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Analyzing Interdependencies between Factory Change Enablers applying Fuzzy Cognitive Maps

Sven Hawer[a]*, Nino Braun[a], Gunther Reinhart[a]

[a]*Institute for Machine Tools and Industrial Management, Technical University of Munich, Germany*

* Corresponding author. Tel.: +49-89-289-15559 ; fax: +49-89-289-15555. *E-mail address:* sven.hawer@iwb.tum.de

Abstract

Enablers of change play an important role for competitive manufacturing systems in a turbulent corporate environment. In the process of designing factories, companies face the decision of which enablers to choose for dealing with market-induced uncertainties and fuzzy planning data. Current research, however, does not provide information on how the enablers influence each other when implemented in real production systems. This paper first provides an overview of relevant change enablers and categorizes them with regard to their degree of abstraction, based on an intensive literature review and expert interviews. With the aim of creating a method for the selection of feasible enabler-combinations, a fuzzy cognitive map to analyze fuzzy interdependencies between the different change enablers is developed. To validate the relations modelled in the fuzzy cognitive map in industrial practice, a survey-tool is presented and applied in enterprises from the field of factory planning. The developed method for modelling change enablers' interdependencies empowers the factory planner to actively select a combination of enablers that influence each other positively and thus allow for a cost-efficient design of changeable factory layouts in early planning stages.

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1. Introduction

An increasingly turbulent environment, more volatile and dynamic markets and growing competition makes the ability to change, i.e. changeability (see chapter 2.1), a major success factor for producing enterprises [1].

To design factories under the premise of changeability, so-called change enablers (in short: enablers) are of rising importance [2]. Over the last 15 years, several authors have developed planning methods for changeable factories in which they identified change enablers of varying degrees of abstraction and top-down. However, interdependencies between these enablers are not taken into account, although highly important for deciding on which enablers to choose from the vast field. In addition, about 90% of all planning scenarios in reality are brownfield [3], meaning that a certain combination of enablers is already implemented and others are not applicable. In order to identify a combination of enablers that fit together, meaning that enablers do not weaken each other's functionality or effectiveness, it is vital to know about how the enablers affect each other and their impact on invest. This information is neglected in existing planning approaches for changeable factory structures. According to [4] it is more important to be aware of a system's elements' interdependencies than possessing exact knowledge about the elements themselves.

A further deficit in many contributions is the enablers' high level of abstraction, making it difficult for practitioners to realize change enablers like "Universality" in factory planning projects.

This paper is structured as follows: In Chapter 2 we review the state of the art regarding changeability and its enablers as well as methods for modelling interdependencies. In Chapter

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3 the research methodology applied is described in more detail.

Chapter 4 is based on chapter 2 and 3 and comprises the elemental part of this paper. The goal of chapter 4 is threefold: Firstly, we identify and categorize change enablers applying a bottom-up approach. Hereby, a catalogue of concrete, practical enablers like “machine on wheels” is constructed which is then structured into more abstract categories (chapter 4.1), making the link to already existing research. Secondly, we determine the interdependencies between these concrete change enablers using a survey tool developed for this purpose (chapter 4.2). Thirdly, the overall network of change enablers’ interdependencies based on the survey is modeled in a fuzzy cognitive map (chapter 4.3). Chapter 5 gives further research directions and a conclusion.

2. State of the Art

2.1. The Concept of Changeability

Until recently “the ongoing industrial and academic interest in flexibility, robustness, adaptability, and many other properties closely related to changeability has not yet converged in a precise domain-neutral definition of terms” [5]. Acknowledging this deficit, Plehn et al. determine definitions for the above-mentioned notions, which they summarize under the umbrella term *Changeability*. In our contribution, we follow this idea of changeability comprising the concepts of *Robustness, Resilience, Flexibility, Adaptability* and *Transformability* which are defined in [5]. Thus, changeability can be defined as “umbrella term comprising more specific properties describing a system’s ability to change its structure (incl. interfaces), form, and function at an acceptable level of valued resources (i.e., time and money)” [5]. In conformity with [6], we define the term “Change Enabler” as *an action, measure or construct with different possible degrees of abstraction which enhances a factory object’s callable and individual ability to change*.”

2.2. Enablers for Changeable Factories

In this chapter, we discuss the change enablers identified in current research. The number and terminology of these enablers vary and a common understanding has not yet been established.

One of the first to use the term *enabler* (in German “Befähiger”) in the context of factory planning was Hernández Morales [6]. He differentiates between the following 6 enablers which are defined in table 1: *Mobility*, *Expandability and Reducibility* (named *Scalability* in later contributions), *Modularity*, *Neutrality regarding function and use* (named *Universality* in later contributions), *Networkability* and *Integration and Disintegration capability.*
Several later contributions refer to these enablers and build on the work of Hernández Morales [6]: [2,7–15]. The majority of these authors use only 5 enablers, after [7] reduced the number from 6 to 5 by combining *Networking capability* and *Integration and Disintegration capability* in the term *Compatibility*. Further changes in terminology lead to the frequent use of the term *Scalability* instead of *Expandability and Reducibility* and *Universality* replacing *Neutrality regarding function and use* [2,7–12]. In this contribution, we utilize the shorter terms *Compatibility*, *Scalability* and *Universality*.

Table 1. Overview and Description of Change Enabler Terminology

Enablers Name	Alternative Name	Description of Enabler according to [6]
Mobility		Factory objects can be placed and replaced with low effort and their functionality is location-independent.
Expandability and Reducibility	Scalability [2, 7-12]	Factory objects are “breathable” which means they can easily grow or shrink with regard to equipment, space, organization and personnel.
Modularity		Division of the factory structure into standardized, functional, pre-tested and autonomous elements.
Neutrality regarding function and use	Universality [2, 7-12]	Capability of factory objects for being employed for varying requirements and tasks.
Networking capability	Compatibility [2, 7-12]	Enables diverse and efficient material, information and personnel flow within and outside the factory.
Integration and Disintegration capability	Compatibility [2, 7-12]	Products, components and processes can be included or excluded with low effort into the factory structure due to uniform interfaces.

The resulting 5 enablers *Universality, Modularity, Mobility, Scalability* and *Compatibility* are named primary enablers in conformity with literature.
There are several authors who attribute change enablers to factory objects or design fields (e.g. factory layout, logistics equipment, manufacturing equipment, etc.; [6,9,10,13]) and thus achieve a lower level of abstraction (so called secondary change enablers). Others differentiate between enablers for each factory level (e.g. site, segment, system, station, etc.; [9,10,16]).
Heger [10] names a total of 232 enablers which are either quantitative (i.e. measurable on a discrete or continuous scale) or qualitative (i.e. measurable on a nominal or ordinal scale). For this purpose he uses a top-down approach, deriving the more concrete enablers from 7 abstract ones (to the 6 enablers by [6] he added *Standardization*). The methodology behind this procedure is not explained in detail, however. Nyhuis et al. [9], building on the enablers identified by Heger [10], argues that not every enabler is applicable to each factory design field. The design field *Space* for instance cannot be mobile and therefore has no secondary enabler in the field of *Mobility*.
Pachow-Fraunhofer [13] identifies secondary enablers through expert interviews which are, however, still on an