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Context model design for a process-oriented Manufacturing Change Management

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Abstract

New production technologies, measures to increase productivity or continuous improvements - manufacturing has always been subject to a variety of changes. Concepts for continuous factory planning as well as first applications of engineering change management in manufacturing help to cope with such changes, but still lack a systemic and contextual view on the management of change in manufacturing. This paper presents a context model for a process-oriented Manufacturing Change Management (MCM), designed to support the understanding of the concept of MCM in academia and industry as well as to create a sound basis for a subsequent, more detailed design of the different MCM-related elements (e.g. MCM process). The context model comprises not only tangible elements (e.g. factory, product), but also intangible elements (e.g. change causes, MCM process) and their relations. Accompanying the context model design, requirements for a detailed design of MCM-related elements are formulated, while the element "change cause" as the starting point of any change in manufacturing is already further detailed and described. Concerning the context model design and the formulation of MCM requirements, both consider not only findings from a broad literature review, but also from different expert interviews and workshops.

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1. Introduction

1.1. Coping with change in manufacturing

Even though changeability has become a key characteristic of manufacturing during the last decades [1, 2], coping with changes in manufacturing remains a challenge for producing enterprises [3, 4]. In this context, the concept of *continuous factory planning* has been developed to support the planning of changes in manufacturing based on a control loop analogy (cf. e.g. [5–7]). Other publications specifically address the planning and analysis of exemplary changes in factories, e.g. reconfigurations of manufacturing resources (cf. e.g. [8, 9]). Another, more general concept proposed is the application of *Engineering Change Management (ECM)* (cf. e.g. [10]) for changes in manufacturing (cf. e.g. [11–13]).

On the one hand, all of these approaches share the same objects of observation (change in manufacturing) and deal with different procedures to better cope with change. On the other hand, they either focus on planning activities lacking adequate

management concepts or they directly transfer ECM to manufacturing neglecting the broad scope of available factory planning approaches and potentially required concept adaptations. This demonstrates the persisting need for further research, as up to date there is no concept available dedicated to the management of changes in manufacturing.

1.2. Objectives and research methodology

The objectives of this research are (a) to support academia and industry in understanding the concept of Manufacturing Change Management (MCM) and its context, and (b) to provide a common basis for a subsequent detailed design of relevant MCM elements (e.g. a MCM process). The work outlined in this paper is based on the four-staged design research methodology (DRM) proposed by Blessing and Chakrabarti [14] and has been guided by the following research questions:

- What are relevant requirements to be considered for a

process-oriented concept of MCM?

- How to model MCM and its context to support academia and industry in understanding the MCM concept?
- Which requirements have to be considered for a subsequent, more detailed MCM design?

The research at hand is based on the derivation of the scientific goal and main research questions (stage 1: research clarification), the specification of the research object (MCM) as well as the derivation of relevant requirements and the context (stage 2: descriptive study I). The next steps are conducted iteratively, comprising the context model design (stage 3: prescriptive study) as well as the model-based derivation and/or evaluation of requirements for a more detailed MCM design (stage 4: descriptive study II). This work builds up on a literature review (focusing on the fields of change management in manufacturing, ECM, factory and manufacturing planning, design processes), previous work (e.g. [9, 15]) and several expert interviews and workshops.

The remainder of this paper covers a specification of relevant terms and definitions, a short review of relevant publications and the formulation of context model requirements. Following, the context model for MCM is designed and analyzed to derive and/or evaluate further requirements for a more detailed MCM design in an iterative approach. Finally, the paper concludes with a critical discussion and an outline for future research opportunities. Considering the research objective and the intended context model design (cf. chapter 3), a machine-readable modeling of the context model (e.g. by using SysML) is not in scope of the work presented here.

2. Manufacturing Change Management

Up to date, no distinct term for the management of change in manufacturing has been defined in literature. The few authors dealing with this research topic usually refer to the ECM terminology and transfer it to the domain of manufacturing ("engineering changes in manufacturing") [11, 13]. Referring to Jarratt et al., ECM describes "[...] the organizing and controlling of this process [of making alterations to a product]" [10]. According to Lindemann and Reichwald, ECM describes "all measures to avoid or frontload and efficiently plan, select, implement and control engineering changes" [16]. Based on these definitions, the term "Manufacturing Change Management (MCM)" is defined as "organizing and controlling the process of making alterations in manufacturing, including all measures to avoid or frontload and efficiently plan, select, implement and control manufacturing changes". In this context "making alterations in manufacturing" (e.g. adaptation of assembly stations, reconfiguration of manufacturing resources, correction of work plans) are denoted as "Manufacturing change".

3. Context model design

Browning et al. lucidly deduce the systemic nature of processes [17] and, referring to e.g. [18], depict the potential benefit of modeling processes together with related systems

(e.g. product or tool system) to, for example, verify each other or aid their designing and management. These activities can be supported by both, focusing the ability for explanations and an unambiguous description of relevant vocabulary. As a process-oriented concept, MCM is expected to similarly profit from taking a comprehensive, systemic perspective on MCM – hence designing a context model covering the following characteristics:

- **System-based:** i.e. dividable into e.g. elements, sub-systems, relations, cf. e.g. [19]
- **Explanatory:** "serving to explain [MCM]", cf. [20]
- **Ontology-oriented:** definition and relation of relevant vocabulary, cf. [21]
- **Hierarchical:** "arranged in an order of rank" [20]

4. State of the art

In engineering science, a variety of models with a comprehensive and/or systemic perspective on its respective object of observation (hence context models, but sometimes differently termed in literature) exist. Those dedicated to the management of changes on manufacturing or engineering change management have been identified as most relevant for this research. In addition, models referring to factory or manufacturing planning, design processes and / or design projects are also considered exemplarily due to their thematic proximity to MCM. In the following, some relevant publications of these research fields are outlined briefly.

4.1. System and context models in MCM

Up to date, only few authors addressed the development of context models for MCM. Developing an approach to adapt ECM for manufacturing, Rößing proposed a "reference object model" to describe a general approach for the implementation of changes in manufacturing. The generalized class diagram comprises relevant objects (e.g. "Engineering Changes", "Change Project", "Production object" or "History"), their interrelations and exemplary characteristics [11]. Malak developed a very similar model comprising relevant elements (e.g. "Engineering Change", "Production system" or "Impact"), their interrelations and also their attributes [22]. Considering reconfigurations of manufacturing resources as one type of change in manufacturing, Koch et al. suggest a so-called "Extended Manufacturing System", again with the relevant elements and their relations. Unlike Rößing and Malak, the authors focus on application of structural complexity management methods rather than explanatory model design [9].

4.2. System and context models in ECM

In engineering science, different context models for ECM are available. Thereof, three exemplary models are highlighted in the following.

Pikosz et al. proposed an entity-relationship diagram to provide a comprehensive view on relevant models in ECM (here: "process", "role", "system" and "information") and their

relations [23]. Following, Rouibah et al. formulate a concept for ECM covering four main elements: “Person (Role)”, “Processes”, “Product”, and “Documents” with different sub-elements and schematic relations to further elaborate on improvement potentials in ECM [24]. Focusing on system and context modeling of changes in product development processes, Langer et al. developed an “explorative model” integrating a system and a context perspective. The authors consider relevant elements (e.g. “environment”, “market”, “development system”, “goal system”, or “process system”) and their interdependencies (based on an exemplary model instance) [25].

4.3. Further context models

In the field of factory and manufacturing planning, the common concept of continuous factory planning is generally based on a control loop analogy (cf. e.g. [26, 27]). Despite their differing designation, the proposed models resemble context models in certain ways. Specifically, Nofen proposes a control loop model covering different elements (e.g. “Strategic planning”, “Transformability monitor”, “Factory operations”) and their relations [27]. More recently, Azab et al. proposed an extended control loop model considering elements such as “change drivers”, “changeable manufacturing system”, “required configuration”, and “supply of solutions” as well as their general (unspecified) relations [5].

In the field of design projects and processes, Hales and Gooch developed a context model for the Engineering Design Process within an (industrial) project setting. They consider not only business functions (e.g. “Engineering”, “Finance”), activities (e.g. “conceptual design”, “Process planning”) and outputs (e.g. “Production documents”), but also other (context) fields (e.g. “Management”, “Company”, “Market”) and external influences (e.g. “social”, “economic”, “legal”) [28]. Eckert and Clarkson also focus on the design process and propose a more high-level model visualizing the interplay between the elements “process”, “product”, “user”, and “designer” as well as contextual aspects (e.g. “design practice” or “design management”) [29]. Browning et al. strengthen the system perspective on development projects and propose a general model comprising five systems (“organization”, “process”, “tool”, “product”, and “goal”) and their relations [17].

4.4. Summary and interim conclusion

Within all domains considered, different context models or similar models exist, at least touching or sometimes even fulfilling the intended characteristics of the MCM context model (e.g. most models are system-based and provide some hierarchical structure, are ontology-oriented and have an explanatory character). This finding strengthens the basic assumption of the generally beneficial activity of designing context models (cf. [17, 18]). Nevertheless, neither of them fully satisfies all characteristics simultaneously, nor (and that is even more crucial) does any actually model the concept of MCM and its context. Regarding ECM-and design-related models, the necessarily different object of observance is

obvious; regarding MCM- and factory planning-related models, none considers the context perspective with respect to e.g. the product or relevant ECM activities (on the highest level of the respective model). Also, the diverse model structures impede the derivation of requirements for developing a more detailed MCM concept. Hence, none of the existing models sufficiently supports the design of a process-oriented MCM, clearly indicating the need for a MCM-specific context model that is based on the findings and requirements stated in chapter 3 and section 4.4.

5. Context model design for MCM

Designing a context model for MCM, first the term “context model” and the general characteristics of the model (cf. chapter 3) are specified regarding the addressed field of research. Then, the actual MCM context model is comprehensively designed, analyzed and evaluated.

5.1. Requirements for a context model for MCM

The most basic requirement is formulated by the model name “context model”—i.e. representing not only MCM as a separate object but together with its accompanying setting / circumstances (cf. [20]). Also, it should support the derivation and/or evaluation of requirements for a MCM process design. Therefore, the general characteristics of the context model are detailed as follows:

- **System-based:** Modeling of MCM and its context as systems with sub-systems, elements and relations
- **Explanatory:** Illustrate and describe the concept of MCM, allow for the allocation of detailed MCM-topics
- **Ontology-oriented:** define, detail and relate MCM relevant vocabulary
- **Hierarchical:** arrangement of all elements to allow for the creation of views with differing levels of abstraction

According to the explanatory character of the context model the selections of elements, sub-systems and relations rather has a claim for clarity and intelligibility than completeness in detail.

5.2. Designing the context model for MCM

Generally, the system-based context model for MCM considers the relevant elements and their relations for the MCM-domain. Each element can be a sub-system itself and contains hierarchical arranged elements (and relations where necessary), which are either tangible or intangible (cf. [9]). All are clearly referred to with a specific term and briefly described.

The context model (see fig. 1) is symmetrically divided into two sections – one for MCM and one for ECM – which are highly interrelated, but also able to operate independently.

Both sections comprise the same kind of elements: change (management) process, change itself, and the object of change. In addition to their interrelations they are linked by two elements: change cause and the supporting framework. These

eight elements are modeled as systems, comprising elements themselves (see as an example fig. 2).

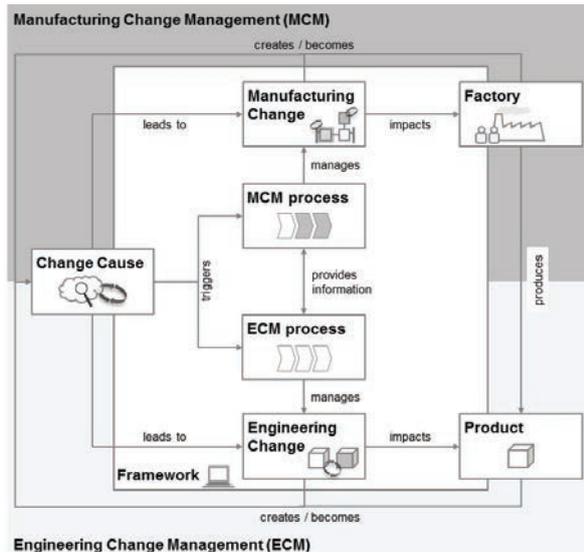


Fig. 1. Context model for a process-oriented MCM

Change cause. This element describes relevant fields or areas where events or triggers for either an engineering or a manufacturing change potentially occur. In literature, also terms like “influencing factor” (cf. e.g. [30]), “change driver” (cf. e.g. [26]) or “trigger of change” (cf. e.g. [31]) are used similarly or even synonymously. For the context model, subtle differences potentially stated are not considered relevant to this model, because those do not further contribute to the description or identification of the relevant fields or areas mentioned above.

The element change cause as a sub-system has been further detailed and comprises eleven specific change causes, which were again symmetrically grouped into change causes corresponding to manufacturing, to engineering and to general occurrence (see fig. 2). These are based on a broad literature review with a focus on engineering science, which included the compilation, consolidation and systematic structuring of the different change causes mentioned. In detail, the following change causes are considered relevant:

- **Factory lifecycle:** factory-internal causes, e.g. aging of manufacturing resources, required acquisitions
- **Manufacturing change:** conducting a manufacturing change can trigger subsequent changes in engineering and/or manufacturing (cf. change propagation)
- **Complications:** factory-internal causes, e.g. non-fulfilment of manufacturing requirements, mistakes in production planning, performance related issues
- **Product lifecycle:** e.g. varying number of units, change of product mix, facelifts, introduction of new product variants
- **Engineering Change:** conducting an engineering change can trigger subsequent changes in engineering and/or manufacturing (cf. change propagation)
- **Errors:** product-related causes, e.g. non-fulfilment of

quality of functional requirements, design issues

- **Laws & Regulation:** company internal and external causes, e.g. stricter environmental or labor regulations, new norms, standards or patents
- **Business operations:** company-internal causes, e.g. new management objectives, new KPI-targets, performance improvements
- **Kaizen:** causes resulting from suggestions for continuous improvements (e.g. from employees, customers)
- **Technology:** product or production technology related causes, e.g. introduction of new technology, technology development / evolution
- **Procurement:** supply-related causes, e.g. new or changing suppliers, different materials, delivery problems within the supply chain

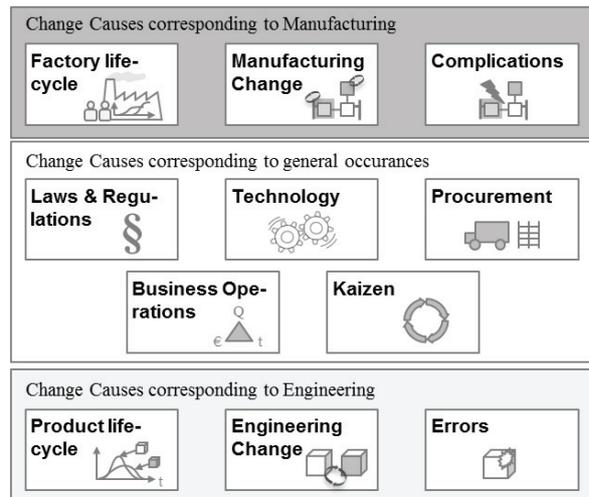


Fig. 2. Sub-system model of "Change cause"

Manufacturing change. This element describes any change (e.g. adaptation, reconfiguration) that occurs within the factory. It comprises relevant attributes to describe a manufacturing change (e.g. cost, duration, impact on factory) and constitutes one of the main elements within the MCM-section, as it is related to all other MCM-elements. Here, especially the relation to the element change cause should be mentioned, expressing that a manufacturing change can lead to further changes, hence become a new change cause.

MCM process. This element describes the reference procedure to manage changes in manufacturing. Based on the systemic modeling approach and the process modeling approach proposed by Browning et al. (cf. e.g. [17]), it comprises relevant process elements such as stages and gates and constitutes the core element of the overall context model. Building on this and the model-based design requirements the MCM process shall be developed further in subsequent research activities.

Factory. This element describes the grouped production factors fulfilling a defined part of the value stream to produce a tangible item (relation to product). Hence, it comprises four different elements: factory system, manufacturing processes, documentation (documents) and factory organization (e.g. job

shop and order control). The factory is impacted by manufacturing changes and can become a change cause (cf. “Factory lifecycle”) due to aging equipment (e.g. manufacturing resources) or due to complications in manufacturing.

Engineering change. This element is the counterpart to the element manufacturing change, describing any “[...] alteration made to parts, drawings or software that have already been released during the product design process.” [32]. It comprises relevant attributes to describe an engineering change (cf. e.g. [33]) and is related to all other ECM-elements. It impacts the product and can become a change cause triggering subsequent changes (in ECM and/or MCM).

ECM process. This element is the counterpart to the element MCM process and can be described as a small, highly constrained design process or project [34]. Regarding its structure and content, multiple publications are available in literature (cf. e.g. [10, 35]).

Product. This element describes a tangible item produced by the factory, which is a simple but sufficient definition for the purpose of this model. As a sub-system, it comprises elements such as components and documentation (e.g. drawings). The product can become a change cause in terms of changes in number of units (cf. product lifecycle) or the non-fulfillment of quality and/or functional requirements (cf. errors).

Framework. This element describes the supporting structure or underlying “skeleton” for the other elements of the MCM and ECM sections. It comprises the relevant knowledge, tools and software for MCM (and ECM) and connects all elements setting up a kind of information network. Its position in the background of the context model (behind the other elements) visually underlines this setup.

6. Requirements for a subsequent MCM design

Accompanying the design and enhancement of the context model, a set of requirements for a subsequent, more detailed MCM has been formulated (i.e. especially the elements MCM process, Manufacturing change and Change cause, which are in focus for a subsequent, detailed MCM design. For the other elements requirements could also be derived). Besides the actual context model, the previous literature review, expert interviews and workshops provided relevant input for the iterative derivation and/or evaluation of requirements during the context model design. Based on these, the following set of requirements has been formulated and assigned to the respective MCM element:

MCM process

- Support the planning and organization of manufacturing changes (e.g. provide suitable process stages and gates)
- Consider change causes, support their early identification and suitable handling
- Enable sufficient information flow between ECM and MCM process (e.g. suitable interfaces)
- Provide and utilize relevant information to the framework

(e.g. status information, change cause information)

Manufacturing change

- Enable a suitable MCM process design depending on the type of change
- Allow for an identification and analysis of its impact on the factory and regarding its potential as a new change cause
- Provide change relevant information to the framework

Change cause

- Support the identification and analysis of the change cause occurrence
- Provide change cause relevant information to the framework and allow for a close link to triggered manufacturing changes (and engineering changes)

Besides the formulation of requirements, the context model proofed its value for explaining the concept and vocabulary of MCM in various workshops and industrial expert interviews. Also, several use cases (with different exemplary change causes and change situations: e.g. “misspelling in work plan” causing a correction of the document; “new environmental law” causing an adaptation of machine tools and a subsequent product design change) have been analyzed testing plausibility and consistency of the context model. Summarizing, all activities conducted indicate the logical correctness, consistent and plausible structure as well as the explanatory character of the designed context model.

7. Conclusion and outlook

The research outlined in this paper aimed at supporting academia and industry in understanding the concept of MCM and its context, and to provide the common basis for a subsequent detailed design of relevant MCM elements (e.g. a MCM process). Therefore, a context model for a process-oriented MCM has been developed, while requirements for a subsequent, more detailed MCM design have been derived and/or evaluated iteratively. The context model comprises eight elements (which again are sub-systems with multiple elements) and their relations in a symmetrical setup. Besides its explanatory and ontology-oriented character, which directly supports the understanding of MCM, the context model is system-based and hierarchically structured – hence providing a sound basis for further research on MCM as well as on a potential integration of ECM and MCM into a joint change management.

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