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Evaluation system for autonomous control methods in coupled planning and control systems

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Abstract

Autonomous control is an approach to cope with increasing complexity in production and logistics. Autonomous control methods are characterised by decentralised coordination of logistic objects in a heterarchical organisation structure. Autonomous objects themselves are capable of processing information in order to make and execute decisions on their own. Up to now, research in this field mainly focuses on the effects of autonomous control methods disregarding their integration in existing planning systems. Thereby, it is currently not possible to give a substantiated recommendation, which combination of planning and autonomous control methods achieves a sufficient degree of logistic objective achievement in production systems of different complexity. Existing evaluation systems in the field of autonomous control methods remain on a mainly qualitative level disregarding the planning system. Therefore, this paper presents a quantitative, three-dimensional evaluation system. First, it operationalises the degree of complexity in production systems depending on shop floor conditions and disturbances. Second, the paper operationalises the degree of autonomy of production systems. Thereby, it considers the type and intensity of coupling between the planning and control level. Third, a vector of performance indicators is defined to measure the logistic objective achievement and the degree of plan fulfilment. The result is an evaluation system which allows a complete quantitative evaluation of autonomous control in production systems. Furthermore, the focus of consideration is expanded from the mere control level to the planning and control level. The influence of the strength of coupling between planning and control methods on the autonomy is also taken into account and operationalised. Finally, the evaluation system is exemplarily applied to a published simulation study.

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1. Introduction

Nowadays production is confronted with the consequences of several megatrends: Globalisation and the growing instability of market conditions impose high pressure on producing companies. Especially the global economy and markets are characterised by increasing dynamics and volatility. [1] Dynamic product life cycles and a simultaneously rising number of product variants with deeper integrated technologies are complex problems for production planning and control [2,3]. Common concepts of production planning and control (PPC) are being pushed to their limits in such an environment [4]. In contrast, autonomous control methods are considered as a promising approach for coping with increasing dynamic and complexity in logistic processes [5]. The concept of autonomous control comprises the decentral coordination of autonomous logistic objects within a heterarchical structure [6]. Thereby, autonomous objects are capable of processing information in order to take and execute decisions on their own [6]. The advantages of autonomous control have been proved in several studies [4,8-10]. Nevertheless, to benefit from these advantages, strategies for the integration of autonomous control methods in existing planning systems are required. Thus, our research deals with the development of methods for a combined application of production planning and autonomous control (in the following referred to as “coupling”). In order to identify suitable couples of planning and control methods, an evaluation system is

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required which allows the evaluation of coupling strategies regarding their impact onto the logistic objective achievement.

Existing evaluation systems in the field of autonomous control methods remain on a mainly qualitative level disregarding the planning system [3,11-13]. Consequently, it is currently not possible to give a substantiated recommendation, which combination of planning and autonomous control methods achieves a sufficient degree of logistic target achievement in a production system of a certain complexity.

Therefore, this paper presents a quantitative, three-dimensional evaluation system. Section 2 introduces and operationalises the axes of the evaluation system considering the type and intensity of coupling between the planning and control level. First, the x-axis "complexity" is operationalised in section 2.1. Second, the y-axis "autonomy" is operationalised in section 2.2. Third, the z-axis "logistic objective achievement" depending on the x-y-position is explained in section 2.3. Section 3 gives an application example and proves the applicability of the evaluation system. Finally, section 4 gives a short summary and an outlook on future research activities.

2. Evaluation system

2.1. Complexity

Several approaches to describe the complexity deal either with complexity in general [14-16] or the systematisation of production systems [17-21]. Characteristics of production systems are also systematised in the context of scheduling [22-24] as well as disturbances of production systems [25-27]. Furthermore, also production scheduling schemes are considered [28] and [29]. Up to now the most prevalent approach for our purpose is given by Windt et al. [3]. Thereby, the authors introduce basic complexity categories and describe them by exemplary characteristics. Philipp [13] offers an evaluation system including the complexity dimension, but the author remains on a solely relative level, so that a comparison of different production systems is only possible to a limited extent. Windt et al. [11] underline the research demand for the definition and identification of complexity relevant parameters. Therefore, as depicted in Fig. 1, we present an approach which allows the specification of production systems considering the characteristics' influence on the complexity level of a production system. Furthermore, the characteristics are quantified without scope of interpretation, so that a precise classification is possible.

The general approach of operationalisation is carried out analogue to Böse [30]. First, complexity categories are specified top-down by several criteria (cf. Fig. 1 column A). We distinguish the static production system and dynamic influences. Referring to van Brussel et al. [31] the production system comprises resource, product and process characteristics, which are detailed by several criteria based on existing classification patterns (references cf. Fig. 1 column B). The dynamic influences (cf. Fig. 1 line 61-84) are distinguished by their origin, which can be located within the production system (internal) or outside (external). These influences are also substianted by several criteria. Afterwards, each criterion is weighted from 1 to 3 according to its significance (cf. Fig. 1 column C). A weighting of 3 represents a "must-criterion", which is necessary to classify the basic production system, cf. [17-19], and occurring disruptions, cf. [25-27]. The weighting of 2 contains information and criteria, which are important to classify scheduling approaches, cf. [22-24]. A weighting of 1 is given for additional constraints, which are neither compulsory for the characterisation of a production system or a scheduling approach. Finally, the defined criteria are itemized up to possible characteristics (cf. Fig. 1 column D). These characteristics serve as a morphologic pattern to describe production systems and possible influences. Then, the impact of each characteristic on the complexity is quantified by values ranging from 0 to 3 and multiplied with the weighting (cf. Fig. 1 column E-F). The quantification is to be interpreted relatively within a single criterion, so that the relative impact on the system's complexity is evaluated. For instance, the number of production stages can be defined as "1", "2" or "more than 2" stages (cf. Fig. 1 line 1-3). Since the systems' complexity increases with the number of stages, the lowest quantification value 0 is assigned to the characteristic "1 stage" and the highest value to the characteristic "more than 2 stages". The evaluation pattern shows that other than in previous work a shop floor size from a number of more than 2 stages and more than 1 stations per stage, the machine quantity has no significant influence on the system's complexity. Windt et al. [11], for example, model from 38 up to 80 work stations and state that this increases the system's complexity. We refer mainly to the work of Nanot and Baker & Dzielinski [32,33]. Based on their work, Rajendran & Holthaus [34] conclude that "shop size is not a significant factor in affecting the relative performance of rules and that a shop with about nine machines should adequately represent the complexity". Therefore, the sole number of machines is not a decisive criterion for us as long as a complex structure is depicted. Furthermore, we introduced characteristics of dynamic complexity. While Philipp [13] considers dynamics as derivation of the complexity vector over time, Windt et al. [12] do not consider dynamics explicitly, and de Beer [35] considers only external dynamics disregarding internal dynamics such as breakdowns. For deriving characteristics and boundaries out of the categories, we apply the Six-Sigma-concept (6σ) due to its broad acceptance, which is based on the normal distribution. The total system complexity is calculated as the sum of each characteristic's weighted complexity. Fig. 1 exemplarily shows the complexity values of three possible production scenarios. The production scenario with the lowest possible complexity has a complexity value of 0, the most complex scenario results in a complexity value of 189 (cf. Fig. 1, column G-H). The application example (cf. Fig. 1, column I) is explained in section 3.