1 INTRODUCTION

The increased turbulence of corporate environments for production enterprises is characterized by shortened product lifecycles and cumulative variants. Customers demand smaller delivery lot-sizes with higher variance and shorter delivery times. Short lead times and the resulting need for fast reaction to dynamically changing environments play a major role in production planning and control (Wiehndahl, 2006).

However, today’s Enterprise Resource Planning Systems (ERP) and Manufacturing Execution Systems (MES) are not able to predict and coordinate detailed micro sequences of the production between the operators and the technological resources. These systems focus the planning and scheduling of machines and technical resources and they insufficiently support the operational coordination of the operator-machine interaction. This means that operators face situations where they have to make many decisions without being sufficiently supported by IT-systems. They are often provided with an excess of irrelevant and useless information, while critical coordination information is not available, at least not at justifiable efforts.

The individual qualification, knowledge and experience of the operators become increasingly important for manufacturing companies. As production systems become increasingly complex and the productivity of both machines and operators rises, the responsibility of each operator rises as well.

2. DECENTRALIZED DECISION-MAKING IN PRODUCTION PLANNING AND CONTROL

The cybernetic production planning and control approach thrives for a self-learning and adaptive coordination of the complex interaction on the operational shop floor level. The vision of the approach is to invert the traditionally centralized planning paradigm on the shop-floor level to a decentralized self-learning and adaptive production system based on cybernetic design principles:

- Coordination of the production planning and control systems based on the viable systems model (VSM) of Stafford Beer (Beer, 1994) and
- A set of decentralized and adaptive decision-making modules (called systems in the VSM) based on homeostatic feedback control loops.

The viable systems model (VSM) is a model of the organizational structure of any viable or
autonomous system. Especially the underlying principle of **relative autonomy** is important for the organization of production planning and control systems. It controls the range and allows the adjustment of the degree of freedom between local autonomy and central coordination without inconsistency (Malik, 2006).

Until now the model was adopted to a number of scientific works. The fundament of the Viable system model is the theorem of invariancy which says that complex systems do possess isomorph control structures independent of the materialized structure (Wegehaupt 2004). Starting with this theorem Beer derives control mechanisms and structures of viable Systems based on the functionality of the human nervous system. Beer identifies five control components which he calls system 1-5 (Beer 1973) (Figure 1).

The systems that can be considered as Control units allow a coordinated, local optimisation and the survey of different hierarchical levels. However control units can describe systems only from a technical and mechanical perspective. In fact the guiding mechanisms of a soziotecnical system like assembling are more complex and more versatile than those of mechanical systems because of the human beings bringing in their function as controller own targets to the decision process and thus can not be described by easy to define transfer functions (Schwaninger 2004). This aspect is considered by the Viable System Model (VSM) through explicitly accounting for the special skills and behaviours of the human deciders (Beer 1979, Malik, 2006). The VSM integrates the described basic control mechanisms as well as autonomy and self-organisation principals to an integral model for the guidance of soziotecnical systems. This model describes the collectivity of functions necessary for guiding a system and allows allocation of these guidance-functions to the decision agents of the system. Furthermore the homeostatic control loop defines the information flow between the decision agents. The basic of the local regulation integrated in the Viable System Model consists of the autonomy principle which implicates a two-dimensional understanding of autonomy (Malik, 2006). In principle all the assembly groups involved in the order processing should be granted completely freedom of attitude, that means unlimited tolerance of disposition, within they can react through autonomous action and self-organization to the complexity of the local environment and compensate interruptions. As they act as a part of the whole, they are not completely free concerning their behaviour, but have to act according to a superior frame of action synchronising the actions of the vertical and horizontal cooperating divisions and optimising in terms of the whole system. This frame of action is provided by a central decision agent regarding the situation from the perspective of the whole system - the assembly in our case.

Dispostion, communication and guidance functions are integrated in the guidance mechanism. Communication functions make demands exceeding the configuration of the information structure to the decision agents involved in the regulation. It is necessary to communicate relevant information and thus bring in the local available knowledge to the decision process. The existence of information respectively the communication of information is only a necessary but not a sufficient condition for an efficient guidance. That’s why monitoring functions have to be integrated to the guidance mechanism, which can verify through suitable circular criterions the stability of the internal balance of the assembly. The combination of provision of information via push principle and the surveillance via pull principle causes a decoupling of material and information flow and is necessary for a proactive pre-regulation. Variations of the adjusted balance, caused by assembly intern or extern interruptions, mean activators for the disposition function which provides mechanisms recovering the stability of the inner balance.

While the viable system model defines the roles and the Structure of the involved sub systems the homeostatic feedback control loop defines how an

![Figure 1 – The Viable System Model](image-url)
adaptive and self learning system works inside of one sub system. The viable system model thus is the macro-level and the homeostatic feedback control loop the micro level of the model.

A model permitting the local compensation of interruptions is the control cycle, known from technical systems. A control unit influences the process through the actuating units aiming to adjust the output to the target-setting of a superior entity. Thus interruptions influencing the process can be compensated locally. Two basic principles can be used. The feedback principle measures the output of the process and compares it to the input. At the date of data check interruptions have already taken place. Hence the reaction to the measured divergence can only compensate impacts caused by the interruption. This principle is, referring to the date of the interruption, relating to the past (reactive). In contrast the feed-forward control principle is forward-looking. Within the feed-forward control information of future interruptions is used to prepare the system through suitable manners and thus to compensate the impacts of the interruption. The disadvantage of the control principle is the fact that only known interruptions can be monitored and for this reason compensated. In contrast the feedback principle can also be used concerning uncertainty of potential disturbance variables. As the regulation and the control principle complement one other, it becomes obvious that a synthetical approach would be suggestive. This integration of regulation and control is called guidance in the field of cybernetics.

The idea of a homeostatic feedback control loop comes from an electronic apparatus and the principle behind the apparatus build by Ashby.

The homeostat is a electric apparatus, that transfers electrical input into output. The input current runs through an inductor and generates a magnetic field, which induces a torque to a needle or indicator on the machine. The needle itself is part of an electrical circuit. The lower end of the needle is placed into a semicircular bowl filled with water, in which a battery secures a constant voltage. In this way the changing position of the needle steers the currency that runs through it, and which is – intensified – the output current of the homeostat sub-system. In the constellation of figure 3.2 a the output current of each homeostat is the input for three other homeostats. All four homeostats are coupled therefore via electric feedback loops to each other. In this constellation the needles of all homeostatic sub-systems will finally turn back to the starting position in the middle (Pickering, 2007).

The approach of the homeostatic feedback control loop is threefold. First the negotiation and processing of targets between planning and control entities is integrated into a target adaption control loop.

Second, the coordination of input and output information is realized by a service oriented architecture that connects the planning and control entities among each other and with the proprietary IT-system of the company via web service bus (Schuh, 2007).

Third, the worker himself makes the decisions based on this information and his implicit knowledge. He is supported by a set of alternative predefined workflow-fragments that generate the activity chain.

By concretising the guidance function described in the model and the necessary information flow of the use case of the box assembly, we established within the research project “Adaptive Logistik” a basis for a software based assistance system supporting the actors in performing their tasks.
3 DEVELOPMENT OF APPLICATIONS IN INDUSTRY CASE

Based on an industry case in the assembly planning and control of a machine building company the implementation of the introduced approach is examined and analyzed in detail. The goal is an advanced synchronization of the assembly progress and the required material provision, while planning and communication facilitate reactive adaptations of assembly operations to improve continuous assembling. In order to enable easy integration of the planning procedures into the existing IT-structure, a SOA (service oriented architecture) is introduced, using XML-messages which are based on unified data sets (e.g. bills of materials, resources, work plans, processes, orders). With full transparency of material availability and arrival at every assembly step, local optimizations of operations and adaptations of plans become feasible.

Successors (e.g. final assembly) narrow down the expected requirement definitions as they proceed in assembly, so that their predecessors (e.g. sub-assembly) are able to adapt their order priorities accordingly. In return, predecessors project their expected finish dates of sub-assemblies, always trying to stick to the centrally agreed time-frames. By receiving continuously approved time-frames or pre-notifications of plan violations, the successor can adapt the own plans to changing preconditions by way of precaution. To gain profit from these complex and dynamic requirements it’s necessary to provide a great amount of in plant flexibility. Assembling, the final step of the productions process, has a great influence on compiling the predicted dates of delivery. However, studies showed that 20% to 60% of all applications conclude delayed (Evers, 2002). The reasons for this are on the one hand the internal complexity of the assembly and on the other hand the high degree of disruption influencing the assembly. In addition to the complex product structure, particularly the high flexibility of assembly processes can be seen as the reason why the complexity of assembling-control is higher than the complexity of manufacturing-control.

The processes in the assembly possess the structure of a network. That means there are both activities that can be processed in parallel by a greater use of resources and activities that, for technological reasons, need to be processed sequentially (Figure 3). Since the applications often require the same resources, the network structures of several applications are linked through these capacities with each other. This problem is intensified by the fact that such a network structure is not limited to one assembly-group. Furthermore it contains also the pre- and final assembly working together on one customer order.

The production planning and control systems used today are not able to master this complexity, as the centrally developed plans possess only a limited period of validity because of the dynamic processes and the disruptive influences (Baumann, 2006, Frackenpohl, 2002). In practice, this result often leads employees to try with a lot of effort, on the basis of their personal experience and knowledge, to assure an on-schedule assembling (Frackenpohl, 2002). One may assume that, without any the assistance of a suitable planning-system, the human being is overstrained because of the complexity, the
dynamic and the intransparency of the assembly processes.

The specified concept of control is currently implemented for the first time within the research project “Adaptive Logistik” at the assembly of DECKEL MAHO Pfronten – a company of the Gildemeister group. A software based Workplan editor makes possible the creation of network working plans replacing the existing sequentielle working plans (Figure 3). A network working plan provides the possibility to describe the predecessor/successor relation of a working process. Thus all alternative assembling sequences can be considered. Furthermore the workplan editor provides the possibility of allocating different resources to one assembly sequence and so integrates the material requirement of one working operation. Through the integration of conventional working plans and the bills of materials the network working plan becomes a central tool for planning (Figure 4).

The further steering functions of the scheduler serve as surveillance of the realisation of the parameters through the assembly divisions as well as the identification and compensation of disruptions. Thus the function scheduling of the pre-assembly is based on the need to smooth manually the unbalanced burdens of the pre-assembly, caused by the final assembly orders. Thus temporary bottlenecks can be eliminated and furthermore loss of power caused by not use capacities can be prevented. Disruptions according to the principal of relative autonomy have to be compensated primarily by using the local scope for decision making. Only if the impacts of a disruption exceed the possible compensation of the local steering level, the scheduler has to intervene.
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