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Planning and optimization of changeable production systems by applying an integrated system dynamic and discrete event simulation approach

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Abstract

Today, the planning and optimization of changeable production systems (CPS) has become a top priority item for the strategic management in most industries. Research has already provided a whole bunch of supposedly effective, mainly technical solutions that enhance the changeability of production systems. However, to actually select solutions for CPS, decision-makers do also need tools for their ex-ante evaluation. These are still missing – especially to assess the impact of organizational measures. Further, it appears that decision-makers have difficulties in coping with the dynamic complexity implied by CPS in planning activities. CPS are complex socio-technical systems – both in terms of their structure and their dynamic behavior – and so must be the underlying planning problems. Thus, any planning approach and in particular its related decision support tools must not only fit the dynamic complexity of the planning problem as a formal requirement, but must at the same time foster the decision-maker's understanding of the underlying managerial problem, i.e. it must foster managerial insight.
Therefore, this paper aims at closing this gap and proposes an integrated planning approach based on a hybrid Discrete Event Simulation (DES) and System Dynamics (SD) framework. Both simulation methods are interlinked by an integrated planning approach sharing the same conceptual model and a common set of parameters and key performance indicators (KPI). The DES is applied (1) for an in-depth analysis of the effects of any measures to improve the changeability, based on KPIs relevant to the decision-maker, and (2) to verify the major parameters utilized in the SD model. However, the DES can only be applied for a given structural state of the system. Consequently, SD is utilized to investigate its dynamic behavior when it changes from one structural state to the other. The planning approach was successfully applied in an industry context, where it proved its ability to actually leverage the decision quality in current practice to manage CPS.

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1. Introduction

Dealing with uncertainty is nothing new for the management of industrial companies. However, the dynamics of these uncertainties and their impact on planned versus actual performance has significantly increased recently. Actually, the ability to timely react to unforeseen developments is widely acknowledged today and the planning and optimization of changeable production systems (CPS) is a top priority item for the management in most industries. [1–3]

Consequently, the design, planning and implementation of CPS has been in the focus of research for quite some time yet – basically centering on the content of strategies to enhance the changeability of a production system and on their implementation. [4, 5] However, to actually plan solutions for a CPS, decision-makers do also need tools for their ex-ante evaluation. This domain of CPS research has just picked up momentum. In particular, applicable instruments that allow for a quantitative strategy evaluation are all but non-existent today. Further, in industrial practice it appears that most decisions related to plan and optimize CPS are still based on

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rather simple, qualitative decision support tools or even on experience only. [6]

As a consequence, the introduced measures fail to have the desired effect. Yet, this can only be partly accounted to the lack of adequate planning approaches and tools. Since CPS are characterized by a high dynamic complexity, it appears that decision-makers have difficulties in developing a deeper understanding for the various interdependencies to be considered within this socio-technical system and transferring them into the planning process. These circumstances imply three major requirements on an adequate planning approach and its related decision support systems: First, the decision support tools have to provide appropriate capabilities for the dynamic complexity of CPS. Second, the understanding of the underlying managerial problem has to be improved. And third, the instruments must be convenient to apply.

Therefore, this paper proposes an integrated planning approach that combines Discrete Event Simulation (DES) and System Dynamics (SD). It is integrated, because both refer to the same conceptual model and are interlinked by a common set of parameters. The DES provides detailed insights on the effects induced by (structural) changes to the production system and its environmental conditions on relevant key performance indicators (KPI) – in particular on such that are otherwise not obtainable/observable in practice. However, the DES considers only a given (stationary) structural state of the system. Consequently, the SD simulation is applied to analyze the (long term) behavior of the production system when it changes from one structural state to the other, and thus, to gain a deeper understanding of its dynamics. The SD model is elaborated and calibrated based on insights and parameters provided and validated by the DES.

This paper will be structured as follows: First the existing literature on the state-of-the-art of instrumental decision support in planning CPS is reviewed. We will then outline the methodology, the overall planning approach, and provide a conceptual model to describe the changeability of a production system for planning purposes. Afterwards the planning approach is described, before the applicability is shown in a case study from the German medical industry. Finally, this paper is concluded with a summary and outlook.

2. Literature review

2.1. Making the case for computerized decision support systems to plan CPS

To make a long story short: There is no rational decision-making without applying either formal, verbal and/or at least mental models in the context of solving a decision problem. [7, 8] Given that, a planning process usually deals with the systematic solution of a related decision problem. In this context, decision support instruments, or their combination into (computerized) Decision Support Systems (DSS) for that matter, usually aim at supporting the decision-makers in one or more stages of the planning process. [9] Their application is particularly advised in complex and unstructured decision problems. [10] Consequently, the application of computerized decision support systems has not only become common practice in operational production management, but also to effectively support and solve decisions in (complex) strategic planning situations as well. [11]

In the case of CPS, computerized DSS approaches such as simulations have to be considered as not being established yet. The vast majority of contributions in this domain focus on providing tools to support the decision, given their decision problem is fully described as a decision model. The application of simulation-based approaches to actually explore and quantify the effects of the measures to be evaluated has not been explored yet on a broad basis. First approaches using computerized methods can be found in [12–16], though.

2.2. State-of-the-art in decision-making/planning of CPS in general

The changeability of production systems is generally described as a feature that enables them to adapt to new conditions by structural changes to its technology and organizational configuration. The adaption can be reactive and proactive. [2, 3, 17, 18]

When it comes to deal with the systematic management and in particular planning of CPS, today two major schools of thought can be differentiated: [19] The research activities around Westkämper and Zahn are already based on a system thinking approach. But they focus, however, on tools that allow accelerating changes with different planning and controlling instruments (e.g. indicators, technical and organizational guidelines) [20]. They are generally not aiming at an integrated decision support for planning purposes. In contrast, the research activities around Wiendahl and his successor Nyhuis elaborate on the system thinking approach centered on a conceptual model that explicitly introduces a closed loop system for changeability. [17, 21–25] They emphasize on providing a tool-based decision support to actually plan CPS. However, they generally focus on supporting the decision for given alternatives, situations and evaluated consequences – as opposed to analyze them by quantitative means. Thus, they are mostly based on multi-criteria decision-making approaches.

2.3. Potentials of simulation approaches to plan CPS

In fact, simulation-based DSS are still widely missing - which is interesting given that the planning of CPS is usually described as a complex problem that is (1) strategic to the decision-makers in terms of its impact on the competitiveness of their company, (2) characterized by a long planning horizons, and (5) “new” as a management item, and thus not yet fully understood by the decision-makers. [6] Although the application of DSS is not unchallenged, [11] it is without doubt their property in helping the decision-maker to understand the decision problem and to (systematically) realize/analyze the consequences of his actions. [26] In particular the exploration and solving of decision problems that are only hard to structure, such as the planning of CPS, is the domain of simulation-based approaches. [27] Because of