Engineering Change Management Method Framework in Mechanical Engineering

Alexander Stekolschik

Engineering Design and CAD/CAE, Cologne University of Applied Sciences, Betzdorfer Str. 2, 50679 Cologne, Germany

alexander.stekolschik@th-koeln.de

Abstract. Engineering changes make an impact on different process chains in and outside the company, and lead to most error costs and time shifts. In fact, 30 to 50 per cent of development costs result from technical changes. Controlling engineering change processes can help us to avoid errors and risks, and contribute to cost optimization and a shorter time to market. This paper presents a method framework for controlling engineering changes at mechanical engineering companies. The developed classification of engineering changes and accordingly process requirements build the basis for the method framework. The developed method framework comprises two main areas: special data objects managed in different engineering IT tools and process framework. Objects from both areas are building blocks that can be selected to the overall business process based on the engineering process type and change classification. The process framework contains steps for the creation of change objects (both for overall change and for parts), change implementation, and release. Companies can select single-process building blocks from the framework, depending on the product development process and change impact. The developed change framework has been implemented at a division (10,000 employees) of a big German mechanical engineering company.

1. Introduction into Engineering Change processes in Mechanical Engineering

There is a daily rise in product and process complexities relating to mechanical engineering, not the least because of stronger customer orientation and individualization of customer-specific solution packages [1]. Additionally, increasing quality standards and shortened delivery periods have necessitated the introduction of integrated processes in the product lifecycle, in combination with high process reliability and stability. Manufacturers must respond quickly with engineering changes to maintain and increase their market shares. Such changes might be necessary to respond to market demand, governmental requirements, safety issues, service requirements, or functional and competitive reasons. Changes can be initiated in the different operative structure levels and parts (Figure 1) of the product lifecycle [1].

Such changes impact different process chains in and outside the company, and result in most error costs and time shifts. Most of the operative product structures are dynamic during the product lifecycle and will be reworked due to changed customer requirements. In early stages of product development, correction loops are intentionally planned to optimize the product and to make it ready for series production. Therefore, an integrated change management process is important for all phases of the product lifecycle, thereby automatically involving all affected parties across product definition, development, and manufacturing.
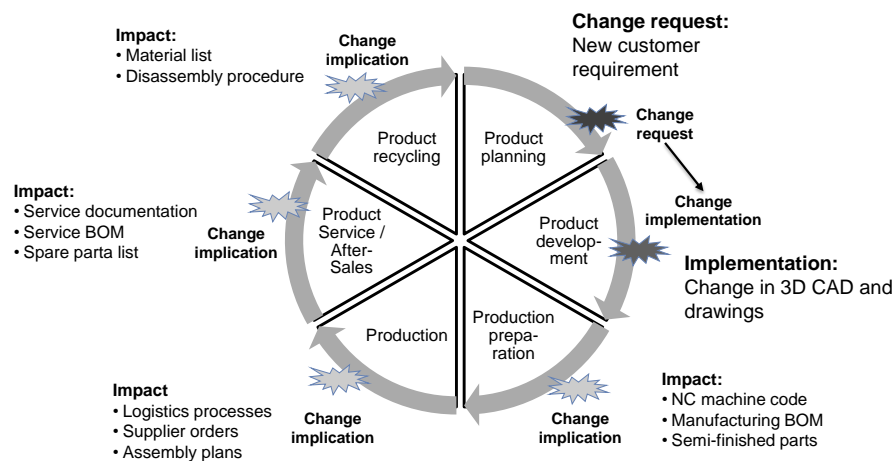
**Figure 1.** Engineering changes within the product lifecycle

Controlling change processes can help us to avoid errors and risks; it contributes to the cost optimization and a shorter time to market. According to research studies [1,2], up to 85 per cent of companies report that their change management procedures are either broken or could be improved. Change management, when done effectively, provides a major opportunity for improving development efficiency. Change management can lead to 'lessons learned' and process optimization. When done incorrectly, it can lead to delay as stakeholders lose time in waiting for decisions and updated information or work that must be redone because it was based on outdated design details. It can also lead to higher costs when errors lead to scrap and rework.

Engineering change management can be defined according to different standards [3] such as the coordinated management and uniform tracking of changes—i.e., collecting ideas or need for product and product-related changes, elaborating one or more possible solutions, evaluating them with respect to technical and cost aspects, and implementing them with respect to engineering and manufacturing [3]. The ECM process can be broken down into a number of key stages as follows [4, 5]:

- Identification of engineering change requirement, evaluation of benefits, implications, and affected products
- Preliminary authorization of change request
- Engineering of detailed solution
- Final authorization of the proposal
- Implementation of the solution and final review

2. Engineering change classification and requirements on engineering change management in product data management systems in mechanical engineering

The first step of the research has been the classification of different change types. In different projects, conducted at the institution, engineering changes were analysed and classified (Figure 2). The main criteria are change impact and change implementation effort. The impact of a change can be the adjustment or even complete stop of production, initialization, or change of purchase orders. Moreover, external parties can be affected. The change can lead to production stops at suppliers or new plant designs at customer site. The change implementation effort mainly depends on the number of affected parts and assemblies, the required change activities, and the impact on other products. The consequence for an enterprise is the risk related to high costs. Both change efforts and generated process chain costs (change impact) lead to the monetary project risk. The management demands a clear and transparent classification of the change risk, which can be provided by the ABC analysis (Figure 2).
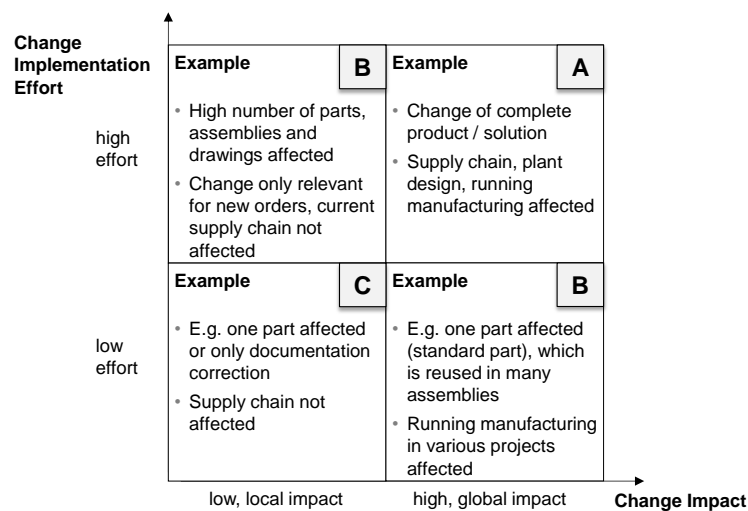
Figure 2. Engineering change classification

The change categories can be defined as follows:

- **'A' changes**: high and very high costs both within and outside the enterprise, internal, and external supply chain is affected
- **'B' changes**: medium change costs, caused by high change implementation efforts or the affected supply chain
- **'C' changes**: minor or no cost affects, local change implementation

Both classifications are the basis for the engineering change method framework. The next step is the definition of the requirements on the engineering change support in engineering IT tools. Today, the storage and management of product data and engineering changes is dependent on the used data management system like product data management (PDM) or enterprise resource planning (ERP) systems [6]. Additionally, specific product data can be found within product configuration and sales systems, manufacturing systems, or service systems. Each of these systems uses their own use case specific form of product representation and storage. In engineering systems, primarily, technical product structures are maintained, while logistical systems focus on process-related structures (e.g., order transactions) and cost structures. Especially business processes producing mechanical product enterprises are the basis for the main requirements. The following requirements of the engineering change management were acquired from engineering departments within the product creation chain:

- Management of problem reports, change requests, change orders, consequences and impacts
- Support of different change complexities (fast, standard, complex, complete)
- Workflow support, involvement of all stakeholders and decision-makers, access to all relevant product data, decisions and the current valid product configuration
- Legally compliant documentation and traceability of all changes and decisions
- Status-driven synchronization of revisions and validity between IT systems (PDM and ERP)

The complex engineering-to-order product development process [7] leads to additional requirements regarding change management, both internally and with suppliers and customers. Product and change data has to be available for decades due to legal requirements and service needs.

3. Development of a method framework
The developed method framework consists of two main areas: special data objects managed in different engineering IT tools and process framework. Objects from both areas are building blocks that

can be selected to the overall business process based on the engineering process type and change classification.

3.1. Development of data objects for engineering IT systems

Data objects in engineering systems store part and process information related to engineering changes. Research projects have identified and proved the need for different types of necessary change data objects (Figure 3). The developed data objects are created and managed in data management systems within the engineering change process, independent of the change complexity.

- **Change-related data**: The change object is an 'information folder' that contains information necessary for the management and control of changes. The change object contains data of a descriptive character (such as the reason for the change) and control data (such as effectivity data, object type indicators). Besides this data that the user maintains, there is also data that is automatically updated by the system (management data). Change objects should be identified by a unique change number. Number Assignment is made according to the defined criteria. Such objects contain information to all parts, assemblies, and other product data related to the change.
- **Part-related data**: Some change information concerns only singular parts or assembly. Such data is known as part change description, which describes modifications of a concrete part in detail. Such data cannot be applied to overall product change because it does not concern other parts or assembly. In many cases, part-related change data is linked with the overall change-related data (overall change objects).
- **Run-time-objects**: Stakeholders within the product creation process often require different types and scopes of change's describing information. In many cases, additional information, such as project performance indicators or cost overviews, is needed to the change description. It can be implemented by using run-time-objects like business reports. Such reports contain information from different sources—e.g., change objects, part descriptions, and cost database. These reports can be defined with stakeholder requirements on the information scope.
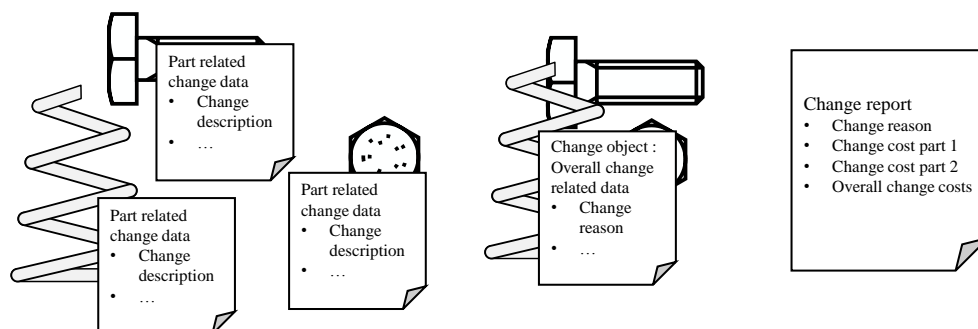
Figure 3. Types of Engineering Change data objects

3.2. Engineering change process framework

The developed engineering change process framework is the generic business process through engineering IT tools. It is the so-called end-to-end process, beginning at the change initiation and ending at the change impact implementation at production (Figure 4).
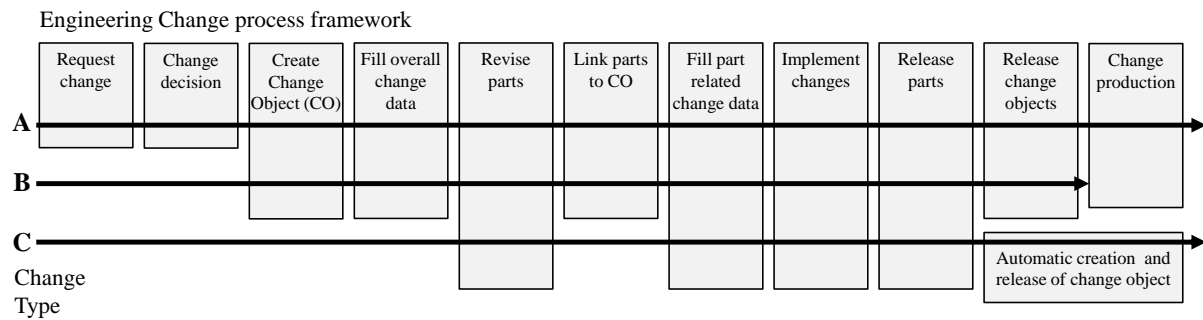
Figure 4. Use of the engineering change process framework

The process framework contains steps for the creation of change objects (both for overall change and for parts), change implementation, and release. Companies can select single process building blocks from the framework, depending on the product development process and change impact. Complex changes (Classification A) will be carried out by using all the steps for the effective change control, while changes pertaining to Classification B could be done without formal change request by the direct change start at the department. Changes pertaining to Classification C without impact can be done without creating the overall change object by only filling part change descriptions (the overall change object is created for each part automatically for tracking purposes in this case). The flexibility of the developed framework enables its use at both small and big enterprises.

4. Implementation and outlook

The developed change framework was implemented at a division (10,000 employees) of a big German mechanical engineering company. Engineering Systems NX (for CAD modelling), Teamcenter (PDM), and SAP (ERP) were used. Special system-based process workflows were implemented for different change types (A-B-C). Guidelines and access right system supported the selection of the proper workflows. The list of affected parts and departments were managed in the workflow so that automatic processes at production and the supply chain could be started on demand. Various implemented reports were created for project managers and the management. The implementation proved the practical relevance and usability of the framework.

Next steps in its research and implementation will be developing algorithms for automatic selection of change types, depending on different criteria (e.g., part referencing in assembles or production processes). Moreover, the process framework will be extended for being used outside the enterprise—e.g., for engineering change processes involving engineering and production suppliers and customers.

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