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Modeling and analyzing dynamic cycle networks for manufacturing planning

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Abstract

Knowledge about cyclic influences and their interdependencies supports the prediction of future changes in manufacturing systems and is thus highly valuable for manufacturing planning. Based on system dynamics and former research regarding cycle management, a dynamic cycle network is developed. This enables quantitative analysis and comprehension of cycles within the network, helping to understand future behavior of cyclic influences in manufacturing and to anticipate their potential effects. The results contribute to the development of a planning framework for continuous production planning by further elaborating the innovative concept of cycle management in manufacturing.

Keywords: Cycle management; Cyclic influences; Manufacturing planning; Changeable manufacturing; Changeability; System dynamics

1. Introduction

"Nothing endures but change" (Heraclitus 535 BC – 475 BC). For more than a decade changeability has been a research topic of high relevance in manufacturing science. Changeability affects manufacturing companies on every system level – reaching from manufacturing technologies, manufacturing resources and factory structures up to global supplier networks [1]. Within this article changeability is used as an umbrella term for a variety of more specific terms like flexibility, reconfigurability, agility, etc. What these terms all have in common is that in a turbulent environment manufacturing companies are always better off if they manage to enhance these properties with respect to their manufacturing plants, structures, systems, and resources. However, increased changeability generally correlates with higher cost or reduced efficiency or even both [2,3]. Hence, at least theoretically, an economic level of changeability can be determined [3,4].

But where does the importance of changeability originate? Usually some of the following reasons are mentioned in literature: companies have to struggle with an increasing number of product variants [1], shortened product life cycles [5], high uncertainty of future requirements (e.g. demand, product mix, new technologies, and regulations) [6], increasing importance of resource efficiency and sustainable manufacturing [7,8], and finally a general compulsion for cost-efficiency caused by global competition. On the one hand, this challenging manufacturing environment leads to a high frequency of necessary reconfigurations of the manufacturing system – e.g. adaptations and integration of product or process innovations – and an increasing importance of equipment reuse to save resources. On the other hand, costs for the implementation of changes are growing with the degree of uncertainty about future requirements because long-term production planning becomes highly unsure; thus, even far-reaching decisions unavoidably have to be made rather short-term in practice [9].

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In order to be able to perform effective planning under these circumstances, planning processes in manufacturing have to be designed for a continuous execution [10,11]. However, continuous planning must be based on a continuous “flow of information” relevant to the planning task at hand. As many influencing factors, changes, and processes in manufacturing can be abstracted by means of reoccurring patterns over time – so called cycles – the concept of Cycle Management has been proposed to cope with the complex cycle networks arising from the interrelations of all relevant influences [12]. Also, a generic model for the characterization of cycles has been elaborated and operationalized in the form of Cycle Information Sheets (CIS) [12].

Relevant cycles in manufacturing planning are selected and used to illustrate modeling and computation of their time-varying interaction in so called dynamic cycle networks. To achieve that, a system dynamics based approach is presented. As an outlook, promising fields of application are discussed and future research topics are outlined.

2. State of the art

In recent years, the concept of influencing factors on manufacturing enterprises causing changes was broadly investigated. Wiendahl et. al [13], ElMaraghy [14], Dashchenko [10] and others [15] identified different change drivers such as products, markets or new manufacturing technologies and proposed different categories for clustering (e. g. internal and external influences). On the other hand, change objects, e. g. on the manufacturing system or factory level [16], enablers for change, e. g. modularization or mobility, have been analyzed [1], and indicators for required change depending on the actual influencing factors have been defined [17]. In this context, Cisek et al. [18] and Möller [18,19] developed a recipient model explaining the effect of influencing factors on manufacturing.

At first, these change drivers are seen as rather static influences, but actually most of them show a dynamic behavior over time [20]. Therefore, different models have been developed describing the respective influence dynamically. Common examples are the product life cycle or the technology life cycle [21].

In factory and manufacturing planning relevant influencing factors are analyzed and evaluated with respect to the factory to be planned [22,23]. Well established approaches are mainly analytical ones, focusing on e. g. product planning data, layout constraints and optimal material flows incorporating general constraints and factory objectives [23–25]. Other potentially uncertain influences, e. g. new manufacturing technologies, product life cycles or occurring engineering changes, are usually considered as time-varying change drivers, but their dynamic behavior caused by interdependencies is usually neglected.

An approach to cope with those uncertain influences is the scenario analysis introduced and further developed by e. g. Dashchenko & Gausemeier et al. [10,26]. Considering interactions between influences, different future scenarios can be created – but historical observations and data as well as a dynamic modeling of influences are not covered yet. This aspect is addressed by the introduction of cycles to model influences on manufacturing by Zäh et al. and Reinhart et al. [20,27]. Koch & Plehn et al. [12] developed a generic cycle model capturing relevant influences and hence prepared the basis for the elaboration of a dynamic cycle network. In this context, first activities explored the application of design structure matrices to create a static cycle network depicting interdependencies of cycles [28]. Following that, fuzzy sets have been investigated as a tool to model those interdependencies on a qualitative basis. Results indicated possible applications for analysis and prediction of influences on manufacturing, but also showed a high demand for pre-set rules about the relation of influences and a lack of quantitative dependencies [29].

Summarizing this, influences on manufacturing are and will remain a highly relevant field of research for manufacturing planning. Despite the amount of knowledge created about influences and change drivers, their time-dependent behavior, and their interdependencies, the need for a dynamic model of the network of influences is ongoing. This paper provides an approach for modeling such a dynamic cycle network.

3. Method for cycle networks

3.1. Construction of cycle networks

As a preparation for computing dynamic cycle networks (cf. 3.2), firstly, a static framework has to be developed. For this purpose the following three step approach is proposed:

(1) Selection of change-relevant influences in manufacturing
(2) Description of each influence’s cyclic behavior
(3) Identification of plausible interrelationships between influences

(1) Based on an industrial survey, previous research results [20,27], a literature review and expert interviews, change-relevant influences in manufacturing systems and characteristic patterns have been selected: the product life cycle (PLC) [30], the manufacturing technology life cycle (TLC) [31], the engineering change cycle (ECC) [32] and the manufacturing change cycle (MCC) (based on [32]), the manufacturing resource