but also man-robot interactions will fundamentally change, as increasing machine intelligence will update the strict separation into independent working spaces. Man-machine collaboration will replace these setups. Adequate agents' design may be seen in object-oriented design patterns for units or subunits involving encapsulations, (abstraction and information hiding), Separation of concerns and single responsibility rule and interface segregation postulate. Adaptation and restructuring may be executed internally and externally; autonomous units are internally adapted, if deviations of internal and external objectives trigger improvements. The measures relate to the decision mode, the decision cycle as well as the decision logic, where best procedures for optimisation point at automation and digitalisation, regardless of their actual feasibility (everything that can be automated will be automated, everything that can be digitalised will be digitalised) (Kühnle, 2014).

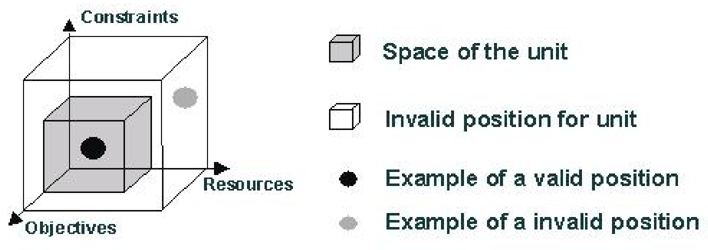
2.2 Smart properties induce new principles

There is a clear need to understand how these smart units and their interactions determine the functions and the nature of these enormously complex manufacturing networks. As a stovepipe application, but also when surrounded by other units, rapid advances in distributed manufacturing indicate that universal principles offering conceptual frameworks that could point to eventually revolutionise how you on manufacturing. Various types of interactions, as negotiations, linking, identifying, forming value chains embedded into a topological platform, forum networks and also networks of networks, which are not independent (different layers of detail, alternative process chains). A major challenge to manufacturing science is to embark on integrated theoretical and experimental mapping for understanding and quantifying the topological dynamics: laws behind. In this paper, we outline a number of principles as encountered in manufacturing networks, derived from different theories and verified by multi-agent simulation. Especially the transformation from hierarchical networks into peer-to-peer structures brings major shifts. Surely topological approaches must be enriched by other disciplines contributions, as outlined above, especially from complexity theory, from network management, from multi-agent systems, from decision sciences and evolutionary biology. ICT plays a key role and it must be acknowledged that structure, robustness, dependability and functions are deeply interlinked, naturally forcing to complement the smart units' local properties with integrated approaches addressing overarching loss of game. It is evident that decisions on the structure and improvement of the network are keen for networked manufacturing; therefore, the negotiation mode as well as the dependability improvement cycle will be highlighted in this outline. Influences from the network as well as on the network will be responsible for the behaviour of each unit.

2.3 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 distributed manufacturing (DM) (Kühnle, 2010). 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 1). 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 1. Space of Activity (SoA) as mapping of network node for monitoring the behaviour of the unit by relevant indicators and observable



This "biologically" inspired manufacturing approach addresses challenges in complex (unpredictable) manufacturing environments tackling aspects of self-organization, learning, evolution and adaptation. They easily adapt to unforeseen changes in the manufacturing environment, and achieve global behaviour through interaction among units. Applied for manufacturing network decisions, such behaviour thinking supports levelled manufacturing network adaptation procedures.

2.4 Parallelism

Any manufacturing item may be identified, tracked, morning tours and localised. Many so-called points of action will come up with these technologies, producing events that trigger other actions or decisions at the points of control or the points of decisions, inevitably causing simultaneous actions at many locations and at multiple process steps. Not one time hierarchical decisions, however, gradually evolving configurations and reconfigurations will be observed. This simultaneity brings enormous advantages for manufacturing setups. An optimum base for collaboration 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 DM applications. Eventually each node of a task can have multiple implementations that target different architecture. 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.

2.5 Iteration

Network structures require both: verification i.e. checking the correctness, and validation i.e. comparing the result with reality. Complex structures always need to be revised and improved, as catching errors and checking oversights are natural elements of a conjecture and refutation procedure.

Developing configuration options and deciding about favourable configurations are a highly iterative process and not a straight-line journey. Loops back are possible, as factory and network capabilities identified 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 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. in some cases, decisions are finalised of the one iteration, in others, agent are allowed to revise with new information. Negotiation mechanisms may include agents on the same hierarchical level that negotiate e.g. local goals of high priority, but in corporation mechanisms agents may choose suboptimal policies to achieve better overall network performance. This can only be done by intelligent iteration. 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). Deterministic planning becomes less important whereas iterations have to be promoted, which is easily possible by the technological options making iterations easy and low-cost. Moreover, unforeseen changes may generally be coped with only by iterations and local adaptations.

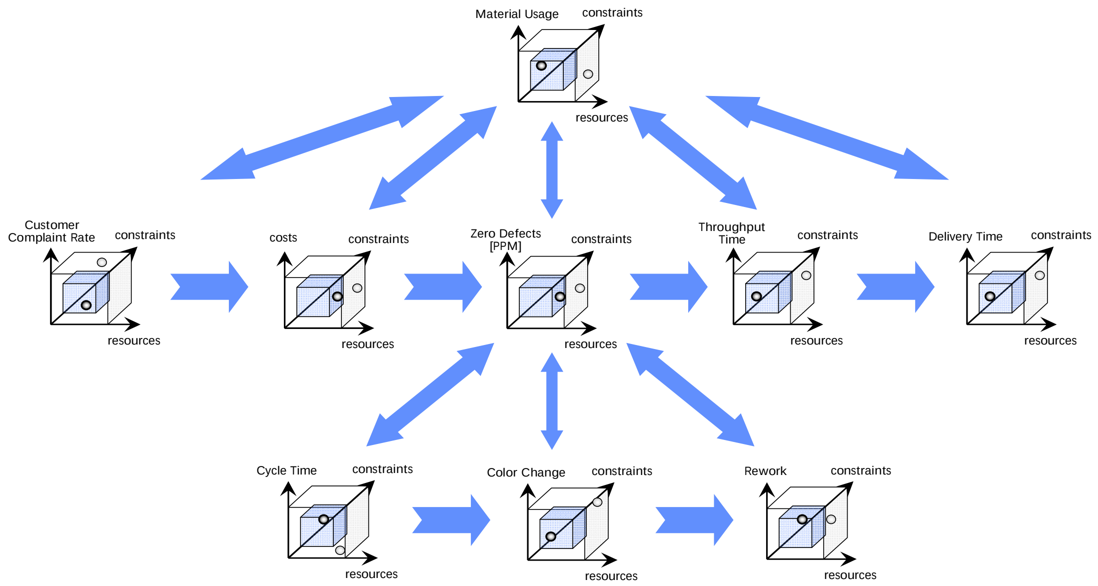
2.6 Encapsulation

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). 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. 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 are 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. Encapsulated models of units and connectors, may arbitrarily be compressed/ broken down resp. fold/unfold (Figure 2). 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.

Figure 2. Breakdown (unfolding) of encapsulated behaviour models including criticality spaces into desired levels of detail



2.6.1 Strategy and objectives

The network gets vision, mission and network draft that are later detailed to design and operation. 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.

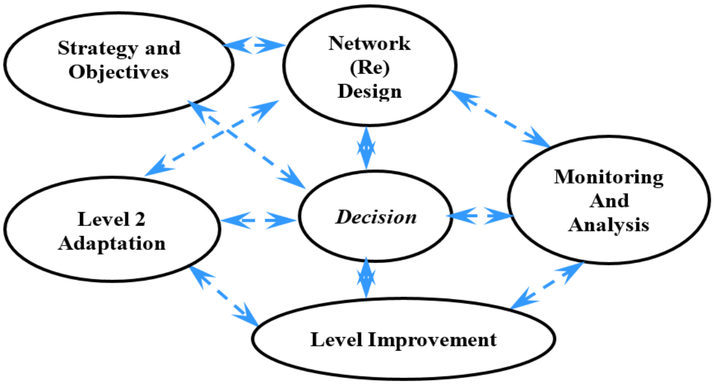
2.6.2 Monitoring and analysis

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.

2.6.3 Network design

The network is to 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 3. Revolving decision cycle procedure of levelled interventions in manufacturing for gradual continuous configuration



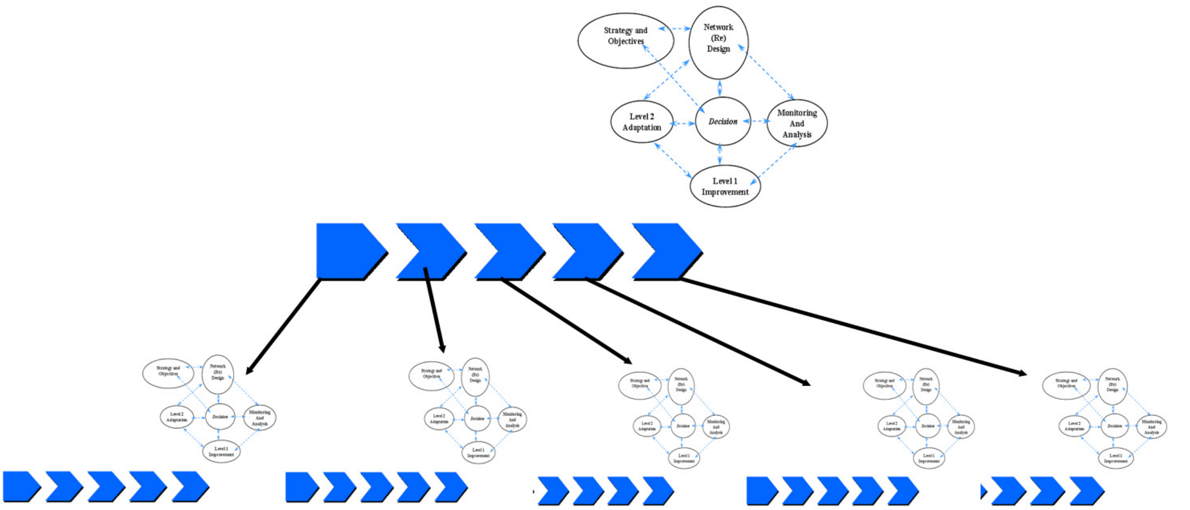
The strategy elements may be broken down to the decisive factors and the respective indicators that cover all key areas of the networks. They may result in relations of sub objectives and/or aggregated objectives' systems.

2.6.4 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 (Figure 3) 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 extend the actual configuration has "suboptimal" effects on the results.

Figure 4 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 process is enforced and the encapsulation enforces additional rules to ensure the overall process optimum. A unit component encapsulates all necessary models and procedures. A composite component also encapsulates computation and control (Lau and Taweel, 2007). 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.

Figure 4. Meshed decision cycles including encapsulated models and instruments to negotiate and decide on manufacturing networks' process fulfilment on several levels of detail according to DM/properties

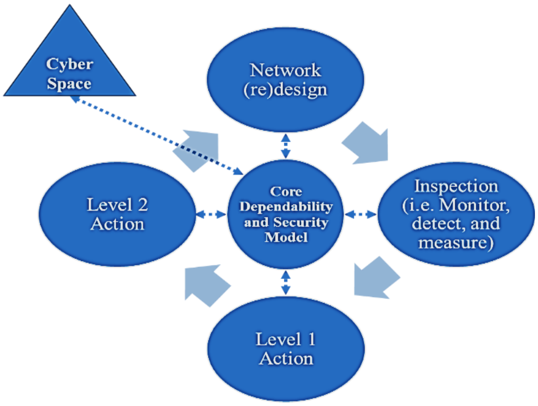


2.7 Dependability and security

Smart manufacturing systems equipped with cyber-physical systems (CPS) are posed to various types of threats on each of their layers (i.e. physical, cyber, integration and data communication). Some of the major security risks in industrial control systems and cyber-physical systems that can vary based on the type of components under consideration are namely, Distributed/Denial of Service (DoS/DDoS) attacks, social engineering and fishing attacks, malware and viruses infections, intrusions, compromising control systems (cloning, masquerading, repudiation attack, manipulation, etc.), whereas among dependability issues, package delay/loss, connection loss, failure or breakdown, observability coverage loss, etc. are some to be named. Taking these risks into the account, to assure dependability throughout the enterprise, the adopted approach must be capable of dealing with all components, information flows among them and to the cyber area, networks, databases and servers, etc. To meet this goal, a distributed Dependability and Security Model (Figure 5) is introduced to be considered in the entire system, in every units and components down to levels of detail. It aims at guaranteeing smooth and resilient performance by having its main focus on security and stability. The model consists of a control loop, a core model, and connection to virtual world.

The ***core*** is based on the objectives and strategies, functionalities, priorities, etc. dependability and security objectives and challenges. Requirements, and accordingly risk analysis model, will be defined for each component. It consists of two main sections: object description, and risk model, where the former focuses more on objects' context and self-awareness, and imports data about object's environment, collaborations, functions and modules, objectives, application and task description, etc., and the latter covers accordingly the dependability and security parameters, vulnerabilities and risks, and the ways of measuring and dealing with them. The core model in other words, feeds the control process which is going to be described later. In object description section, the model provides the overall objectives of the component, the tasks performed, the operations involved, the interacting modules and the structure it has, its environmental parameters and its position, the components in the group or in other layers it is collaborating with, and other required data in helping

Figure 5. Smart Dependability and Security architecture as a derivative of the decision cycle



developing a more accurate risk model. These data can be imported from the cloud or sensed as a part of object's self-/context-awareness. The risk model, in collaboration with the descriptions provided and dependability and security objectives, deals with vulnerabilities and risks that the object is susceptible to. It also contains a model of assessing risks and possibilities and their possible effects on the object and on the system in total (e.g. Failure Mode, Effect and Criticality Analysis (FMECA)/Fault Tree Analysis (FTA) model). The model is to be designed modular so that its parts can be imported or used in other similar or related objects. It is self-optimizing through sharing knowledge with other objects, and updating its own structure and database through feedbacks it gets from its control loops.

The ***Control Loop*** on the other hand, invokes the process of Inspection (i.e. monitoring, detecting, and identifying and measuring), and Reaction (i.e. giving alarms, taking action, and doing the reconfiguration afterwards) in real-time. All steps can be carried out fully- or semi-autonomously by smart objects through this attached core model. As shown in the figure 5, all the steps are in communication with the core model, which is located in the cyber space and is in collaboration with all other models. This gives the components all the abilities to collaborate with the common objective of raising and maintaining the dependability and security of the total system.

2.8 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 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 termed "emergence"; arising of unforeseen new structures with unexpected new properties (Goldstein, 1999). The process chain emerges as a result of the interactions between units. There is no ultimate configuration solution beyond continuous adaptation and restructuring. To say 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. Dependency is observed in manufacturing as one of the emergence conditions in manufacturing networks. Emergence may in no case be reduced to the properties of participating units. The network's structures and topologies might rather be created in any rifle sense, bears interaction and coherence is insured by bottom-up mechanisms rather than top-down control. The essential structural property sought is the value chain resulting from the relevant and variable objectives on the base of the set of concurrency principles, as given here.

3. Summary and conclusions

Smartness of manufacturing units strongly supports peer to peer interactions and common location that become more comfortable and much cheaper than planning and hierarchical decisions. Fully relying on decentralized communication, negotiations, decisions and actions for value chain optimization totally change the game. Well accustomed systems modes will be totally replaced by novel concurrency principles adapted to the intriguing smartness of manufacturing units and networks. Especially the encapsulated behavior and decision modes as well as the overarching subject of security and dependability may easily be embedded for further refinement.

References

Bitkom, VDMA and ZVE (2016). *Implementation Strategy Industrie 4.0.*

Goldstein, J. (1999). Emergence as a construct: history and issues. *Emergence, 1*(1), 49-72.

Kang, H. S., Lee, J. Y., Choi, S., Kim, H., Park, J. H., Son, J. Y., Kim, B. H. and Noh, S. D. (2016). Smart manufacturing: past research, present findings, and future directions. *International Journal of Precision Engineering and Manufacturing -Green Technology*, *3*(1), 111-128.

Kawsar, F. and Nakajima,T. (2009). A document centric framework for building distributed smart object systems. *2009 IEEE International Symposium on Object/Component/Service-Oriented Real-Time Distributed Computing.*

Kühnle, H. (2014). Smart units in distributed manufacturing (DM)–key properties and upcoming abilities. 18th Annual Cambridge International Manufacturing Symposium.

_________ (2010). Distributed manufacturing: paradigms, concepts, solutions and examples. In H. Kühnle (Ed.), *Distributed Manufacturing,* 1-9, London, Springer London.

_________ and Bitsch, G. (2015). Core models, principles, and networks' structuring. In *Foundations & Principles of Distributed Manufacturing: Elements of Manufacturing Networks, Cyber-Physical Production Systems and Smart Automation,* 27-53, Cham, Springer International Publishing.

_________ and Dekkers, R. (2012). Some thoughts on interdisciplinarity in collaborative networks' research and manufacturing sciences. *Journal of Manufacturing Technology Management*, *23*(8), 961-975.

Lau, K.-K. and Taweel, F. M. (2007). Data encapsulation in software components. In *International Symposium on Component-Based Software Engineering* (pp. 1-16). Springer, Berlin, Heidelberg.

Marwedel, P. and Engel, M. (2016). Cyber-physical systems: opportunities, challenges and (some) solutions. In Guerrieri, A., Loscri, V., Rovella, A. and Fortino, G. (Eds), *Management of Cyber Physical Objects in the Future Internet of Things: Methods, Architectures and Applications.* Cham, Springer International Publishing, 1-30.

Möller, D. P. F. (2016). Digital manufacturing/industry 4.0. *Guide to Computing Fundamentals in Cyber-Physical Systems: Concepts, Design Methods, and Applications*. Cham, Springer International Publishing, 307-375.

Monostori, L., Kádár, B., Bauernhansl, T., Kondoh, S., Kumara, S., Reinhart, G., Sauer, O., Schuh, G., Sihn, W. and Ueda,

K. (2016). Cyber-physical systems in manufacturing. *CIRP Annals - Manufacturing Technology*, *65*(2), 621-641.
Zahra, S. A. and Newey, L. R. (2009). Maximizing the impact of organization science: theory-building at the intersection of disciplines and/or Fields. *Journal of Management Studies*, *46*(6), 1059-1075.
ZVEI (2016). Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0).