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A CONTRIBUTION TO A PRODUCTION NETWORK (PN) THEORY

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In Production Networks' planning and control innovative concepts and solutions may result from exploiting network properties and simultaneous application of selected models. Model systems may generate very efficient solution procedures for PN planning and control as proven by several examples. Such Model systems may be interpreted as part of a theory conjecture for PN, based on a topological core. All models appear as embedded structures of network units and connections, carrying fold/unfold properties of graphs and systems. Interoperability requirements induce standardisations for the models. The theory approach proposed intends helping to explain network phenomena and provide solution approaches for PN problems.

1. INTRODUCTION

In recent years, Production Network (PN) concepts, typologies and software supports etc. have been developed generating mostly singular problem solutions. Incoherent approaches for different problem aspects often lead to heterogeneous and non consistent model fragments. Therefore large portions of the acquired knowledge about PN are cast into rather singular models or solution procedures uniquely based on case experiences and anecdotal verifications that need to be further validated. Moreover, most of the methodologies applied have been outcomes of systems theories and the resulting procedures still show characteristics of one-time static interventions not apt to dynamic network configurations.

Since PNs are complex, optimisation of interlinked agents/units is often reduced to ordinary (data) interface handling. A more promising approach for PN Planning and Control seems to be the optimisation of agents/units interrelations, cross impacts and collaborations, engaging distributed and concurrent procedures that continuously and progressively generate "evolutive" solutions, (Bennett & Dekkers, 2005).

Analysing such solution procedures for PN planning reveals that good results have been achieved by synthesising selected models of PNs and PN units. These approaches can be generalised by putting a number production network models upon a common base. The interpretation of PNs as specific topological structures enables to propose a PN theory design, which allows quicker and better problem solutions.

The approach is motivated by complexity theory, topology and fractal organisation experiences and intends to contribute to specific network sciences as called for by increasing numbers of researchers (Barbasi, 2002; Camarinha-Matos & Afsarmanesh, 2005).

2. MODELS AND PRODUCTION NETWORKS

2.1 Models in Production Networks

Networks are obviously controlled/attracted by directives and objectives. Re-configurable dynamic set ups are interrelated, inter-linking/detaching units, establishing and optimising varying and changing process chains. Global order structures may "emerge" as results of local interactions if networks will self-organise towards attractors. Business opportunities may represent "attractors" that orientate and reconfigure production networks. Therefore we may understand a PN as consisting of self-organising, self-optimising units with own processes and structures not developing in a linear way, not exactly predictable, moving towards such configurations. It appears that a few configurations are 'more favourable' than others in some way.

Planning and control does not regard the units themselves but various models and attributes of these units that are manipulated and put into relations. Each PN planning step makes use of a number of such models raising the question of how the dependencies and simultaneous planning actions influence choices, attributes and levels of detail of the models involved. Therefore the network units' interaction structure must be envisioned as a model system's interrelation structure. As an example for this principle the arrangement of equipment within a factory layout may be given.

2.2 Interrelated Models for Planning

Generally it is assumed, that the site of a unit in the layout plan depends on the material flow, the process sequences, the overall layout and technological influences. Traditionally there is outlined, that any conception of production systems is to be executed by top-down-procedures, assuming proportional relations between length of planning horizon and planning object detail. Inevitably the construct will supply correspondent views of planning horizon lengths and details of planning object levels. Long range decisions are envisioned in direct link with rough sketches and low precision, whereas short planning horizons are associated to details in alternatives and variants for processes and factory layouts. It is well known and widely tolerated that the resulting "one time" solutions are sub optimal, not able to cope with volatile market demands.

Variety and unpredictability call for versatile productions. Therefore there is the permanent need for planning, using all model attributes required concurrently. Such concurrent procedures assume a "pool of models", which is permanently available and may be instantly activated at the requested attribute and detail level. Models of the mentioned unit attributes as flows and restrictions and geometrical attributes and impact relations (noise, vibration) contribute to decisions about layout arrangements could be put into a planning impact diagram, and are activated for decision making (Figure 1).

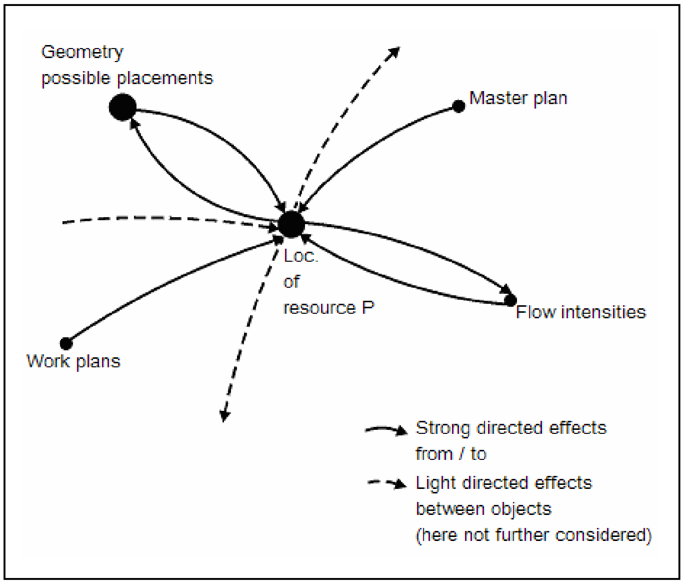

Figure 1 – Planning Impact Diagram - Impacts and relations between units' attributes for a planning issue: Determine optimum location of machine P in layout plan

Production re-configurability requirements evidently turn hierarchical planning into a concurrent planning process engaging interrelated models, attached to the network units.

2.3 Production Network (PN) Control

This procedure may be transferred. For Planning and Control of PN, Decision Support models may be attached to the units. Spaces of Activity, SoAs, (Figure 2), viewing state variables which describe the units' activities and success may be introduced.

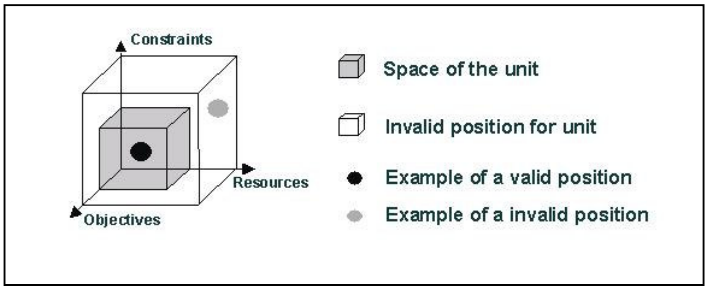

Figure 2 – Space of Activity (SoA) by Mappings for Planning and Control of Production Network units - viewing positions (Klostermeyer, 2002)

The units' objectives are output of the network strategy, the resources and constraints affect the structures. In consequence, the SoA volume represents the unit's decision space, which may be used for self-organisation.

The unit's SoA position gives input for decisions on maintaining the self-organisation mode or reducing autonomy and calling for PN interference. Dependant on the unit's inability to cope with changes in the environment, network "order parameters" may gain influence on units' activities ((self) reproduction, (self) destruction, (self) structuring).

The PN result must be achieved by commitments on overall objectives (Kühnle, 2005). Each unit may

(I) decide on the appropriate methods, tools, etc. in order to achieve the objectives negotiated and agreed upon. Prerequisites are resources, e.g. budgets, competencies, technical and personnel availability and constraints (a unit may have to face may be e.g.. legal restrictions and capacity limits). Units' positions remaining within the predefined SoA allow autonomous decision making.

(II) loose it's autonomy, if positions within the unit's SoA are not achieved. Mechanisms must be activated that prevent the deviations and provide PN plan fulfilment.

The PN reacts on any increase of complexity (diversity, uncertainty and unpredictability) by expansion of the SoAs affected (if affordable). More foreseeable steady conditions allow to shrink the SoAs' volumes.

2.4 Self similarity and folding of SoA

All objectives, broken down onto the units and subunits, must be negotiated and harmonised with the over all PN objectives and consistency checks for the networked organisation on all levels have to be applied (Vasiliu & Brown, 2003). If there is no consistency on the network level u, the procedure has to be lifted up to the next network level u+1, where the PN SoA appears as aggregated model. The iteration has to be continued as long as either highest network level is reached or all objective figures are achieved.

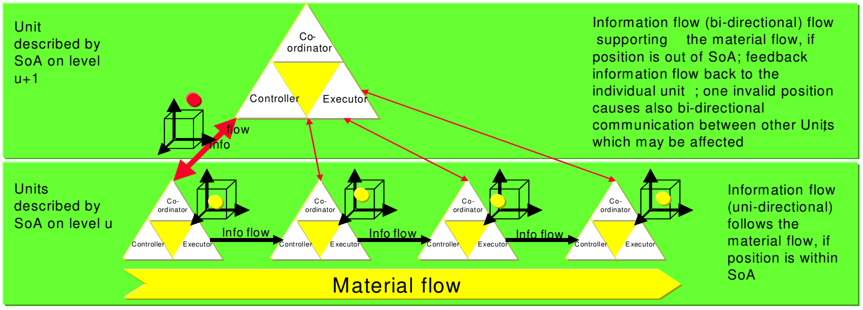

Figure 3 – Information flows for harmonising goal settings of SoAs,
caused by invalid position of the higher u+1 level SoA

Figure 3 illustrates the communication within the meshed control loops established by SoA interferences for PN control. Higher levels of the network are represented by SoAs, carrying all SoAs of lower network levels as (self-similar) folded structures. The configuration is optimised progressively for a short term horizon. Splitting, removal or re-linking of units are possible decisions to be taken, if the deviation can not be avoided by the unit's very own efforts (self optimisation). For medium and long term control of the network, lifecycle procedures may be applied, as described by GERAM, (GERAM, 1999).

The control mode described is different from traditional planning and control of company networks, where elaborate plans are calculated for each unit, covering discrete planning rhythms and horizons. Central control functions (as ERP, MES,..) are applied to accomplish plan fulfilment by time and load shift on the base of fixed, quasi - static order – resource prescriptions. Well aware that these plans are incorrect right after its set ups, the units' staffs are fully occupied with correcting, adapting and improvising, basically trying to fight PN reactions as bottlenecks, inventory oscillations, exceeded lead times, bull whip effects or similar so called "chaotic" behaviour.

Producing much better results (e-Volution II, 2004), the proposed planning and control procedure is continuous, distributed and concurrent, generating solutions progressively. Simple procedures, like the SoA logic, are locally applied. Plans, assignments, units, responsibilities etc. are continuously rearranged, processes newly established or reconfigured. Again, effective control procedures turn out to be communication intensive, objective driven adaptation and configuration processes, using interrelated models.

2.5 Distributed control by Agents

The SoA logic described has also proven to be a useful instrument for Distributed Automation, the SoA and embedded structures may be unfolded to any network structure's level, also to the networks Manufacturing Execution level (Kühnle et al., 2001).

For factory automation, the objective and resource axes may be "rescaled" after being broken down onto the manufacturing equipment unit level in a manner that loads and resource consumptions can be mapped. After the transformation, the SoA visualises and evaluates unit states and objectives for process steps and order loads. Details of objectives, resources and constraints may easily be checked, determined and negotiated by the use of agent technology (Lüder et al., 2004). One generic concept for distributed order control, based this approach is PABADIS (Plant Automation BAsed on DIstributed Systems, (Bratoukhine & al., 2003). In order to execute decision and control in the navigation logic described in 2.4, three types of supporting agents can be defined: Product Agent (PA) for Common Manufacturing Units (CMU), Production Management Agent (PMA) and Resource Agent (RA), (McFarlane & Bussmann, 2000); Sauter & Massotte, 2001). PA is a mobile agent, carrying all information necessary for processing orders between ERP and units. Main decision tasks are the assignments of orders to units as well as the ERP communication, covered by the Look Up Service (LUS) and the assigned SoA. RAs carry unit profiles and information about units' states mapped to the SoAs (rescaled). PABADIS aims at creating an architecture for distributed plant automation as a standard ensuring flexibility, scalability features and plug-and-participate properties for distributed control of PN.

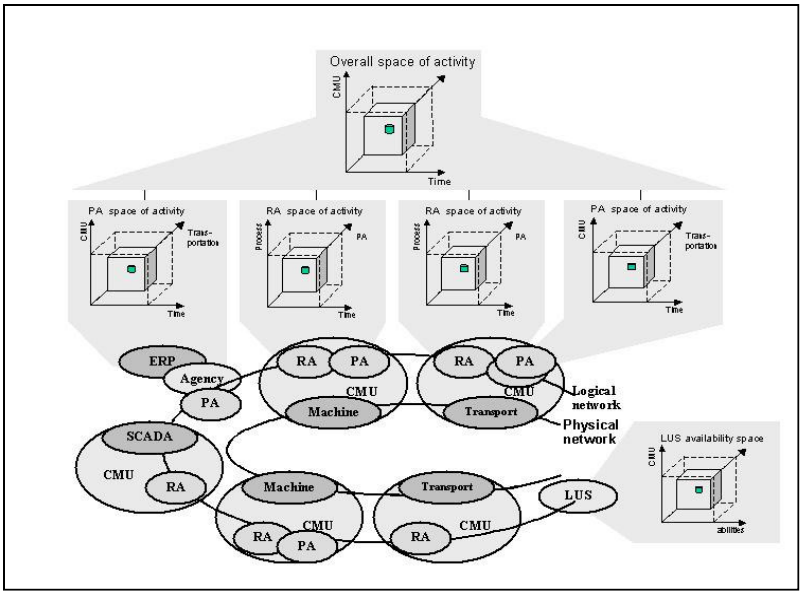

Figure 4 – Example of the PABADIS architecture implementation, involving SoAs and Agents

By splitting up the MES level of the so called "automation control pyramid" into a network of intelligent nodes, adaptable structures are generated (Figure 4). The resulting control solution appears as a structure of interlinked models, detached (virtual) from the manufacturing units, as PABADIS is based on emulated controls, the Java Virtual Machines (JVMs), for all units (Klostermeyer & Klemm, 2005).

Consequently the SoA network of JVMs represents the same degree of complexity as the network of units to be controlled. This rule, generally referred to as "Ashby's Law of Requisite Variety" (Malik, 1993) was the guideline for the pilot "navigation in manufacturing networks" approaches with agents, that later resulted in the architecture (Klostermeyer, 2002) described. Another finding can be stated: Production Planning and Production Simulation can now based on one and the same model system, a requirement, frequently cited for traditional planning, which is -for intrinsic contradictions- unachievable within systems set-ups.

3. THEORY DESIGN APPROACH

The findings outlined above can be generalised. The PN Planning and control examples explicitly deal with phenomena as unpredictability, self-organisation, fractal structures (edge of chaos), diversity and self-similarity (pattern recognition). These are important Complexity Principles (Watts, 2003; Webb et al., 2004). Other findings as the focus on the model world or synergies by adding network units may be seen as specifications of the New Economy Rules: "From places to spaces" and "Increasing Return", (Kelly, 1999).

Productions facing volatility, speed and unpredictability, reach their limits (Kühnle & Schmelzer, 1995) and the pressure by new phenomena calls for explanation, (Kuhn, 1962). For PN, phenomena as diversity and edge of chaos (Stacey, 1996; McKelvey, 2004) are still waiting to be covered by adequate theories (Dekkers et al., 2004). The examples discussed demonstrate the important role of interlinked models for PN description. Rules and laws could be cited where the approach improves congruence of PN observation and model behaviour.

Such elements may (Thagard, 1988) constitute a theory on the field discussed. In the conjecture proposed, the PN nodes are reduced structures, able to unfold many attributes and properties within model the world assigned.. Envisioning the network nodes as elements, a PN may be seen as a specific Hausdorff Space, carrying attached models of attributes, relations and perspectives as tangent spaces. The PN appears as the Quotient Space of surrounding Kolmogoroff Spaces (in topology terms, Boto von Querenburg, 1979), which may arbitrarily "forget" or "remember" attached models (Figure 5).

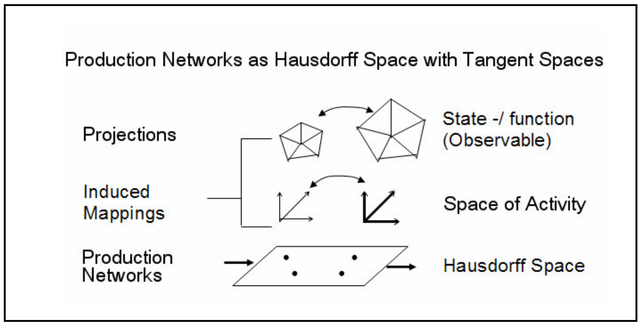

Figure 5 – Production Network as Hausdorff Space with attached the Space of Activity (Tangent Space) model as used above including derived state/function observable

The entire conjecture may be depicted as an orbital/shell set up (Figure 6), with

- Centred formal theoretical core, (Hausdorff Space)
- a shell of phenomenological laws
- a models shell and
- an orbit of real world examples.

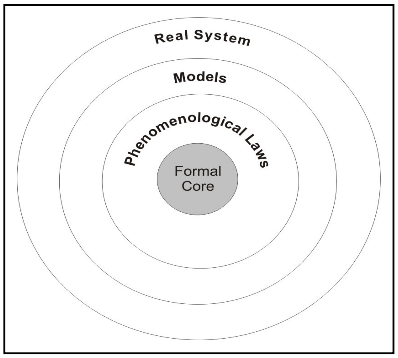

Figure 6 – Production Network Theory set up design: Models derived from Real Systems find a Formal Core Base and follow Phenomenological Laws

Since interlinked models play a key role in the approach, a prepared pool of PN specific models is the precondition for successful theory application. A first set has been proposed by Massotte (Figure 7). This list is open for additional PN models. Some of the models have been applied in the examples outlined.

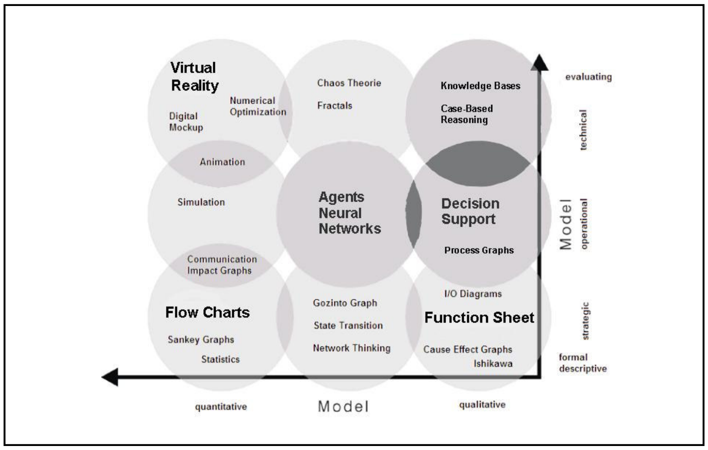

Figure 7 – Portfolio of models frequently used for production according to Massotte, (Massotte, 1995) to be attached to the network units (subset in bold letters is applied for the examples outlined)

As Barbasi (Barbasi, 2005) states already, excellent solutions may be generated by applying/synthesizing rather simple models decentralised and interlinked. For PN, units' interoperability requirements might enforce general standardization needs concerning all models involved.

4. CONCLUSIONS

In the search of competitive excellence in production, PNs have received much attention in the last years. Understanding network characteristics in production gives competitive advantages. However concepts, typologies and software supports etc. have been developed so far mostly as singular not general problem solutions, where PNs are simply seen as structures, which link production units.

This outline could point out, that linking the models of PNs and models of units may generate good results. Therefore a selection of models is proposed for better PN planning and control problems solving. Moreover it may facilitate to integrate other findings; the list of models is open, the collection of laws and rules is just started. Exploiting PN advantages is successful in every day operation. Instead of trying to ignore or even eliminate structural behaviour of network nature, network properties may successfully be used to establish solution procedures.

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