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ROBUST PRODUCTION PROGRAM PLANNING IN RAMP-UP SITUATIONS

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Abstract Producing companies are confronted with a growing number of product ramp-ups, since product life cycles are decreasing and product diversity is increasing. Production Planning and Control (PPC) of ramp-up products is particularly challenging, as there is a significant lack of reliable experienced data. The information deficit is exceptionally high for the first step of PPC process, namely Production Program Planning (PPP). The paper in hand proposes an innovative approach of cybernetic PPP that enables companies with numerous ramp-ups to design reliable and fast PPP processes that can react highly adaptable on unpredictable environmental disturbances. The Viable System Model (VSM) is used as frame of reference for the design of PPP processes in line with principles from management cybernetics.

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1. INTRODUCTION

Producing companies are confronted with a growing number of product ramp-ups, since product life cycles are decreasing and product diversity is increasing (Wildemann 2009), (Romberg 2007), (Fjällström 2007). According to Wack, the car manufacturer Mercedes-Benz Cars has increased its average number of ramp-ups more than three times a year for the last two decades (Wack 2010). 225 ramp-up situations of 100 car manufacturers and suppliers were inspected in a study which showed, that the serial production ramp-up is still burdened with major problems. The economic goal could not be achieved in 33% of the cases; the technical goal was missed in 50% of them.

Production Planning and Control (PPC) of ramp-up products is particularly challenging, as there is a significant lack of reliable experienced data. The production program planning (PPP) is the first step of PPC (Schuh 2012). Therefore its lack of information (e.g. product structure, sales projection etc.) is particularly large. Stich emphasizes this particular role of PPP as follows: "The different conditions in the ramp-up phase compared to serial production are exceptionally affecting the production program planning." (Stich 2007).

While developing the production program, the high planning effort of the PPP of ramp-up products can lead to delays and the lack of information can cause a lack of planning reliability. Such delays and uncertainties can influence the entire result of the PPC, as they may continue in subsequent production planning and control processes.

Hence, the goal of current research activities is to establish a model of PPP based on the principles of management cybernetics. In previous research projects the "Model of Cybernetic Management of Versatile Production Systems" was developed, which is a frame of reference to this interdisciplinary and cybernetic design of the PPP, see also (Brosze 2011). It enables a transparent handling with any complex and interdisciplinary structures, processes and flows of information and is based on the Viable System Model (VSM) developed by Stafford Beer.

PPP must be able to learn from earlier planning cycles. It has to be able to automatically recognize and compensate inner and outer disturbances in order to be self-optimizing. Therefore, high resolution information must be available in adequate granularity, correctness and actuality. The system must be able to adapt itself to new circumstances for disturbance compensation. Cybernetics will be used as the main principle for the creation of PPP, because it fulfils these requirements completely.

2. INITIAL STUDIES

2.1. Production Planning and Control

Scholz-Reiter et al. choose as the central starting point the correct degree of use of self-control concepts for logistics processes (Scholz-Reiter et al. 2007). The proper degree of self-control, which is conducive to the achievement of desired goals can be found by using the concept of positive emergence. These emergent properties can be quantifiable metrics (average lead times, inventories, workloads, deadlines, etc.) or not directly quantifiable values (flexibility, adaptability, robustness of the system, etc.).

SFB 614 of the University of Paderborn deals with the use of self-optimizing systems in mechanical engineering. The focus of the research is autonomously acting and responsive to changing environmental conditions reacting technical systems. Besides the scientific study of self-optimization, tools needed for the design of self-optimizing systems may be developed (Gausemeier et al. 2006).

The so-called Hanoverian school has dealt with the manufacturing control for years. For improved management of the deviation of production schedules of production logistics processes Wiendahl uses basic principles of control engineering to the production planning and control. By using feedback mechanisms the reaction rate by disorders may be increased and a better approximation of actual to set point values may be realized (Wiendahl 2005).

Nyhuis offers an approach to achieve a higher degree of synchronization of production targets by expanding the production characteristics. Basis of the characteristic theory are the flow elements, which summarize the work processes and the flow time of a production order. These flow elements are the basis for various descriptive models such as the funnel model developed by Wiendahl and the based thereon output diagram (Nyhuis 2008).

2.2. Robust Design of Production Management Systems

Below current approaches are presented, which specifically deal with the issue of how cybernetic principles can be integrated in production systems to increase the adaptability of those. Unlike conventional methods and the general approach in engineering or management science, system theory and cybernetics don not omit this complexity by restrictions and simplifying assumptions, but place them at the center of all considerations.

The studies of Wiendahl, which found use within Collaborative Research 467, aim to develop a situational configuration of order management in a turbulent environment. The term order management is introduced to differentiate from the PPS concerning the planning and control of orders (Wiendahl 2002). Turbulence expresses here that a difficult predictable environment exists, which leads to fluctuations in demand and unforeseen events (Wiendahl 2002).

Balve develops within the SFB 467 about the adaptability of companies a framework for designing versatile job management systems (Balve 2002) based on the VSM. Here, an order management system is defined as an ideal and/or real instrument to economically and flexibly handle customer orders. The described model integrates into a comprehensive proceed concept for adaptable job management systems. This includes the stages of team formation, a situation analysis, the formulation of goals, the solution synthesis and a final assessment (Balve 2002).

Espejo presents in his release further application reports by various authors (Espejo, Harnden 1989). The publisher himself initiates the collection with his report on the application of the VSM as a diagnostic tool for P.M. Manufacturers, a medium-sized manufacturing enterprise in electrical engineering. Result of the project is a detailed specification document. The application demonstrates basic techniques, how recursion levels are defined and the responsibilities of the mechanisms of the VSM will be translated into the organizational context.

2.3. Ramp-up Management

The period between the completion of the product or serial development and attaining peak production (beginning of serial production) is called the production ramp-up (Schuh et al. 2008). This period is distinguished by transferring a preproduction model from the development stage into the stage of serial production (Wiesinger, Housein 2002). The production ramp-up represents a critical stage because of the novelty of the product, the poor understanding of the production process and the inevitable integration of new suppliers (Terwiesch et al. 2001).

Schuh developed a holistic and continuous ramp-up management model to structure the tasks, objectives and involved organizations of a ramp-up management, including those three topics as main elements (Schuh et al. 2008). External suppliers, internal production sites and organizations as well as the customers are summarized as involved organizations. Main objectives of ramp-up management in order to gain significant competitive advantages are the reducing of ramp-up specific costs, shortening the production ramp-up time and assuring the predefined product quality. The first main task of ramp-up management is to define a ramp-up strategy; the second is to develop a ramp-up organization affecting Supply Chain Management, production management, cost management and change management.

The ramp-up curve shows the acceleration of the production ramp-up and demonstrates the functional coherence between the production output of accurate products per time unit and the production ramp-up time (Baumgarten, Risse 2001).

Precondition for a holistic and continuous ramp-up management is the control of the critical stages of the production ramp-up. All activities needed for the planning, control and execution of the production ramp-up under consideration of all upstream and downstream processes have to be concentrated in order to reach an effective and efficient ramp-up management (Kuhn et al. 2002). That is why an integration of key or system suppliers involved in the product development process into the production ramp-up stages is indispensable as well.

2.4. Critical Appreciation of existing Work and Theories

Regarding the PPS methods and there development over time it becomes clear that many terms and concepts of organizational cybernetic management have also gain entrance in operational processes. Hence, a development from the early deterministic models of successive planning strategies to strategies and processes of self-control and optimization of production and logistics can be reconstructed. Existing approaches of production planning and control do not meet the nowadays often prevail dynamic processes of the production environment. The, on averages based planning principle of current ERP systems and the underlying successive planning prevent the holistic view of the PPS tasks and lead in most cases to suboptimal planning results. A planning that is aligned with an overarching business managements goal is, because of the isolated part considerations and reduced computational complexity, not possible with today's PPS solutions.

The approaches developed for self-management in different scientific disciplines show, that in analogy to natural autonomous behaviour, forms of self-organization can be applied to social or logistical systems. The researches lead to the conclusion that self-control strategies for the control of dynamics and complexity are suitable in production logistics systems under certain conditions and have stable system behaviour. The analysed deployment of self-organization strategies in the examined research is often based on restrictive assumptions regarding the flow of materials and structures and refers on simplified abstract models.

In summary it can be stated that there are currently no models that define in detail a structure for a decentralized, self-optimizing planning and control of the production system and its embedding in the strategic-normative production management.

3. RESULTS

In order to support managers dealing with complex systems, Beer deduced the VSM from the human central nervous system and cybernetics (Beer 1972). Following Beer, viability is the continuous conservation of system identity against the background of a steadily changing environment, not just the survival at subsistence level.The three fundamental principles VSM is based on are viability, recursivity and autonomy. Viability implies that a company must react to internal and external disturbances in an appropriate way, in order to sustain its existence. Recursivity is a principle to structure organizational systems in a self-similar way. Therefore a viable system is a composition of nested systems, which are viable systems, too (Beer 1972), (Malik 2006). The ability of a system to act independently as long as it is in accordance with its meta-systems' rules, is called autonomy (Beer 1979), (Probst 1987). In the VSM, a structure is defined, which can realize those fundamental principles. Referring to this, a viable system consists of five systems.

3.1. Conceptual approach

The conceptual approach is split into three solution segments:

- Information demand analysis
- Sensitivity analysis for evaluation of information criticality
- Creation and design of a VSM-based cybernetic PPP

The main tasks of intermediate PPP are identified and broken down into several planning processes in order to give a detailed display of the information-flow by the information demand analysis. Methods, formulas and algorithms needed for the solution will be composed for every identified step of the process. Based on those the needed (input-) information and the generated (output-) information will be passed to PPP and consolidated in the following steps. The definition of boundaries of PPP system according to system theory is the base to this research, the result is a detailed map of the overall required information in PPP. The analysis uses the pull-principle to avoid unnecessary calculations and to warrant completeness of the information map. Depending on the aspired result (intermediate production program) the process will be backtracked to the predefined boundary of PPP or rather PPC. The IDEF Standard is used for the steps of modelling (Mayer 1992). A model with high complexity is generated by this systematic approach.

The aim of sensitivity analysis is to identify the criticality of the input information. This evaluation is carried out in the following steps:

- Definition of a ramp-up specific target system for PPP
- Construction of a quantitative evaluation scheme for the quality of input information based on the predefined characteristics (availability, correctness, actuality and level of detail).
- Explanation of the correlation between the quality of respective input information and its effects on the target system and derivation of a sensitivity-index for the necessary input information.

According to Brosze, creation and design of a VSM-based cybernetic PPP aims on a PPP as a part of the Cybernetic Management Model for Versatile Production Systems. The VSM-systems 1 to 5 of PPP and ramp-up management are defined and integrated into the reference model for that reason. Process routing centers, process control centers and process coordination centers, which are the parts of the necessary communication infrastructure, are formed. Also the operational VSM-systems are integrated in the existent VSM-structure. In addition they are identified as alternative sources of information, for example the different entities of ramp-up management or a person as an individual part of the entire system. The creation of knowledge base to warrant interdisciplinary communication and the use of learn effects are getting special attention.

3.2. Viable Production Management

The reference model of SCM based on VSM comprises the whole order processing from the processing of an offer, to the production and delivery of the finished product, is thus characterized by an explicit process orientation (Balve et al. 2001). The improved way of dealing with disturbances and the continuous checking, if system changes are necessary (both can be managed by means of the VSM structure), are the most significant differences between a conventional and a cybernetic order processing. The model must consist of five specific systems (see section 3.2) that will be described below. The company's normative level that aims on its survival by means of changeability and which defines a corporate culture that is followed by all subordinate systems is represented by system 5.

The company's external stability performing strategic tasks are taken care of by system 4. After doing a strategic analysis of external conditions and the internal ability to deal with it, it makes strategic decisions, e.g. concerning vertical integration, network configuration, supplier selection, customer segmentation and the definition of KPIs. The feasibility of the strategic input from system 4 is checked by system 3, which transforms those strategic tasks to tactical operations (e.g. the monitoring of availability of resources, the assessment and optimization of methods, operations and tools in use), in order to achieve internal stability and efficiency.

The synchronization of processes is the main objective of system 2. It designs and sustains communication channels and interferes with operative processes of system 1. Regarding the importance of the operative units, there is a more detailed description of system 1 following. The so called operative unit (system 1), represents the control loop that is responsible for self optimization and stability of the main processes of order processing. The system 1 equals the operative control of the processes and consists of three different elements, which are responsible for specific tasks ensuring the above mentioned criteria.

The tasks of order processing, including the planning, execution and monitoring of single operations is carried out by the process itself. Responsible for measuring the performance of the process and ensuring a bidirectional information exchange between the directly related process and other processes, the process control also initiates reactions to known disturbances. The process management requires human intelligence in order to make the necessary adjusting decision, and can't be standardized and therefore automated like the tasks of the process control. The tactical management therefore passes objectives and target value corridors to the process management, which evaluates the process performance compared to the target values. Thereby derivations, which cannot be corrected by the process itself or the process control, are detected and corresponding measures are developed. Adjustments of target value corridors and adjustments of the process are examples for the measures, the operating states of other processes are integrated in this decision process.

The designing of the process follows the principle of maximum autonomy of the decentralized operative units. It is also reasonable to design it according to control loop principles. The process needs to show a high stability in the assigned corridor of target values and it has to be able to adapt to adjusted target values in a minimal time period. The tasks of process control into such a process can be integrated by differentiated control logics linked with corresponding decision models and standardized information channels to other processes. The stability range of the process has be extended by this enhancement and thereby the variety, the process management has to handle has be reduced.

It was already mentioned, that the process management is not suitable for automation in most cases, instead the practical realization of such a system has to focus on the support of the human decisions. The availability of the necessary information (e.g. by an information board) and the capability of simulation models to support the process of evaluating alternative measures regarding their impact on the process and its performance has to be ensured.

On one hand, the conceptual model and structural framework for the design of production management from the strategic level to the operational level of process management are provided by the VSM. The mathematical methods to simulate, analyse and evaluate dynamic systems on process and process control level on the other hand, can be complemented by applying specific components of control theory, since VSM is missing them. Because the transdisciplinary approach of systems theory is the origin of both, VSM and control theory (they share common elements, e.g. recursivity), they can be consistently integrated. Nevertheless, the described application of VSM to SCM defines abstract characteristics for the control of the processes and the processes themselves, which have to be specified by control theory.

4. CONCLUSION

The paper in hand describes a three step way to form a cybernetic production program planning for companies with numerous ramp-ups. To ensure a high quality production program in terms of actuality, correctness and granularity, the first step describes the complete information flow. The sensitivity of necessary input information on the result of the PPP is analysed in the second step in order to evaluate the information criticality. Finally the information flow is arranged in such a way that an automatic and qualitative high-grade planning is made possible in the third step. Also, information sources for particularly critical information are identified and integrated into the process of planning. Therefore this is an improvement of the planning quality in ramp-up situations. Faults can be compensated in best possible way and learn effects can be used reasonably by the arrangement of the information flow according to principles of cybernetics.

Ramp-up intensive companies can create reliable production programs in short time taking advantage of the results of the explained research activities. Learn effects can be used without neglecting diversification. The development of cybernetic-operational ERP-systems is strongly pressed ahead by the conjunction with cybernetic arrangement of other parts of production planning and control.

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