Towards Production Network (PN) Theory Contributions from Systems of Models, Concurrent Enterprising and Distributed Manufacturing

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Abstract- **Production Networks (PN) fundamentally differs from hierarchical organisations, as they emphasise speed, re-linking and reconfiguration. For the decisions for realignment of units and the reallocations of resources, configurations on changing levels of detail and control actions, generic models in line with concurrency modes give an adequate base for the description, the control and the evolution of PNs. Simultaneous application of selected interrelated models may generate very efficient procedures for PN management. Moreover collaboration between dispersed locations is well ICT supported. However, for lack of overall conjectures, management solutions are fragmented. PNs may generally be modelled as Hausdorff spaces and the respective tangent spaces. Specific mappings as well as applications of concurrency modes may be introduced for improving coherence and speeding up decisions. Methods and models appear as embedded structures, carrying the fold/unfold properties of graphs and systems. Interoperability requirements induce standardizations for the models. The specific synthesis of the concurrency modes with criticality thinking results in procedures for gradual and evolving adaptations of production networks' structures, most adequate to PN' complexity. Ground laying theory always strengthens the convergence of terminology, methods and models that are developed and applied on a research area. In this sense this paper intends to contribute to a coherent body of knowledge for PN design and management by theory building.**

Keywords- Concurrency Modes; Generic Models; Network Evolution; Collaborative Planning; Cyclic Decision Procedure; Criticality

I. INTRODUCTION

Production Networks (PNs) are complex. The applied concepts, methods and software have generated so far mostly isolated problem solutions. Singular approaches to handle this complexity, including some of these aspects have brought up heterogeneous and inconsistent description fragments. PNs, often interpreted as Supply Network configurations, are also seen as outcomes of dynamic capabilities, Virtual and Extended Enterprise approaches or Grid Manufacturing. There are considerable impacts of complexity in organizational implementations. Using ICT, solutions are seen in object-oriented modelling and techniques. For globally distributed and coordinated supply networks, comprehensive enterprise architectures and modelling methodologies (EA) have been made available. The most cited methodologies are I-CAM, CIM-OSA and IDEF. Also widely applied are ARIS, SCOR, PERA, GERAM, VERAM, GRAI-GIM or FirstSTEP. These and other methodologies accelerate progresses in descriptions and norms. However these frameworks are not aimed at describing network phenomena or supporting to run PNs. To close this gap, specific more implementation oriented frameworks have been proposed with Covisint, Everest, ICON, LiNET, STEP, PL, XML and the (ML) open COLLADA standard. The results underperform as well, since the company interrelationships have to be the starting point of any ICT implementation and cannot be expected as desired outcomes thereof. For interoperation and to enhance the responsiveness of manufacturing networks, Supply Chain Cooperation SCC is propagated. Still, the ICT focus is preponderant. This finding is confirmed with the upcoming of Built-to-order supply chain (BOSC), Efficient Customer Response (ECR), Continuous Replenishment Planning (CRP), VMI or FGP. These concepts are targeted at smoother flows in PNs by transferring the delivery services' responsibilities to the suppliers with obligations to hold high inventory levels. Marrying forecasts from different partners within the supply networks, varying demand and harmonisation need brought up Collaborative Planning, Forecasting and Replenishment (CPFR). Even if accompanied by firm alignments via standards such as the Voluntary Inter-industry Commerce Standard (VICS), these methods underperform as well, as they are not adequately scalable and the operation is reported to be work intensive. They do not sufficiently address the nature of collaborations involving various self-interested actors, barriers and conflicting motivations [6].

Controls in industry are increasingly designed by introducing agents. In the increasing use of meshed patterns within control systems in manufacturing, agent systems are apt to be introduced to PN control as well. Multi-Agent Systems (MAS) have been set up or implementation and use on a number of fields. The subsequent outline is based on findings according the Holonic and PABADIS architectures, especially the latter had been developed in the author's

responsibility. PABADIS is targeted at the integration of the benefits of most of the above approaches. Its setup is highly flexible and constitutes applicable control architecture for any distributed control. The most cited result from PABADIS the wide spread Automation ML standard [4].

Concerning theory and concepts for PNs, most of the existing works are successful case studies and are expressed by specific models or company solution procedures mostly justified by case success stories or similar anecdotal verifications, so further evidence is needed for generalisation. Novel network principles, favouring evolving and continuous procedures, will outdate hierarchical management rules for manufacturing, as they ensure lasting competitive advantages in comparison to processes run under hierarchical "control beliefs" and "stability certitudes". Companies increasingly have to position themselves primarily as entities in networks, aiming at obtaining maximum value through joining loosely coupled enterprise configurations [11] by exploiting distinct process segments and by developing excellence in attracting a maximum of network resources towards their visions and interests. For analysing operations in networks, the application of Complex Adaptive Systems theory is advantageous [15], as these operations' setups rather resemble dynamic, complex, interdependent and globally distributed webs than static deterministic systems, which have so far predominantly coined management thinking. Within simple configurations of operations, management can still be satisfactorily done applying traditional planning and hierarchical decisions. In PN's, however, management is more sophisticated, because the involved units and their attributes are dynamically changing. Notably these properties, especially when activated for incorporating network partners as well as new capabilities and shifted competencies, enormously increase the companies' adaptabilities and strongly amplify differentiations and uniqueness [14].

Main tasks are restructurings, improvements and adaptations of the resulting manufacturing networks as well as linking, questioning or breaking up relations and connections in PN's generic models and modes may be seen as valuable support. Therefore the paper contributes to generalise approaches that have been successfully applied for distributed manufacturing contexts [7]. A theory set up is proposed, which is influenced by self-similarity and newly established concurrency modes. The contribution intends to strengthen endeavours towards specific manufacturing network theory.

II. PLANNING AND MODELLING IN DISTRIBUTED STRUCTURES

Precisely spoken, planning and control does not deal with the units themselves but puts into relations models and attributes of these units that are coordinated and interlinked. Planning procedures therefore use models, exploit model structures, link models and synthesise modelling results. Simultaneous planning actions influence choices, attributes. Therefore the network units' interaction structure must be envisioned as an interrelations' structure of the models on

the respective levels of detail, as required. Planning steps for the equipment layout on the shop floor of a factory may illustrate this interpretation.

A. Interrelated models for planning

The optimum arrangement of the units within a factory layout is generally determined by the material flow, the operations sequences, the master plan as well as technological impacts or building restrictions. Traditional planning claims that design of production systems is strictly to be achieved by top-down-procedures, propagating proportional relations between the length of the planning horizon and the planning object details. Inevitably the resulting plans will show corresponding views of the length of the planning horizons and the projected details of the planning object levels. Long range decisions are seen in combination with less detail, rough sketches and little precision, whereas the details in alternatives and variants for processes and factory layouts are assigned to short planning horizons. This is well known and widely tolerated although the resulting "one time" solutions are visibly sub optimal and inflexible. Turbulent markets and subsequent adaptations of structures require versatility. The new methodology facilitates modelling, needs less time and offers better reusability of model parts. All models can be detailed, modified and replaced easier. Models are therefore already established and stored for the "case if", are put into a planning impact diagram and are activated for cases of concrete decision support (Fig. 1).
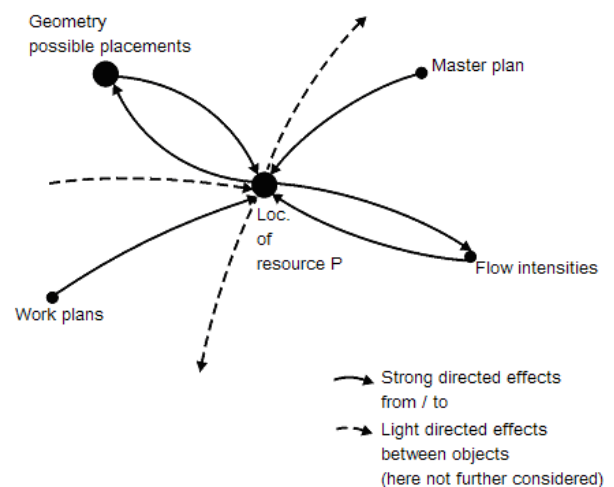

Fig. 1 Planning by Cross-Impact - Impacts and relations between units' attributes for a specific planning problem: Determine optimum position of machine P in a shop floor

New re-configurability requirements modify hierarchical planning into concurrent planning procedures using linked models that are attached to the production network units of interest. The permanent need for planning may need to make use of all these models and their attributes concurrently and everywhere, also in geographically dispersed structures. On-line Collaborative Workspaces, using methods as conceptual modelling, CSCW, or mind mapping etc. are available that offer online interaction options. Such concurrent planning steps, too, need "thresholds of models" that are readily

available and may immediately be introduced for planning with the required attribute and level of detail. Models as material flow charts, respective restrictions or geometrical attributes for example are necessary as a base for decisions on resource arrangement. Put together as a planning impact diagram and activated for collaborative decision making (Fig. 2) e.g. decisions on an optimum machine layout within a multisite PN can be done in interactive collaborative planning.
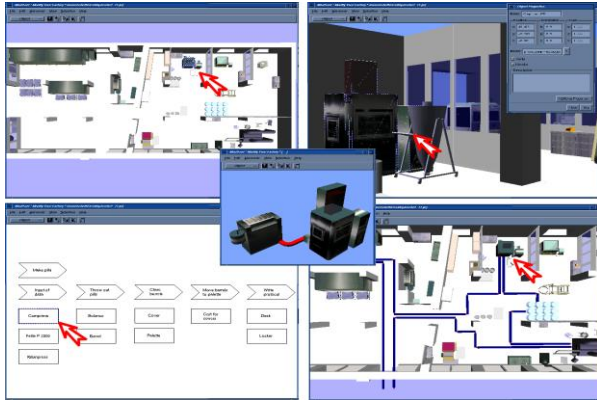

Fig. 2 Concurrent Planning by Virtual Reality Collaborative Workspace: Planning situation in Leadtime Optimization

Parallel steps need actual and detailed information on relations between attributes and planning items as well as the attached models. Relations and dependencies are of network nature (e.g.) and may be mapped by impact arrows. Intensities of impacts may be formalized (cross-impact matrices); the strengths of relations may provide support for the choices of models as well as the perspective chosen in the various collaborative planning stages. That way, the procedure disposes of model systems that can be used for a variety of planning problems, research questions and verifications alternatives. For the machine layout, the adequate models to be chosen are flow charts, Sankey graphs, DMU/VR and geometry of plants and machines. A few models are necessary for start; the model system will gradually evolve with every planning session. Possibilities are offered to quickly generate planning alternatives which would not have been elaborated in traditional planning. The big progress of the method is the possibility to be able to do planning steps in parallel. Even more options may be taken i.e. interdisciplinary teams may navigate through the model system on demand. These excellent technical solutions, originally offered for production systems planning, may be extended for optimising PNs.

B. Collaborative working environments (CWE)

Other ICT approaches tackle collaboration in network issues, as within PN structures, people will work in groups of diverse and complementarily skilled professionals using Collaborative Working Environments (CWE). Work patterns become extremely rich for the growing variety of activities and the larger number of dispersed and moving entities, as well as the progressing virtualizations [13]. As business becomes more global and broadband connections are increasingly available, PNs should be benefiting better from its multiple advantages. However a number of novel factors are affecting collaboration effectiveness and efficiency, as they provoke novel types of distances. A table of CWE tools and technologies contributing to overcome collaboration barriers from the viewpoints of a representative number of individuals is presented below (see Table 1).

TABLE 1 A FRAMEWORK FOR TOOLS AND TECHNOLOGIES CONTRIBUTING ELIMINATING DISTANCE FACTORS

Dimensions	Distance Factors (due to the lack of)	WebConf	IM	Whiteboard	SW	Forum	Blogging	Wiki	eMailing	VR & AR	MWC	Polling	Semantic	Modelling	Workflow	SN	SG	EA	EN
Structural	Collocation (shared-space)			X	X			X		X									
Structural	Communication	X	X			X	X		X										
Structural	Coordination														X			X	X
Structural	Leadership											X					X		
Structural	Incentive															X	X	X	X
Structural	Cohesiveness															X	X		
Structural	Shared vision									X				X			X		
Structural	Interoperability												X	X					
Structural	Balanced decision	X											X				X		
Structural	Synch. interactions	X	X	X															
Structural	Asynch. interactions				X	X	X	X											
Social	Shared culture					X	X	X						X		X	X		
Social	Mutual understanding			X					X				X	X		X	X		
Social	Trusted relationships							X								X	X		
Social	Context awareness									X	X							X	X
Social	Social translucence																	X	X
Social	Interpersonal relationships							X								X	X		
Social	Social interactions	X		X		X	X									X	X		
Social	Emotional awareness	X	X					X		X						X	X		
Social	Absorptive capacity		X							X							X		
Technical	Shared references							X									X		
Technical	Technology skill									X							X		
Technical	Shared meanings			X									X	X					
Technical	Shared relevance													X		X			X
Technical	Correlation												X						X
Legal	Common IPR							X											
Legal	Common Privacy Rules				X														
Legal	Common Security Rules				X														

This framework (TABLE 1) aims at separating these distance factors, also by using interrelated models. It consolidates important outcomes of several surveys and improves the knowledge about distances in collaboration. ICT availability and new devices could even bring other kinds of distances into collaboration on one hand or contribute to overcome or lower distances on the other by motivating effects on specific distributed collaborations. There have already been remarkable steps ahead, but planning in distributed structures has not yet sufficiently included CWE.

III. GENERIC MODELS

One of the keys is certainly a change in network management. Networks evidently seem to be managed as well as formed by rules and objectives. Variable set ups are connected, disconnected, linking or detaching units, and are able to build up and to optimize versatile process nets. General network structures spontaneously emerge resulting from units' interactions, as the units move towards incentives (attractors). Business opportunities offer such "attractors", able to drive, to operate and restructure PNs. Therefore PNs are to be envisioned as being composed of self-optimising, self-interested entities, defining proper and genuine processes, initiating interaction, which float within network configurations and communicate on different levels of detail. Attached models should therefore encapsulate fold

and unfold properties as well. Some of the configurations are more profitable than others in some respect, so some kind of monitoring has to evaluate for stepwise decisions.

A. Models for Decision and Control

The nodes, depicted by Spaces of Activity (SoA), are mapped via the units' objectives, the put in resources and the constraints, that are imposed. The SoA volume may be interpreted as the competence space of an entity i.e. allowed zone for a specific units' parameters. A unit's performance indicator, e.g. given by respective measuring, may prepare decisions on self-organizing modes, turning on or off the unit's autonomy as well as dimensioning the network influence. If a unit constantly fails to meet the requirements or to adapt to challenges of the surroundings, the network representatives may come in to take over the units' activities.
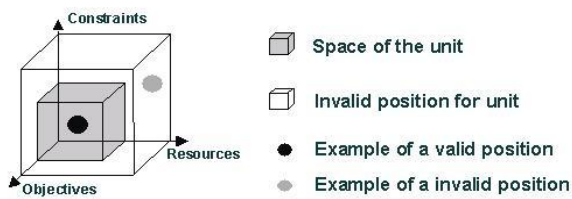
Fig. 3 Units' Space of Activity (SoA) - monitoring (valid or invalid) projections of all relevant indicators and observable

For the decision for improvements or even adaptations of the network, the SoAs may have the effects of criticality thresholds [5]. In cases of ignoring an "interaction flag" - i.e. a unit's indicator shows an invalid position (Fig. 3), immediate actions are initiated. Usually there are several options to react a critical situation, actions may range from "the unit should be adjusted or adapted" to the decision that "severe interactions" are taken. If any units constantly miss to make capabilities available as proposed, these units turn into "critical units", i. e. units that's roles will be scrutinised. In cases of lasting criticality, decisions could be taken to remove the unit from the network, to replace the unit by other units or to find solutions without the unit.

In order to differentiate criticalities, an additional integer for labelling repeated "Not admitted" cases may be used to decide, if a position may be tolerated in a specific situation: Higher integers for "Not admitted" situations express that the unit becomes more critical. If the number of "Not admitted positions" is higher than the tolerated integer, the unit will be subject to the restructuring decision cycle. In Manufacturing Network management, this „criticality thinking" might replace traditional ordering and control procedures, as it leads to levelled manufacturing network adaptations, similar to findings in complex adaptive systems [3], then are considered more adequate for optimising networks' evolution.

B. Meshed Criticalities supply Decision Support

Fruitful network units' decisions will gradually evolve the networks in economising resources, in meeting the goals and strengthening and enhancing the competitiveness of the entire network. Most favourable for management in PNs seem to be procedures, engaging distributed and simultaneous logics that continuously and progressively generate small step progresses [1]. All processes appear as embedded in rich structures of actors, units and connections, which may arbitrarily be compressed respectively detailed by fold or unfold properties (Fig. 4) applying self-similarity properties [6]. Any critical state on a lower level may have an impact on the criticality of the involved unit as well as on units on more aggregated network levels or even the configuration of the total network.
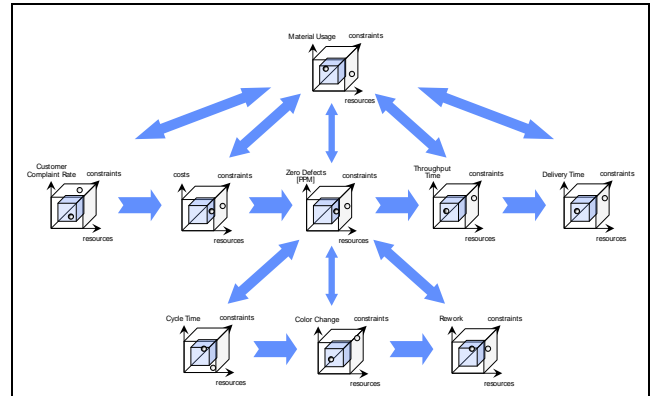

Fig. 4 Self-Similar Breakdown of SoAs and Criticality Thresholds onto Levels (of Detail)

Critical situations have to be leveraged and straightened out with other units' objectives and resources. In severe situations, the entire networks' target system has to be repositioned in order to achieve a consistent arrangement of criticalities.

If comparisons, indicating "not acceptable situations", are beyond the proposed limit, the unit will be taken into stricter ruling. Eventually the comparisons provoke decisions, if the self-management mode should be carried on, suspended or completely removed. Instead, PN interference could be installed. In more precise terminology, a unit may

* Decide on application of methods, adequate instruments, etc. to finally achieve all objectives that have been agreed upon. Units that succeed to stay within the SoA limit, are permitted to remain autonomous. This status is tied to decisions on resources, as budgets, skills, technical and human assets.

* Loose autonomy, if non critical positions by the unit's activities are not achieved. Superior network logics are installed that ensure the achievement of the entire networks objectives**.**

* Be removed and new or other network entities will cover if II) is reconfirmed.

Dependant on the unit's (un)ability to cope with challenges, network order parameters may overtake the units' activities according to the subsequent logic:

a) tolerable situation: No action

b) Rare overriding: Uncritical, optimisation by the entity is assumed

c) Repeatedly non-tolerable situation (but according to threshold): autonomous, but self-organisation has to immediately eliminate the criticality;

d) Repeatedly non-tolerable position (outside threshold): network will interact, the network starts decisive rearrangements in structure and re-dimensioning of the criticality arrangement (SoA Volumes), as well as finding out the reasons that have provoked the situation; and

e) Constantly non-tolerable position (total and long-term beyond threshold): entire restructuring, introduction of novel structures (removing links, adding new entities).

For networks, the capability to act fast, exploit and sustain attributes and indicate settings, is necessary for reliable objective systems as well as for the availability of resources and the network management in total. Fast re-configurability alignment of processes and units or restructuring of activities as well as corrections should be possible without long delay. The criticality framework, as suggested, provides such features and supports the management of PNs. Settings, arrangements, and the configurations, and responsibilities are continuously to be checked, sequences and newly established or configured, for instance if necessary by additionally inserted units or by removing distinct units or links. In addition, after execution, the framework defines a network enquiry, i.e. an explication of the courses for decisions.

For fundamental reasons of economising, networks naturally tend to keep the volumes of the Spaces of Activities somehow limited. The PN may react on the rise in complexity (diversity, uncertainty or non-predictability) by enlarging the SoAs in question, but only if the resource situation may allow this. Pleasurable and stable regulations allow lowering the SoAs' sizes.

For manufacturing execution for example, these activities can be executed by the agents. Using Order Agents, Ability Brokers, Resource Agents, and Product Data Repository a criticality may be formalised by introducing the logic how to provide or to use the existing manufacturing capabilities [9]. Therefore, the thresholds may be usually aimed at the minimum capability provision for start. The threshold monitoring of the involved entities will take into account registered capabilities and manufacturing resources, where the improvement and adaptation processes as the top priority. On the level of ERP, criticalities are expressed by capacities, ready for the execution of the intended manufacturing steps. Therefore, all introduced agents are complying with minimum criticality thresholds scenarios.

However all procedures that are completely executed through agents, do not yet reach to the Decision Support level for PN. The respective extensions will also have to give support to network in achieving the overall objectives,
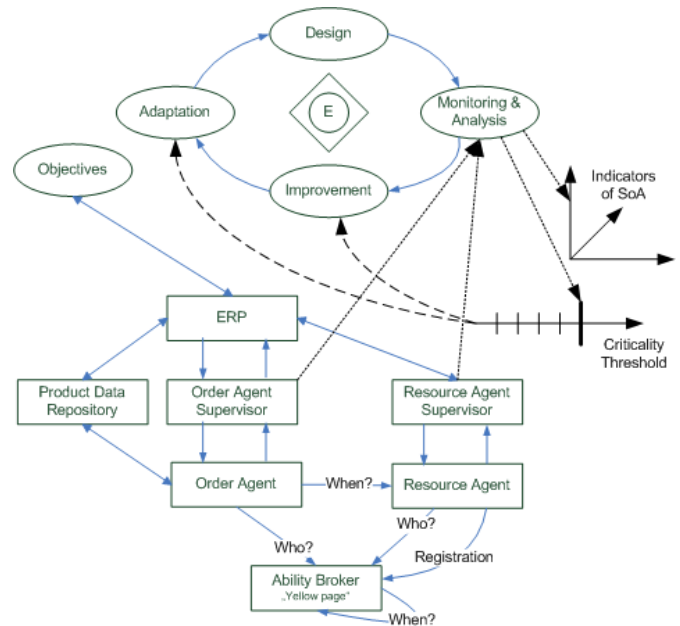

Fig. 5 Distributed control architecture: PABADIS PROMISE in MES as an example for the implementation of the criticality concept

evaluating and analysing attributes and indicators (Fig. 5).

For the decentralised mode of decision making, based on network business models, special logics, algorithms and methods for network management are needed. As both, objectives and resources, are dispersed, matching of partners as well as the temporary collocation of operations in PNs; units as well as their interrelations have to be monitored. Extending the criticality procedure, as described above, to the network management level may as well include the approach to automatically generate adequate alternative manufacturing processes and possible units' candidate lists. Therefore, as such extensions will require major changes of the models, as the procedures have to contribute complex decisions support and may, at the present state-of-the-art, not yet be completely left to multi-agent software logics.

All network resources are embedded in a strategy and the resulting objectives for the manufacturing network. Units or even subunits criticalities' may have an impact on all enterprise units involved. Both objectives and resources may be assigned "dispersed" and self-similarly modelled as well, introducing levels of details. On the basis of this generic model, logic for the meshed control of (partial) autonomous units for configurations decisions, containing systems and networks in networked manufacturing structures, may be established.

A. Strategy and Objectives:

Well defined visions and clearly stated missions along with strategic paths are inputs for the parameters that define the network design. The environment may bring about major and disruptive changes, potentially including excellent new opportunities. The network updates the vision, the mission and thereof generates the network draft, later the detailed

design to operation. The network strategy has to support the fact that in order to truly align the infrastructure with business requirements, all units must be able to choose the solutions that meet their unique needs best.

B. Network design:

Networks are to be configured in the way that allows meeting customer requirements best. To this end, entities, links and other players are identified and added to a network structure. Procedures and established standards as GERAM have been set up and made available to support these steps. Process segments have to be connected and provided with responsibilities. Overall objectives have to be the detailed and the available resources have to be assigned. The strategic elements may be broken down to the basic attributes and the respective indicators that cover all interests of the networks' businesses models. All objectives may be detailed and the breakdown logic adapted to the structure of the units that should be configured. The result may be expressed in vertical relations of sub-objectives or corresponding aggregated objectives' systems.

C. Monitoring and analysis:

Networks have to be constantly updated, the potentials have to be checked, capabilities and availabilities have to be monitored in order to prevent the network from underperforming. With this end, elements that notify the network in cases of outages, caused by units' criticalities, have to be introduced. By this means, structures, mechanisms and outputs are continuously evaluated, benchmarked and assessed. All steps should be possible down to sub or sub-sub levels to where the resource configurations and their relevance to the objectives are checked. Correspondingly, the SoAs structures (incl. the criticality settings) are broken down according to the self-similarity principle.

Resulting actions, necessary as consequences of the monitoring and analysis results as well as of the criticality of indicators and units, are foreseen as outlined:

1) Improvement

For situations of negligible criticalities, minor structural-functional or parametric adjustments or objectives' alignments are sufficient. Improvements can be can be made in a narrow frame of action within the network units themselves, most of these can be made without network inclusion. Important steps are seen in the introduction and implementation of methods supporting adequate improving steps. Modified settings of the objectives may ease or remove criticalities and strengthen the entities' input into the network. In consequence, certain criticality thresholds can be adapted, which accelerates further improving actions.

2) Adaptation

High criticalities will make necessary entire network configurations or re-configurations. Adaptations have to be seen as the most severe and the most powerful interventions

of networks for catching up on the overall networks objectives and corrections of variations and underperformances. Such interventions may be necessary, when feedback processes were unable to adjust or the improvement potential of the network can't produce the intended result. In cases, where all actions for improving performances and continuously fail, the network management will have no choice to avoid major and radical changes. New patterns of behaviour and different structures may be needed, and may become built-up by activities and signals of units.

3) Decision

The decision step is always returned to, if necessary actions are to be taken in order to bring forward the network and do support the networks development. It ensures the networks evolution towards the intended direction. In the starting phase, the objectives may be structured corresponding to the granularity of the units referring to. For the steps in PNs required the evaluation of all interrelations of objectives, processes and network structures. Network units are changing, constellations modify, other entities have to be inserted, to be removed, to be shifted or to be melt. In networks, the focus is always on executable and harmonised objectives, purposeful to the network units' leadership. In this sense, each PN is constituted of linked smallest processes. All network units are defined as a main process on base of the transformations in manufacturing, where the interrelations of units, the sets of objective systems as well as the efficient and effective order processing are the key concerns.

Decisions and steps towards decisions may be (re-)taken, revisited, improved or questioned within cyclic logics (Fig. 6) e.g. previous program strategy, former network structures, in-/outsourcing set-ups, investment decisions, organisation of processes, technology- or equipment applications, etc. are continuously rechecked.
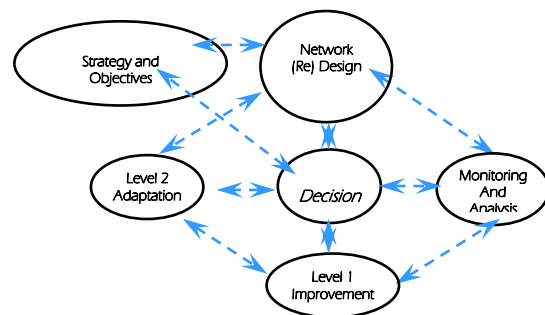

Fig. 6 Decision cycle procedure for levelled interventions for PNs

Existent set-ups (history and time) might keep from implementing the optimum decisions at short term, as structures might exist where changes appear too costly (site invests not yet written off) or acquiring relevant competencies is too time consuming. For optimising a network, several (nice to have) models should be kept ready including the detailed model of the actual network status for

monitoring. To check and to evaluate "what if" scenarios, and to benchmark indicators for visualising gaps between the present situation and the network optima show the non-exploited potentials of the network.

IV. LAYER EXTENSIONS: RESOURCE AXES FOR PRODUCTION UNITS AND NETWORK SPECIFICATION

For quick modelling of the resources, the constituent components may be detailed in a way that the configuration of processes as well as the representation of performance indicators on all levels of detail will be covered. In versatile and agile manufacturing systems, aspect focused decompositions have been successfully applied for distinguishing information flows, organisation and processes as e.g. the specification of the CIM/ OSA framework and consecutive standards suggest. Equivalent resource co-ordination schemes for manufacturing networks and supply chains have been proposed in different contexts (e.g. 1. physical goods, 2. information, 3. people, and 4. finances).
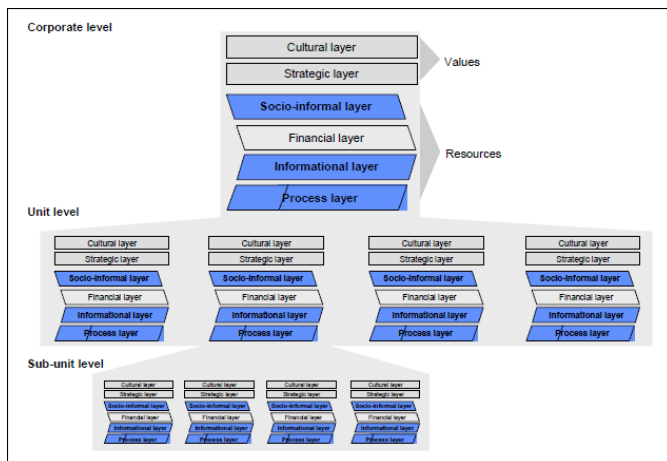

Fig. 7 Self similarity principle, introduced to the aspect layer generic model highlighting processes, information and organisations

In extensive and profound studies concerning self-similarities of fractal organisations, specific decomposition logics have proven to be fruitful, which subdivide entities into six coherent layers (culture, strategy, socio-informal layer, finance, information, as well as processes), The last four layers may be addressed as the resources' scheme (Fig. 7). All layers may individually expressed by PN specific methods or KPIs as pointed out in TABLE 2.

Including all properties, the embedded structures on all the layers will replicate self similarly, covering all (sub-) units as well as on the corporate or network levels. For better expressing the communication links, agreements on one all layers, especially the informational layer, for instance on IT platforms, on cultural values or on standards for interoperability are favourable.

For managing dispersed manufacturing networks, patterns of resources' structures may be prescribed for the mandatory internal use. The items, most frequently referred

TABLE 2 EXAMPLES FOR LAYER SPECIFIC KPIS IN PN BY INDUSTRY BRANCHES

Resource Layer	Large automotive supplier	Automation equipment SME	Pump maker	
Socio Informal	Teams Team incentives Principles of conduct	Production Circles Decentralised units with quick decision (uneven number), team work Incentive salary prop. PZG = (m*Te + Tr) *100/ At with m: Parts per period Te: time per part Tr: time per set-up At: time of presence	Socio informal elements: . Flat hierarchy Decentralised units with quick decision (uneven number), team work Incentive salary dependant on objective fulfilment Visualisation of objective fulfilment	
Financial	Value stream Design			
Informational		EDP supported JIT linked connections VBS (Electronic Kanban)	Kanban EDP supported Kanban connections to supplier	
Process	O.E.E:	Standard processes/parts:		

to are:

- Lean principles, as 5s

- LoD invariant KPIs, inc. dimensions (t, Value,),

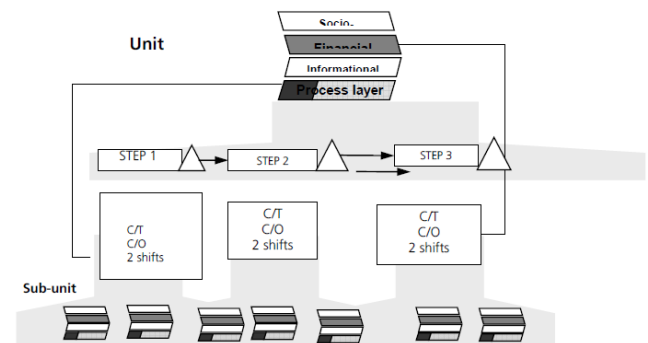- Key methods, as Visual Systems Design (VSD) (Fig. 8)

Fig. 8 Generic Layers mirrored to VSD as specified case

The layer aspects may be used to define company-related (self-similar) patterns that may also be interpreted as a part of the general definition of a company's specific Production Network "standard". Such standards signalise to the PN units as well as to the partners, e.g. the methods and indicators to be applied. These definitions also state clearly, what the requirements are and how future partners can increase their chances to come in or to stay. A number of well-known companies highlight the rank of their network standards by showing their full identification and commitments, and associating the brand names e.g. Toyota, Bosch, Audi, GKN. Often, all key components of these company standards are expressed by self-explaining symbols as hierarchical trees or mind maps, being referred to as the companies' "footprint" – an instantly appealing practical term for self-similarity in the manufacturing system and manufacturing network context. This proves that managers are quite aware of network management requirements as

well as the different nature of the procedures, compared to what they are used to in hierarchical organisations. The feature to permanently restructure and re-link has a substantial new quality and introduces completely novel principles. The focus, however, remains on the efficient streamlining of units. For permanent configurations of the manufacturing networks, the from the SoA and the criticality framework loop has to be widened up and closed to a number of other attributes, represented by the generic models as well.

V. GENERIC OBJECTIVES

For continuously updating objectives and resources' situations, given (also self-similar) patterns that just need to be filled in according to the emerging constellations have proven to be a good planning and decision support. In order to detail the objectives on the network level as well as on the unit level, a useful pattern may be defined and activated.

The achievement of objectives within a constellation does not necessarily imply that objectives on all levels of detail will be self-identically support all corresponding lower-levels. It is the result of continuous communication between the levels and the sub levels that ensures the intended compatibility and results in self-similarity of objectives.
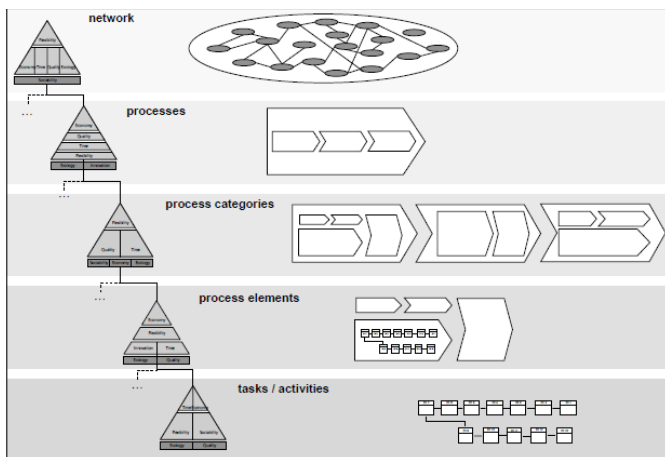

Fig. 9 Self similar generic objective breakdown in networked organisations

With regard to both, single goal and their combination, the consistency can be visualised by an objectives' pyramid.

VI. THEORY DESIGN

The set-up as outlined may be generalized. All examples explicitly deal with phenomena as unpredictability, self-organization, diversity and self-similarity, which are referred to as important Complexity Principles (e.g. [12], [16]). Other findings as iteration, behaviour and emergence may be associated to complex adaptive systems as well as concurrent engineering. Evidently a comprehensive PN theory has to build upon fundamental characteristics of complex systems and decision-making in network design

and process engineering. The procedures, as described, implicitly follow five basic modes, also referred to as concurrency principles:

1. the 'Parallelism' mode achieving shorter execution times by performing in parallel or with some overlaps;

2. the 'Behaviour' mode defining the dynamics of the synthesized networks and the dependencies on event driven data and logics as well as interactions of operations;

3. the 'Iteration' mode highlighting the fact that there is an inherent, evolving nature to structuring. Iterations result in changes which will become visible through the structure's stages, passing through continuous process rework and

4. the 'Encapsulation' mode with all its powerful self-similarity features, able to establish networks and processes by synthesising elements for new structures or for atomising units into elements as well as to condense or decompose network features i.e. methods that operate on network data.

5. the 'Emergence' mode which expresses the full composition of the overall network or value chain from smaller segments which seem to be managed autonomously.

These are the fundamental modes or principles that have decisive impact on the methodologies, applied to describe PN's, and their case specifications. Models apt to these modes and principles inherently show generic properties. For a PN network theory, these models are to be considered a part of the theoretical core.

Manufacturing systems, coping with volatility, speed and uncertainty, reach limits. The pressure by new phenomena calls for paradigm change; all chapters that have been discussed above, demonstrate the adequacy of generic models for decision and the central role of interlinked models for PN planning and describing. Therefore the model constructs may as well contribute to a theory on the field.

In the conjecture proposed, PN nodes are not just simple vertices, but elements that encapsulate rich structures, ready to unfold many attributes and properties by using the model worlds as attached. Envisioning the network nodes as such, a PN may be seen as a specific Hausdorff space. The algebraic topological structure of the Hausdorff space allows separating the points (nodes), representing the PN vertices, and therefore supports smooth mappings, which can be expressed by mappings. This simple structure proves to be rich enough to capture most issues of PNs and their configurations. By "attaching" models of attributes, relations and perspectives as tangent spaces to the PN nodes [6], the PNs represent Quotient Spaces (of surrounding Kolmogoroff spaces in topology terms), which may arbitrarily "forget" or "remember" attached models (Fig. 10), an important feature that works on fold/unfold properties.

There all PN's and their varying configurations may be presented by indicators, attributes, and the different views are expressed by "attached" (tangent spaces) to the nodes. The resulting topology is also referred to as manifold with

boundaries [8]). In topology, these attachments as well as all projections thereof are assumed to be homeomorphisms. Transferred to production networks, this requirement expresses the need for compatibility of the models involved. As for supply chain management solutions, standards are needed to ensure such restrictions.

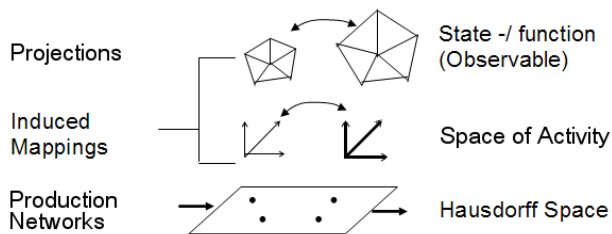Production Networks as Hausdorff Space with Tangent Spaces

Fig. 10 Production Network as Hausdorff Space with attached Space of Activity (Tangent Space) models as used above including derived state/function observable

The entire conjecture may be depicted as an orbital/shell set up (Fig. 11), with

- Centred formal theoretical core, (Hausdorff Space)

- a shell of phenomenological laws

- a models shell and

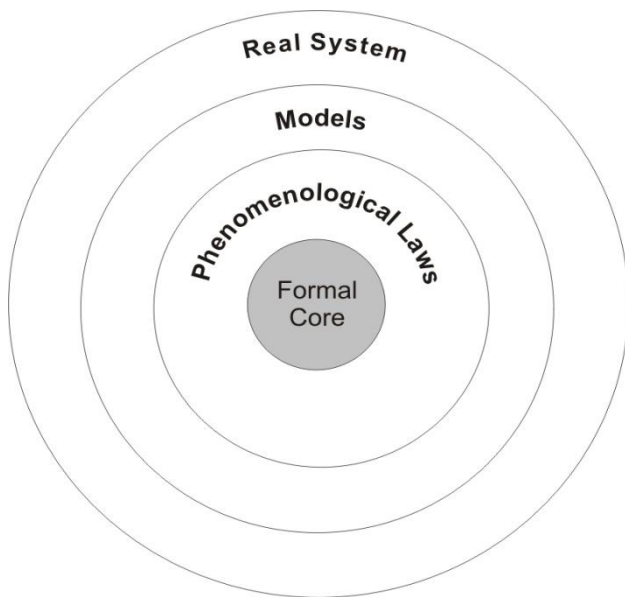- an orbit of real world examples.

Fig. 11 Production Network Theory set up design: Models derived from Real Systems towards a Formal Core Base obeying Principles, Modes and Phenomenological Laws

Since instantaneous and varying models and their relations play a key role in the approach, a prepared pool of PN specific models is the precondition for successful theory application. A first set can be proposed in Fig. 12. This list is open for additional PN models. Some of the models have been used in the examples above.
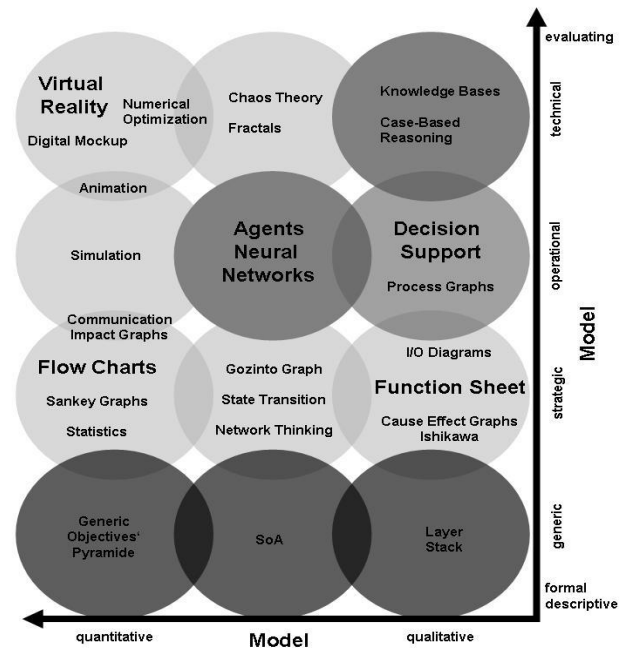

Fig. 12 Portfolio of models as frequently used for PN and generic models attached to the units

As Barbasi [2] advocates, excellent solutions for network problems may be generated by synthesizing simple and decentralised models that can be interlinked. This statement is verified by a specific system of models for PNs with the introduction of simple generic models. Resulting interoperability issues are satisfied easier and may marginalise further standardization needs concerning all models and methods involved. The theory approach, as outlined, helps to discover additional strands and narrow down avenues of research in these directions.

VI. CONCLUSIONS

PNs are of increasing interest in recent manufacturing research. To fully understand network characteristics in manufacturing management ensures considerable competitive advantages. However concepts, typologies or software supports have been developed so far mostly as singular, incoherent solutions, where PNs are simply seen as manufacturing setups that handle, which just link production units. This outline at the intention to make clearer that the main issue is not about linking units, but about linking the models of units of PNs. Instead of ignoring or even trying to eliminate PN behaviour of network nature basic network properties may successfully be utilised to improve network management and to establish powerful solution procedures. Exploiting network properties is has proven to be successful in every day manufacturing operation planning. Decision procedures in networks should be of gradual and evolving nature. The paradigm behind evidently exceeds systems

thinking and includes complexity. Planning steps induce a number of random iterations. It provokes different decision behaviour that optimises the networks' structures in total and which smoothly directs PNs within ever-changing markets and surroundings. In order to understand how interdependencies and connectivity evolve over time and what their implications in PNs are, CAS frameworks and MAS applications are frequently pointed at. There have been attempts already to extend the application of complexity theory to the management of supply chains and operations networks. Although these works could lay down some basic ideas for the analysis of PNs, they definitely call for more comprehensive research to synthesise and to further refine and evaluate these constructs. There is also a number of promising approaches outside of these disciplines e.g. in bioinformatics, as well as interdisciplinary work to be considered for PN specification and theory building as well, e.g. [10].

Considering the full range coverage of PN problem areas, many advantages of the network interpretations of manufacturing and manufacturing networks, based on topology and generic models, have been demonstrated. It could be pointed out that optimization of processes and not dynamic interlinking of units has been emphasized in modelling in the past, and that there is a lack of models and methods, apt for dynamic linking (emergent processes) in all layers (personal, informational, process …) and on all levels of detail. By introducing the concurrency modes and a generic model class, a substantial step towards methods and models for efficient PN management has been made. Further research is suggested for the development and integration of models and methods as well as the logics for coupling, breaking up and (re)linking instruments. More cyclic decision procedures have to be defined; additional generic models have to be developed on the way towards a coherent growing and powerful theory base for PN management

REFERENCES

[1] Bennett, D., Dekkers, R. (2005), Industrial Networks of the future – a critical commentary on research and practice, 12th International EurOMA Conference on Operational and Global Competitiveness, Budapest Proceedings, pp. 677-686.

[2] Barbasi, A-L. (2005), Network Theory—the Emergence of the Creative Enterprise- SCIENCE, 308, 639 641.

[3] Ivanov, D. (2009), "DIMA – A Research Methodology for Comprehensive Multi-Disciplinary Modelling of Production and Logistics Networks", International Journal of Production Research, Vol. 47 No. 5; pp. 1133-1155.

[4] Kalogeras,A., Ferrarini, L., Lüder, A., Alexakos, C., Veber, C., Heinze, M. (2010), Utilization of advanced control devices and highly autonomous systems for the provision of distributed automation systems, in: Kuehnle(ed.) Distributed manufacturing, Springer, London [u.a.].

[5] Karasavvas, K., Burger, A., Baldock, R., (2005), A Criticality-Based Framework for Task Composition in Multi-Agent Bioinformatics Integration Systems, Bioinformatics 2005, 21(14), pp. 3155-3163.

[6] Kuehnle, H. (2006), A Contribution to a Production Network (PN) Theory, in IFIP International Processing, Volume 224, Network-Centric Collaboration and Supporting Fireworks, eds. Camarinha-Matos, L. M., Afsarmanesh, H., Ollus , M., Boston.

[7] Kühnle, H., Lüder, A., Heinze, M. (2011), Criticality based decentralised decision procedures for manufacturing networks exploiting RFID and agent technology, in: Dynamics in logistics, Springer, Berlin [u.a.].

[8] Lee, J.M. (2000), Introduction to Topological Manifolds, Graduate Texts in Mathematics 202, New York.

[9] Lueder, A., Peschke, J., Bratukhin, A., Treytl, A., Kalogeras, A., Gialelis, J. (2007): The Pabadis'Promise Architecture, Journal Automazione e Strumentazione, November 2007, pp. 93-101.

[10] Merelli, E., Armano, G., Cannata, N., Corradini, F, d'Inverno, .M., Doms, A., Lord, P., Martin, A., Milanesi, L., Moller (2007), Agents in bioinformatics, computational and systems biology, Brief Bioinform, January 1, 2007; 8(1), pp. 45-59.

[11] Norri, H., Lee, W.B. (2006), Dispersed network manufacturing: Adapting SMEs to compete on the global scale, Journal of Manufacturing Technology Management, Vol. 17, No. 8, pp. 1022-1041.

[12] Olson, E. E., Eoyang, G. H., Beckhard, R., Vaill, P. (2001), Facilitating Organization Change: Lessons from Complexity Science, Jossey-Basss/Pfeiffer, San Francisco.

[13] Pallot, M.; Bergmann, U.; Kühnle, H.; Pawar, K.; Riedel, J..(2010), Collaborative Working Environments and Factors Affecting Collaboration, In: 16th International Conference on Concurrent Enterprising: Collaborative Environments for Sustainable Innovation" (2010), Lugano, Switzerland, Centre for Concurrent Enterprise, University of Nottingham, Nottingham.

[14] Srai, J.S., Gregory, MJ (2005), Supply Chain Capability Assessment of Global Operations, Euroma Conference proc, Budapest, 2005.

[15] Surana, A., Kumara, S., Greaves, M., Raghavan, U. N. (2005), "Supply-chain Networks: a Complex Adaptive Systems Perspective", International Journal of Production Research, Vol. 43, no. 20, pp. 4235-4265.

[16] Webb, C., Wohlfahrt, L., Wunram, M., Ziv, A. (2004), The Secrets of the Six Principles: A Guide to Robust Development of Organisations, Israel: Innovation Ecology.