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Advances in Smart Manufacturing Change Management

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Abstract. Many manufacturers lack comprehensive and seamless management for the change processes occurring between planning and the shop floor – particularly when it comes to cross-location, cross-disciplinary, and cross-departmental planning. This paper describes the emergence of the PSI/VDA recommendation which addresses this challenge. It´s Manufacturing Change Management (MCM) defines a reference sequence of steps for managing the changes between planning and the shop floor. To define this reference process, the recommendation first discusses how MCM fits into the business environment and identifies the main participants of the change processes. Next, the best possible structural steps involved in the processing of a change enquiry are detailed and the typical tasks and their extents are described. Leading on from the conceptual basis of the MCM process, its suitability for specific applications within companies is then discussed in reference to relevant use cases. Next, the recommendation shows how to work out a software-based support structure for the concept and implement as a prototype. The key element of the software-based implementation is to map the changes within a superordinate change list. Lastly, the solution provides an easy-to-use practical tool for initiating change enquiries. This can be deployed flexibly on mobile devices such as tablet PCs on the shop floor.

Keywords. Digital Factory, Product Emergence Process, Production Planning Process, Reference Process, Manufacturing Change Management

Introduction

A dynamic business environment and the rapid changeover to a seller's market have gradually increased the complexity that companies are facing today. Change management within the product creation process has been turned into a vital success factor for globally active manufacturers [1]. The coordination and structural mapping of product changes known as 'Engineering Change Management' (ECM) covers only part of the change processes within the digital product creation [2][3][4]. The production systems for manufacturing and assembly of the products are likewise subject to many different changes [5]. Some of these changes are pre-planned, and they are implemented specifically to achieve efficiency increases [6]. Other changes are subject to processes that are less structured or planned, which means that their practical repercussions often cannot be adequately predicted. Typical for all of these types of change measures is the fact that the production system's applicable documentation and the actual state of production are inconsistent with each other – they are asynchronous.

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The applicable documentation for the creation, commissioning, and operation of production systems is provided by the planning documentation. At the commencement of production, the documents and definitions of the planning departments serve as a reference for everything. There are many different ways in which the planned state can be deviated from [7]. There may also be entirely different adjustments which cannot be visually mapped and evaluated as easily [8]. The triggers for changes can vary, and they may be identified and suggested by a wide variety of parties [9]. Starting with the implementation of the initial production process, the many changes that are introduced subsequently therefore represent the actual manufacturing process at any given time.

In the context of holistic production systems (HPS), the adaptability of manufacturing processes is crucial to competitiveness. Across-the-board efficiency increases are usually demanded on a yearly basis, creating a strong need for streamlining. In order to permanently adapt and optimize the process, the planning documentation will, sooner or later and indeed necessarily, deviate from the actual state of the production system. This means that all producers will experience their manufacturing processes deviating from the original planning state to some degree. Any changes to the manufacturing process and planning then take place over the course of an iterative process requiring the agreement of numerous participants [10][11].

Long-term production efficiency relies on a well-coordinated interplay between planning improvements and ongoing optimizations. Continuous and parallel process optimization means that every production and work plan is changed several times over [12]. The challenge today is that the departments involved in changing the processes cannot fall back on generally acknowledged methods, which leads to coordination problems further down the line. This results in delays in the documentation process – not to mention delays in adapting the plan and/or implementing it on the shop floor. There is a definite need for collaboration, particularly in order to [13][14][15][16]:

- optimize sustainable implementation of planned production processes,
- identify and minimize discrepancies between planning and the production process,
- improve synchronization between production planning and production, and
- provide IT support for management during the manufacturing change process.

In order to embrace these goals, the Digital Manufacturing project group, founded by ProSTEP iViP Association in 2010, has been working on Manufacturing Change Management (MCM) since 2013 [17]. The project group has begun to define implementation scenarios as typically experienced in the change processes [18][19]. The recommendation at hand describes the ideal procedure and detailed processes that have been proven to be meaningful and helpful for all involved companies [20]. With insights gained from user interviews on general practical needs, change processes are divided into individual, formalized sub-processes. These sub-processes form the basis of a recommendation for a MCM reference process. In addition, the recommendation describes the current state of processes within MCM, the role of various parties within these processes, and the problems that arise from the inadequate synchronization of processes and planning due to documents that are not updated as frequently as required . To achieve efficient management and coordination of changes within the production system, it is also necessary to implement technical software support; this is to provide for easy capturing and administration of changes as well as presenting them in suitable ways [21]. The remainder of this paper describes the emergence of the recommendation as well as the introduction in a prototypical implementation of the requirements.

1. Description of the MCM Process

However, as much as production planning cannot work without the input of many business units, so is it also impossible to say that the change process is subject to the influences of planning and production alone. Although not a complete list, the following is a look at some potential sources of input [22][23][24]:

- Production planning analyzes the market and customer requirements, leading to decisions on which product should be put into series when.
- To do so, it requires data and input from technology and innovations planning. The product and technology planning sets the prerequisites for final product development.
- Product development then provides both product data and the requirements for material, machine, and installation parameters (e.g., torque values).
- Quality planning requirements, in turn, influence the production systems to be deployed.
- Tool planning is a cornerstone for engineering the production system itself.
- The holistic production system provides a framework for determining strategic guidelines on production development.
- During preproduction and even after series production has begun, additional changes are recognized as being either necessary or expedient, and are implemented into the process. They are subject to the continuous improvement routine (Kaizen / CIP).
- The companies suggestion system also provides input by giving incentives to suggest operational improvements; this is particularly active as a source of input once production has begun.

The sheer amount of those involved is challenge enough, as the company must find a procedure that acknowledges relevant input and is accepted and used by all parties. There are in fact two important locations at which the production plan is stored: production planning, and the shop floor. The shop floor receives the plan in the form of work plans and work place documentation, but it is production that takes responsibility for the shop floor documentation. Changes to the production and installation documents, usually available to these departments only in paper form, are in the worst case documented by hand only.

As there often is no formal way to report to production planning, the plan and the actual production are no longer synchronous. As the changes take place dynamically and for a variety of reasons, a regular documentation schedule simply means locking in the asynchronicity between production planning and shop floor. The results of asynchronous documentation of manufacturing processes are so severe that the group participants view official information management between planning and production as an urgent requirement. In the recommendation, this information management is described as Manufacturing Change Management (MCM). This basically consists of two structural stages: the Manufacturing Change Request (MCR) and the Manufacturing Change Order (MCO).

To be implemented, however, MCM should not entail the creation of any new departments or units, but rather be integrated into the existing organizational structures for planning and production. Changes which may have considerable consequences for production require unambiguous documentation and assignment of responsibilities. In some areas, such as ideas management (company suggestion system), these approaches are being applied already. A guided change process for planning and production therefore relies on a predefined role concept that details the required tasks and responsibilities. In terms of the MCM stages, this suggests two employee roles for MCR and MCO operation respectively. The responsibilities of the MCR and MCO operators are derived from the requirements of day-to-day production, which in many cases are identical to the responsibilities of the organizational structure for planning.

While the causes behind manufacturing changes may vary, their inclusion in the MCM's change processes need to be uniform. Especially if a large number of employees and other parties are involved in production planning and manufacturing, it is important to be able to consistently map the change processes. Product changes necessitate additional assembly steps, new technologies alter the production flow, and employee suggestions help to optimize processes in production and logistics.

Within the scope of MCR, all of these manufacturing changes are captured and checked in terms of their permission to trigger a MCO. Within this first stage of the overall MCM process, both the initiators of the change enquiries as well as the employees who implement them are known; they are predefined as part of the company's in-house rules and modalities. Structurally, the MCR process can be subdivided into eight sub-process steps with varying levels of complexity. Steps one to five serve to fully capture the change enquiry, whereas steps six to eight initiate and implement the enquiry's evaluation in terms of downstream process flows within the overall MCM process. Within the given level of abstraction, these steps are context-independent and can thus be applied to any parties (any relevant MCM change enquiry).

Having uniform management and tracking of change requests provides a significant advantage, namely the reinforcement of standards within the improvement of standardized production systems. Approved changes to the production system can offer significant opportunities of improvement for other system areas – or even other departments or company sites – that are identical or similar. The last step of the MCR process is to prepare the change order. Essentially, this step comprises two implementation tasks. First, a suitable contact person needs to be chosen for implementing the change request. This person acts as the MCO operator and is responsible for all subsequent processing of the change request. After the MCO operator is assigned, the change order itself, the Manufacturing Change Order (MCO), is issued. MCO specifies the implementation of the requested manufacturing change.

2. Implementation of MCM in the Company Environment

Although a tightly structured and standardized MCM workflow is not yet facilitated in most companies, it is of paramount importance to analyze how change processes between planning and the shop floor are currently handled in companies. This involves identifying important methods and systems that are compatible with the MCM concept. As part of the Digital Manufacturing project group's activities, extensive interviews were held across the participating companies to find out more about this. A big part of the interviews was to capture and categorize the participants of the MCM process, the deployed or deployable methods, and the IT systems available for the implementation and documentation of the change processes. In order to create a clear picture of how change communication is currently being implemented, the interviews were followed by a concept phase of extracting commonalities from the company-specific constraints and integrating these into a neutral overall concept that will be outlined below.

The company-specific view of changes in planning and production has confirmed the initial hypothesis that there is a multitude of change triggers and initiators needing to be dealt with within a company's day-to-day operations. Next to product and technology advances, the main triggers for change are the continuous improvement process, expert projects, and a dual stream of strategic changes. As well as external triggers for change from customers or suppliers, there are also different internal groups of potential initiators which are spread across the product creation process.

As well as the different ways of initiating change, day-to-day company practices have also revealed a variety of methods and bodies for examining changes and decision-making processes. When it comes to work structuring, companies frequently rely on the expertise of their in-house HR and industrial engineering teams; more complex technological decisions are usually made by expert teams or dedicated core technology teams. In terms of the measures potentially resulting from a change project, the estimated project volumes are frequently a crucial factor in shaping the decision-making process. In addition to the project structure, there are many other implementation structures to be found in the area of MCM: from specific adjustments through to more extensive change measures, and through to large-scale projects such as technology changeovers or the redesign of entire manufacturing and assembly areas.

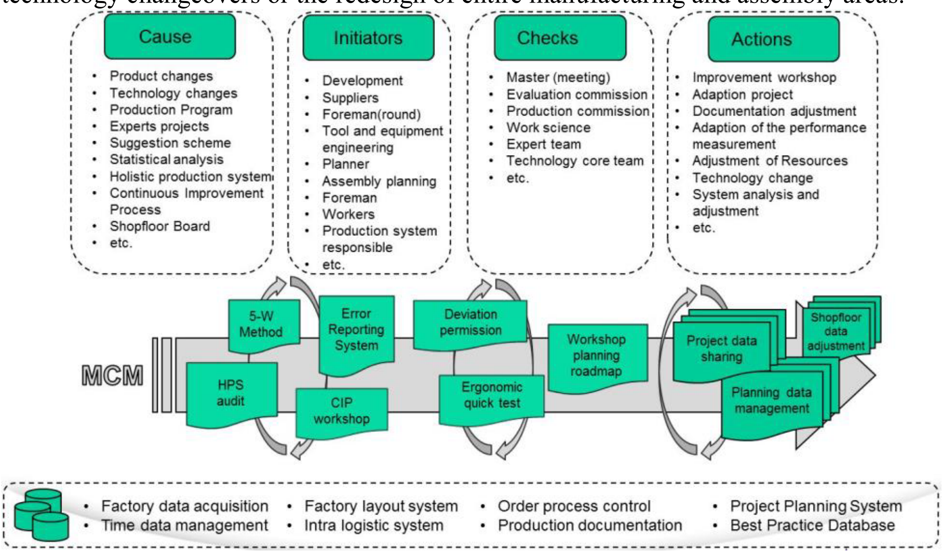

Figure 1. Change communications in manufacturing companies

In order to make their heterogeneous MCM environments more manageable, the analyzed companies are deploying many different methods and tools for a variety of practical purposes. Many of these methods are designed to identify divergences between the actual system and its current documentation. They aim to find out how these arose and also to trigger the synchronization of the actual system and its documentation. Companies are striving for an efficient combination of flexibility and stability in the interplay of documentation and shop floor. This enables methods such as deviation permissions or quick ergonomics tests to examine and evaluate actual states without significant administrative involvement. The described methods are complemented by a wide range of mechanisms for consistently and uniformly managing the planning data being created. These include workshop planning roadmaps, planning data management, project data sharing, and shop floor data adjustment.

Product development is one of the main triggers of change processes in planning and production. The product requirements implemented here – triggered either in-house through quality management etc. or externally through customer change requests – result in a change process that is established very rigidly in most large-scale manufacturing companies. Engineering Change Management (ECM) is a widely-used standardized approach for implementing change processes pertaining to product data as well as the controlled adjustment, approval, and deployment of the changed information. The changes arising from ECM when a new product or derivative is introduced, or when existing products are changed, additionally require validation in the downstream planning and production areas.

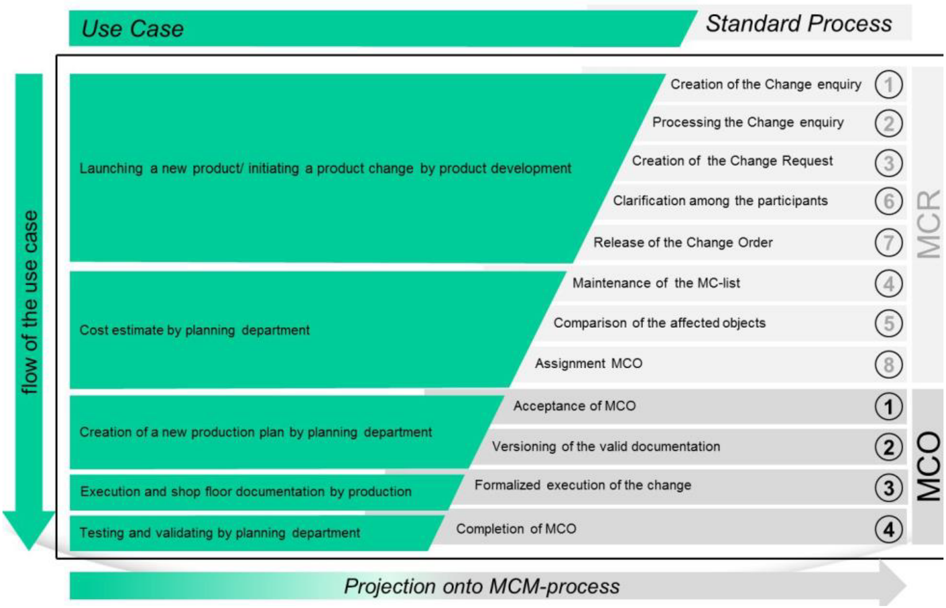

Figure 2. Mapping the 'Engineering Change Management' use case to the MCM process

Here, the changed structures in product development are made accessible to the planning department. If the changes apply to individual parts, the updated drawings and any available updated descriptions are also transferred. In this context, the main task for the planning team is to identify and capture the production system objects being affected by the change, and to estimate the costs of adapting the system to the changed product characteristics. After that, the planning team puts together a new or revised production plan and updates the shop floor documentation to reflect any changed details of the process implementation. In the event that the system adjustments require investment into new production equipment, machines, or systems, the planning department is also responsible for acquiring these alongside any needed raw materials, which may take the shape of a first batch. The changes are transferred to the production team in the shape of a work plan alongside detailed.

In the next step, this same documentation is used for physically implementing the changes on the shop floor. The production team is responsible for implementing the changes to the physical system in a way that conforms to the documentation. Following the adjustment process, the changes implemented within the actual system and within the documentation are validated and confirmed by the planning department.

One of the main drivers for change to the physical manufacturing system is the continuous improvement process (CIP), which is a well-established concept in many companies. The objective of the CIP is to gradually adapt and adjust a production system in order to increase its performance. For the purpose of implementing major changes to production systems that go beyond adjustments during regular operations, many manufacturing companies run so-called CIP workshops where the implementation of efficiency-boosting measures can be discussed in-depth. A CIP workshop typically focuses on the improvement measures of just a single area of the production system; this makes it one of the prime drivers of change processes pertaining to production and the associated planning areas.

Looking at the use cases overall, it is evident that while they may vary in the way they relate to the structural MCM process within operational practice, they can nevertheless be mapped to it very consistently. What has also become evident is that in practice, multiple steps of the standardized MCM process can be grouped together within a single process step, which makes them more manageable. The possibility of mapping the standardized MCM process to use cases therefore provides a feasible basis for a streamlined, software-based implementation; however, due to the individual functions being integrated very differently, the implementation cannot at this stage follow a fixed technical workflow.

3. MCM Prototype

A key factor in implementing the Manufacturing Change Management concept is to implement the process in a way that causes the participants as little added effort and cost as possible. This is particularly relevant to the ‘CIP’ and ‘Undocumented changes’ use cases, as there is very little willingness for these to take up additional effort and cost for documentation. What’s needed to make MCM implementation possible is a highly flexible IT support structure that facilitates the use cases to be implemented in practice. In the production environment, a large portion of the input is to be entered automatically, such as the user name or the production line in question. To provide a rough idea of what kind of shape the required IT support might take, the Digital Manufacturing project group within ProSTEP iViP has developed the so-called MCM Prototype; this is a prototypical implementation that demonstrates the kind of IT support needed for the MCM process. As the prototype was developed with a German user interface, translations for the relevant elements used in the screenshots are given in parenthesis where necessary. The demands placed on the MCM Prototype are informed by the task to manage the manufacturing changes as efficiently as possible. For this, individual change objects need to be both creatable in the context of linked structures as well as manageable in the context of other changes (Figure 3). The central element of the MCM data model is the MChange object. This represents an individual manufacturing change. The MChange object is created and persistently stored within the first step of the MCM process – the creation of the change enquiry.

Throughout the MCM process, the MChange object is populated with attributes and links to other objects. Besides the unique ID, the status is the object’s most important attribute, as this is used to map the progress of processing the manufacturing change within the MCM sequence of steps. The status can also be used as the key characteristic of a workflow engine controlling the MCM process. The MCM Prototype at hand does not feature a workflow engine because support for the MCM process needs to remain flexible; the aim here is not to prescribe fixed processing methods but to support responsible parties in the management of change processes. Also, most companies already have their own workflow systems – the prototype at hand is designed to be integrated into these rather than adding yet another workflow engine. Further attributes of the MChange object include type, scope, responsible party, and planning periods. 'Type' indicates the type of the manufacturing change. In the MCM Prototype at hand, the values stored here include 'ECM' for engineering change management and 'CIP' for continuous improvement process. 'Scope' contains a more detailed description of the planned or ordered change. The 'responsible party' attribute indicates the person responsible for the change, which usually is the assigned MCR or MCO operator. At the point of creating the change, the 'valid to...from' period may not yet be defined, so the entries here are optional and can be estimated. Over the course of the MCM process, this attribute will therefore need to be updated and locked down, as it is needed for defining the time axis when mapping a series of planned changes.

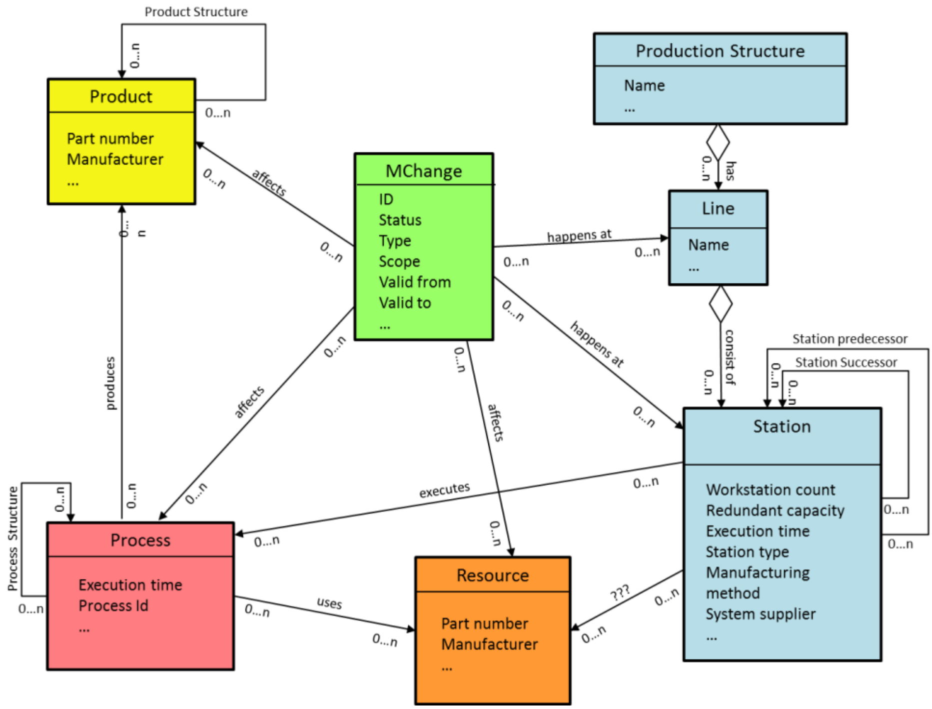

Figure 3. Data model of the MCM Prototype

The most important aspect of the data model introduced in Figure 3 is that the central MChange element is linked to the objects of the digital factory, i.e., the process, the product, and the resource. The resource is particularly important in this context and its use is expanded. By distinguishing between resources such as machines and tools – as well as between manufacturing structures such as lines and stations – it is possible to consolidate resource uses and see how resources are linked to manufacturing changes. For example, all of the MChange objects linked to a particular station can be determined this way. Similarly, this process can be consolidated to determine and display all of the stations of a line, as well as the MChange objects linked to the line itself. Single resources such as tools can be allocated to multiple stations and conversely multiple tools to a single station, and again they can also be linked to the

MChange object directly. The product and process structures are mapped in the same way, permitting context-specific views of planned manufacturing changes currently being implemented, as well as future planned manufacturing changes. For each product and each component contained within the product structure, the allocated MChange objects can be viewed. The same applies for the processes and process structures. In addition, the products, processes, and stations are linked together. This makes it possible to determine the processes allocated to a product, as well as the stations allocated to the processes where these are being implemented.

The network structure of the data model centered on the MChange object forms the basis of the MCM Prototype. The MCM Prototype is a web-based application with a client-server architecture. The interface is provided in the form of a web page, which can be opened via a standard browser from any user device that has access to the MCM web server.

The MCM concept is currently being tested in pilot projects by the manufacturing companies participating in the Digital Manufacturing project group. The testing involves users from many different areas including production planning, industrial engineering, and manufacturing. To support the pilot projects with supplementary measures, the project group has compiled a number of different work packages. On-site workshops are being offered to teach users about the overall system structure of the Manufacturing Change Management. Because the pilot projects are being carried out using the MCM Prototype, additional installation and configuration support for this is also on offer, as is a training module on how the MCM Prototype is used. Over the course of each project, a dedicated user support team is recording any issues that are arising, as well as the experiences gathered during the pilot project. Upon conclusion of the pilot projects, the participating companies will validate and assess the MCM implementations.

On the vendor side, a range of different PDM and PLM systems are being analyzed for their suitability to support or even integrate the MCM concept. Based on the experiences collected from the pilot projects and the analyses of the vendor systems, an MCM Implementation Guideline will be compiled to aid companies in implementing the MCM collaboration concept within their planning and production environments.

4. Summary and Outlook

With its Manufacturing Change Management, the Digital Manufacturing project group from ProSTEP iViP has created an informational collaboration concept to address the dynamic manufacturing changes taking place between engineering, production planning, manufacturing, the production system, and ideas management [25].

The formalized MCM process facilitates the creation and management of manufacturing changes across a company's different departments; due to their diverging priorities and the possibility of overlapping implementation schedules, manufacturing changes have the potential to interfere with each other. To prevent this from happening, the MCM process facilitates the systematic processing of these changes in the context of existing production structures, manufacturing and assembly processes, resources, and other planned changes [26]. A prototypical software implementation, the MCM Prototype, provides the necessary IT support for implementing the MCM process in practice.

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