Interlinking central production planning with autonomous production control

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Abstract: - The process of production planning and control contributes significantly to the efficiency of modern production systems. However, common central planning methods in industrial application show deficits in complex and dynamic production environments. In contrast to prevailing central control methods, approaches of autonomous control offer the chance to cope with these dynamic conditions more efficiently. An interlinking of central planning with autonomous control methods promises the advantages of both approaches. Nevertheless, there is currently a lack of knowledge concerning the interlinking of central production planning with autonomous production control. Therefore, the interdependencies have to be analysed in order to combine both approaches efficiently. In this context, the paper on hand describes the basic approach and potentials for the interlinking of central planning and autonomous control and gives an outlook on further research activities.

Key-Words: - Autonomous Control, Production Planning and Control, PPC, Central Planning

1 Introduction

Due to increasing market dynamics and the resulting fluctuations in demand, the processes of production planning, optimisation, and control have become more challenging for manufacturing companies [1]. This situation is characterised by growing complexity [2], which is intensified by the rising integration into global value chain networks [3]. Existing central methods for the process of production planning and control (PPC) are often not able to cope sufficiently with the increasing dynamic and complexity. Unplanned disturbances of the production process can lead to deviations from the production schedule and thus to deviations from defined delivery dates. In this context, autonomous control methods are considered as a promising approach for coping with increasing dynamic and complexity in logistic processes [4]. Whereas central methods use predefined production schedules, autonomous control methods enable logistic objects (e.g. production orders) to decide depending on the current situation. Thus, central methods allow detailed and structured planning, while autonomous methods are able to cope with dynamic situations more efficiently.

However, central planning and autonomous control methods were commonly developed and evaluated independently of each other. Successfully interlinking these approaches promises the benefits both of central planning and of autonomous control.

The development of methods for the interlinking of both approaches is also of high relevance for industrial application. Nowadays, most production planning and control systems mainly process central methods which do not consider autonomous control approaches. To gain the benefits of autonomous control, it is necessary to integrate these methods into existing PPC systems. Today’s PPC system users appreciate the detailed and structured planning basis, which is granted by central planning methods. Therefore, it is crucial for the acceptance of autonomous control methods to maintain this benefit. Our current research deals with the development of methods for interlinking central production planning with autonomous control. The expected results will provide production planning instruments, which create stable plans and are able to cope with dynamic influences.

In this context, the paper on hand explains the approach for interlinking central production planning with autonomous production control.

2 Central production planning and autonomous control methods

2.1 Production planning and control process

Production planning and control provides the basis for organising and executing the production process [5]. PPC comprises the planning and control of manufacturing and assembly processes regarding adherence to delivery dates, production volume and capacity. Thereby, the generic aim is the efficient utilisation of the production system [6].

PPC generally focuses on creating a production program for several planning periods, deducing demands of resources and afterwards realising the program [7]. Initially, the primary demands and the production program are generated out of market and sales forecasts. It determines the volume of final products to be produced in each planning period. Subsequently, the demand planning process determines secondary demands in terms of material and resources for each planning period. The make-or-buy decision is also based on these primary demands. External production for example is relevant if the demands exceed available in-house production capacities. In case of in-house production, the planning and control determines batch sizes, detailed scheduling of production orders, the resource balancing of production resources as well as the order release and control [7]. These planning results determine the planned behaviour of the production system as an input for the production process. The detailed scheduling comprises the allocation of production orders in terms of place and time to available production resources, e.g. in a production schedule for particular machines. This planning step considers the spatio-temporal allocation as well as planned capacities of resources [8]. There are diverse methods for supporting the detailed scheduling such as interactive control centres, sequencing rules or optimisation methods. Sequencing rules and optimisation methods generate production plans based on algorithms, respectively predefined rules. Control centres provide the additional possibility to check the consistency before or during the plan execution and, if required, to take appropriate corrective measures [6, 8].

The following sections present tasks and approaches of detailed scheduling from the field of central production planning as well as autonomous control approaches with their benefits. The resulting research gap and necessary work is concluded at the end of section 2.

2.2 Central production planning

There are various optimisation methods and heuristics for the planning process depending on the production environment. This environment is characterised by the type of available machines and their arrangement. It is generally differentiated between single-machine arrangements, arrangements with identic parallel machines and arrangements with non-identical machines [9]. An integrative notation enables the description and classification of various production settings depending on the machine environment and considered performance figures [10]. In general, sequencing rules can be applied to various production environments [11]. Sequencing rules assign priorities to production orders according to specific principles. They usually improve the performance for a particular target value, but they do not ensure global improvement in performance [12].

Optimisation methods, in contrast to sequencing rules, are based on the generation of a production plan that optimally fulfils a predefined target function. Due to the complexity of the optimisation problem, nowadays mainly heuristics can be efficiently applied to larger problems [13]. Thereby, most heuristics are designed for specific problem scenarios. They use problem specific knowledge about circumstances and restrictions to reduce the possible solution space. According to the multiplicity of planning problems, there is a vast number of problem specific heuristics [14].

Dynamic disturbances in the operative execution of production plans such as rush orders or machine breakdowns can lead to a high deviation from the original production plan. This causes rising cycle times and/ or an unsatisfying adherence to delivery dates. Therefore, approaches of reactive and robust planning are increasingly in the focus of scientific consideration [15]. While approaches of robust planning aim at the consideration of dynamic perturbations already during the production planning, reactive approaches aim at the adaption of production plans to changing conditions during the run-time. Reactive approaches adapt the plan partially or induce a full rescheduling. Generally, these approaches can be differentiated into predicative, reactive, predicative/ reactive and proactive ones [16].

These approaches deal with production systems from a central perspective. As an alternative, the concept of autonomous control focuses on coping with perturbations by means of autonomous decision-making authority.

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2.3 Autonomous production control

Autonomous control methods enable coping with undesirable dynamics in the production process. In contrast to reactive, predicative/reactive or proactive approaches they are not based on central planning, but on decentralised decision-making authority [17]. In order to increase the robustness and to ensure the logistic performance under dynamic conditions, logistic objects interact with each other, exchange information and decide for themselves on this basis [1]. The concurrence of these autonomous decisions directly influences the system status, which is in turn the decision basis for future decisions of autonomous logistic objects. According to this behaviour, the chaining of multiple autonomous decisions causes self-supporting dynamic system behaviour. From the perspective of self-organising systems, this behaviour can be described as emergent [18]. Appropriate information and communication technology ensures the interaction of logistic objects in this context. Examples for these technical enablers are component-integrated sensors and communication interfaces. Especially the permanent data availability enables the implementation of real-time production control operations [19].

Prevailing autonomous control approaches focus on the usage of existing flexibility potentials in the production system for generating decision alternatives [20]. For that matter, parts or production orders can be enabled to decide autonomously on available alternative routes through the production system [21]. Applying appropriate autonomous control strategies can have a positive influence both on the logistic performance and on the internal system dynamics. Autonomous control methods increase the logistic performance, especially under the condition of growing external dynamics [22].

In literature there are autonomous control methods comprising several different possible applications depending on the desired logistic command variable, such as cycle time or adherence to delivery dates, or on the machine configuration, like set-up time or machine arrangement [21]. A possible classification pattern contains the criteria time reference, number of planning steps, type of communication, data usage, actuator and data source [22]. This classification can be expanded by differentiating the criterion data usage, respectively its information horizon, into local information based methods and information discovery methods [22]. Parts using local information based methods rely on decision relevant information about the system status, which is acquired from objects in their adjacencies, such as machines or buffers. These methods can furthermore be differentiated according to the decision logic into rational methods and bounded rational methods. Rational methods take solely rational information like estimated waiting time or expected finish date into account [21]. Bounded rational methods comprise for example bio-analogue methods, which adapt the self-organising behaviour of real biological systems. There are bio-analogue methods adapting the foraging behaviour of ants [17, 24], adapting the communication pattern of bee colonies [25] or adapting the kinetic behaviour of flagellated bacteria [26]. Information discovery methods, in contrast, additionally enable local decisions of logistic objects such as machines or semi-finished products. However, these methods use data exceeding the local information horizon. Existing information discovery concepts use methods of data communication, which specifically request information from a network. This enables the anticipation of future system states and the consideration of these anticipations in the local decision making process [14].

2.4 Research gap

Nowadays, mainly predicative planning approaches are used for the detailed scheduling in production systems. However, the resulting a priori plans entail high plan variations and a reduced logistic performance under dynamic conditions. Existing central approaches try to cope with this dynamic by creating robust production plans or reacting quickly to disturbances of the production schedule. Main disadvantage of approaches for creating robust production plans is the dependency on the forecasting quality concerning dynamic influences. The weakness of reactive approaches is the effect of so-called planning nervousness. It describes the phenomenon, that already minor deviations of production parameters can cause strong deviations of the production schedule [27].

In this context, autonomous control methods mark a paradigm shift from a central to an autonomous perspective. These autonomous approaches enable coping with undesired dynamics in production systems. Nevertheless, it is essential to maintain the benefit of planning security of central planning methods. Therefore, there is a need for new methods of interlinking central planning methods with autonomous control methods in the context of production systems.

3 Approach for interlinking central production planning with autonomous production control

3.1 General approach

Successfully interlinking central production planning with autonomous control influences both the production system's behaviour and its performance regarding logistic target values. Fig. 1 illustrates the approach for the interlinking of autonomous control with production planning and the basic relationship between methods of central production planning and autonomous control.

The approach focuses particularly on the interdependencies between detailed planning and autonomous control in the context of in-house PPC. Applying autonomous control methods in the production control process enables efficient reactions towards dynamic influences and disturbances. However, these methods potentially cause variations from the original production schedule. Consequently, adjustments of planned parameters are necessary to improve the logistic performance. This relationship between the degree of plan fulfilment on the one hand, and the logistic performance referring to operative logistic command variables on the other hand is also shown in fig. 1 in the context of dynamic production systems.

3.2 Methodology

Central research task is the development of efficient methods for interlinking central production planning with autonomous control to improve both the logistic performance and the degree of plan fulfilment in production systems. The methodology of managing this task comprises seven fields of action, referred to as tasks in the following.

The first task consists of developing specific categories of production problems to describe different production systems. Using the portfolio technique it is particularly possible to represent complex structures of material flows, such as job-shop, flexible-flow-shop or open-shop problems. The planning process causes different initial dynamic influences for each problem type, which can also be depicted in the portfolio. Additional portfolios for applicable planning heuristics and appropriate autonomous control methods are required to guarantee an integrated modelling approach. These three portfolios serve as basis for a recommendation, which planning heuristic in combination with which autonomous control approach can be used for specific categories of production problems.

The second task enables an evaluation of the effects when applying autonomous control methods concerning the degree of plan fulfilment. This is necessary in order to provide a substantiated recommendation. Therefore, an appropriate evaluation scheme is developed, that can be applied

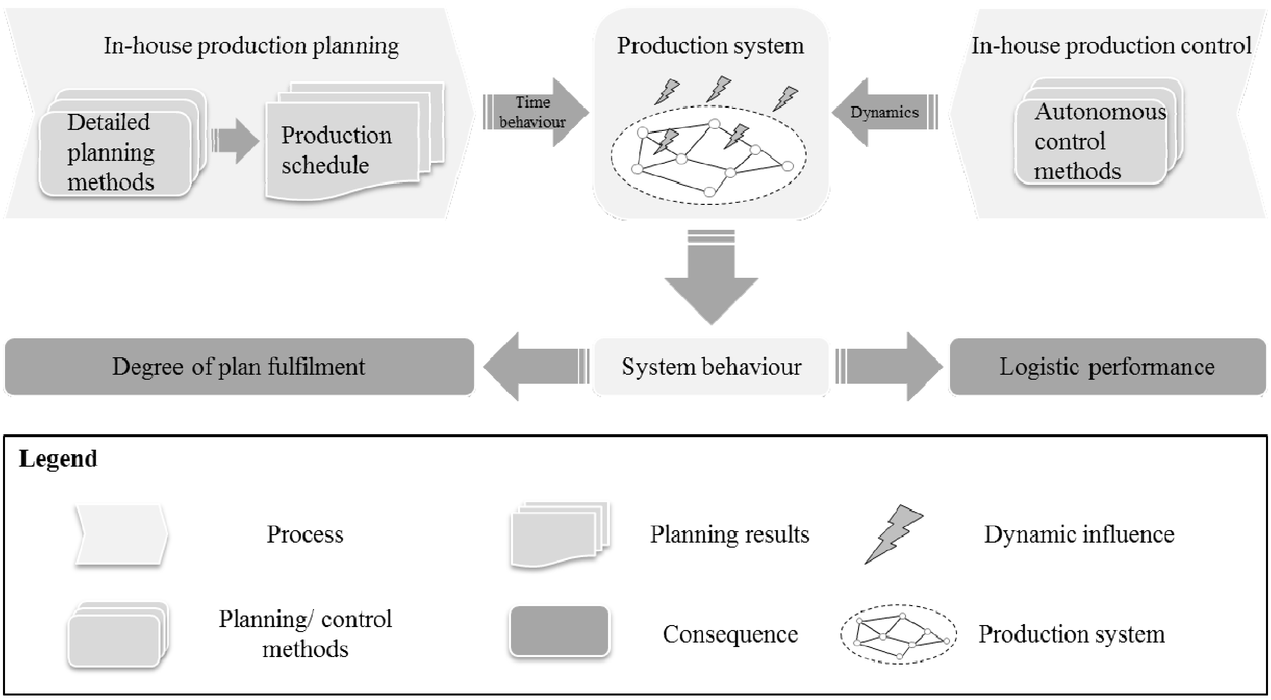

Fig.1: Relationships of interlinking central production planning with autonomous control

to all identified categories of production problems. It comprises the definition of representative production scenarios and evaluation criteria as basis for the later simulation model. As mentioned above, an extensive evaluation explores the effects of interlinked central planning and autonomous control both on the logistic performance and on the degree of plan fulfilment. Therefore, it is insufficient to carry out an evaluation solely on the basis of statistical performance indicators such as cycle time, stock and adherence to delivery dates or utilised capacity. The evaluation rather has to consider the robustness of production schedules, respectively possible plan variations. In literature there are various problem-specific approaches to accomplish this evaluation. These are based on different key performance indicators such as the variation of due dates like start or end of production, make-span variations or variations in the production sequence. Therefore, they are restrictedly comparable.

Setting up an executable simulation model in Tecnomatix Plant Simulation represents the third task. This software contains several interfaces (e.g. to C, SQL), offers functions for structured experiment administration and is therefore particularly suitable for our approach. The simulation model represents the identified production problems, central planning methods and autonomous control methods. It enables extensive analysis and evaluations of possible combinations.

The fourth task lies in the processing of the evaluation results. The systematic preparation of the findings is done by means of an evaluation matrix. The results serve as decision basis for identifying critical combinations of central planning methods and autonomous control methods for the various production scenarios in form of production problem categories. Critically in this context means, that the logistic performance or the degree of plan fulfilment is insufficiently. In these cases, further detailed time series analyses investigate the dynamics in the production system to identify the underlying reasons for the insufficient target achievement.

Designing appropriate and problem specific measures for interlinking central production planning with autonomous control represents the fifth task. This work also includes the identification of inappropriate combinations. A variable degree of autonomy serves as guideline for the design of interlinking methods. It can for instance be achieved by changing the parameterisation or the mathematical decision logic of autonomous methods.

The sixth task comprises the evaluation of the designed methods including the adjustments with real production data. The combination of central planning and autonomous control methods for this use case will be validated by means of a representative and realistic production scenario from industrial application.

The seventh task provides the findings in a generally applicable framework. This framework of central production planning methods and autonomous control methods serves as a decision tool for both academic and industrial application. It enables the selection of appropriate combinations of central production planning and autonomous control methods for design, parameterisation and operation of efficient production systems.

4 Conclusion

Today, production planning and control faces increasing market dynamics and growing complexity caused by on-going integration into global value chain networks. Autonomous control methods are considered a promising approach for coping with these challenges. However, it is important for industrial application to maintain the planning security of central planning approaches. Therefore, there is a lack of knowledge concerning the interlinking of autonomous control methods with central planning methods. This paper presents the basic approach to enable this interlinking. Expected future results are going to provide the scientific basis for the practical application.

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