Chapter 11

Comparison of Seven Company-Specific Engineering Change Processes

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The management of engineering changes is an ongoing topic in academia and practice. To define the ideal engineering change process is still a challenge due to the opacity for necessary activities and the lack of efficacious supporting methods and tools. The comparison of seven company-specific engineering change processes gives insights into a detailed activity level of engineering changes in practice. By comparing the processes based on a reference process, commonalities and differences are derived. Coincidental, a generic engineering change reference process was developed, which describes an ideal process with all possible activities and process steps when dealing with engineering changes.

11.1 Introduction

Engineering changes absorb up to 31% of the product development capacity (Maier and Langer, 2011). This stresses the importance of their management, which is still an ongoing topic in academia and practice. One of the frequently upcoming topics is the opacity of engineering change processes (ECPs) and all necessary activities when dealing with engineering changes (ECs). Even if this was already a research topic several years ago (Eckert *et al.*, 2004; Jarratt and Clarkson, 2005; Lindemann and Reichwald, 1998; Terwiesch and Loch, 1999) and industry is aware of the proposed ECPs, there are still a lot of problems when dealing with ECs in practice. The described ECPs in literature are either not specific enough to use them, or are too specific what makes it difficult to adapt them to companies' needs in ECM (Jarratt and Clarkson, 2005).

In order to derive best practices and to enhance the management of ECs in industry, a comparison of company-specific ECPs was conducted. To allow a consistent comparison, there is a need for a reference process. The development of such an initial engineering change reference process (ECRP) is described in section

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11.4, before the comparison of seven company-specific ECPs is addressed in section 11.5. This includes a revision of our ECRP, the description of the comparison and a discussion of main findings. Section 11.6 concludes the chapter and gives an outlook for further research. The following section gives an overview on the way the research was conducted and describes the corresponding research methodology.

11.2 Research Methodology

Following the strong interest by practitioners in a comparison of ECPs, we conducted a workshop on that topic within an expert group. In order to provide a common basis for terms and understanding of ECPs, we developed a reference process model for engineering changes based on literature. Thereby, we considered processes presented in commonly used scholar databases, engineering standards as well as book publications on engineering change management. The resulting model was used by every workshop participant to describe the ECP within their company preliminary to the meeting. In the meeting, the ECPs were discussed and commonalities and differences were identified in a workshop. Afterwards we adapted the reference process based on the findings in order to provide a generic framework for a comparison of company-specific ECPs and summarized the findings of the comparison in the new framework. In another meeting we evaluated the new ECRP and the findings of the comparison together with further participants of the industrial working group. The participants of the meetings and our research approach are described in more detail in the following sections.

11.2.1 Description of Participants

The group of experts on engineering change management was founded in 2012 and meets three times a year. The group was founded following the interest in more opportunities for discussion and knowledge transfer about ECM between academia and practice. Usually, five to ten participants from different companies attend the meetings, discuss current challenges and draw the advancements of ECM in academia and practice based on the fields of action in industry. The companies represented reach from middle-sized enterprises to large-scale enterprises and from suppliers to original equipment manufacturers (OEMs).

A total of 13 practitioners from seven different companies participated in the first meeting. The objective of this meeting was a comparison of ECPs within the different companies. Anonymized details about the represented companies among the participants are provided in Table 11.1.

Table 11.1. Information about participants of the industrial working group

Company size (employees)	Position in supply chain	Positions of representatives	Industry
~80.000	OEM	Change manager	Commercial vehicles
~45.000	OEM	Process manager	Home appliances
~35.000	OEM	Change manager, process manager	Commercial vehicles
~20.000	OEM	Project/Change manager	Fixation systems
~17.000	OEM	Change manager	Commercial vehicles
~15.000	Supplier	Change manager	Automotive
~1.200	Supplier	Head of development	Manufacturing

11.2.2 Research Approach

In order to compare company-specific process steps in ECM, a reference process was needed as a basic model for comparison. In a first step, we developed an initial EC reference process model based on literature about ECPs. We used this model for the comparison of ECPs of the participants, who allocated their company-specific processes within our model. Together with the practitioners, we discussed the different processes in a workshop and reorganized the different company-specific process steps. Then, we analyzed the workshop results in order to derive commonalities between the companies and to identify gaps; on the one hand, that might be process steps in our initial ECRP which are not used in industry or one the other hand process steps which are not captured in our initial ECRP. As a consequence, we restructured our reference process and changed the level of detail for some activities within the process. As a last step, we presented the resulting ECRP within a second meeting of the industrial working group with further participants, including the allocation of their company-specific ECPs.

11.3 Development of the Initial ECRP

As described before, we developed a reference process model based on literature in order to provide a framework for the comparison. The following sections give an overview of literature that deals with engineering change processes and describes how we derived our initial engineering change reference process (iECRP).

11.3.1 Perspectives on Engineering Change Processes in Literature

As defined by Jarratt *et al.* (2011) an EC is an alteration made to a product or its documentation. Furthermore, they define the organization and controlling of the processes for an EC as Engineering Change Management (ECM). The process behind the management of ECs is often called ECM process or just EC process

(ECP) (Jarratt *et al.*, 2011). The EC process has similarities with the conventional design process or problem solving processes in general as presented by e.g. Pahl *et al.* (2007): confrontation, information, definition, creation, evaluation and decision. But there are also some important differences. Aßmann (2000) mentions inter alia:

- The main focus of engineering processes is the generation of data. In EC processes existing and shared data are modified;
- EC processes are characterized by a variety of administrative steps in order to minimize potential side effects of ECs;
- Due to a large number of boundary conditions (e.g. existing data, increased pressure of time) is the planning and coordination of ECs within design processes complex.

The statements about which processes exactly are part of this ECP differ in literature significantly. The different perspectives on ECM in literature are listed in Table 11.2.

Table 11.2. List of different understandings of ECM in literature.

Characterizations of ECM	Reference
ECM usually includes the four stages: Identifying; Evaluating; Implementing; Auditing Moreover, some common activities: identification and control of product structures; maintenance of revision control; history of all changes of products and its associated documents.	(Huang and Mak, 1999)
ECM is the process of making engineering changes to a product in a planned or systematic way, including the following steps: • Emergence of a need for the change • Request for the change • Management approval of the change • Implementation of the change • Documentation of all impacted product data	(Rouibah and Caskey, 2003)
• Engineering change request raised • Identification of possible solution(s) of change request • Risk/Impact assessment of possible solution(s) • Selection and approval of a solution by change board • Implementation of solution • Review of particular change process	(Jarratt and Clarkson, 2005)
ECM encompasses all documents, methods, actions and processes that are necessary for the avoidance, anticipation, effective selection, processing, approval/disapproval, execution, control and documentation of engineering changes.	(Köhler, 2009)
• Identify change: Initiate problem, Estimate problem, Request change, Initiate Solution • Propose change: Analyze and order change, Propose solution • Alteration: Plan change, verify plan, execute and approve • Implementation of change: Estimate impact, Release change, Modify orders/requests/configuration, Disclose change	(Rozenfeld *et al.*, 2009)
• Clarification of the change case • Selection of change mechanism(s) • Evaluation of alternative change options • Actual decision-making and approval of a change option • Implementation • Review of the individual change process and lessons learned	(Kissel and Lindemann, 2013)

Most of the authors describe ECM as the processes and actions to handle ECs after the need for them was already identified (i.e. the starting point is an EC request). Obviously, everybody mentions the implementation of the change itself as part of ECM. The generation of possible solutions, a risk and impact analysis and the decision process in advance of the implementation, and the retrospective review of already executed changes are not always included.

In order to list all necessary process steps of ECM it is also useful to take a look at the strategies pursued by ECM. Table 11.3 summarizes the different strategies for ECM described in literature. Most of the strategies can be found implemented in the different process steps presented before. Only the avoidance, reduction and the front-loading of engineering changes cannot be matched to the identified process steps within ECM. This is due to the different characteristic of these activities. The ECPs described in literature are executed every time when there is a target deviation. The activities to avoid, reduce or anticipate changes take place on another level, i.e. are incorporated within the overall development process (Lindemann and Reichwald, 1998).

Table 11.3. Summary of ECM strategies mentioned in literature.

Strategies	References
Avoid and reduce engineering changes	(Lindemann and Reichwald, 1998; Terwiesch and Loch, 1999; Aßmann, 2000; Fricke *et al.*, 2000; Rouibah and Caskey, 2003; Eckert *et al.*, 2004)
Front-loading of engineering changes	(Terwiesch and Loch, 1999; Aßmann, 2000; Fricke *et al.*, 2000; Rouibah and Caskey, 2003)
Effective and fast decision making on change implementation	(Fricke *et al.*, 2000; Rouibah and Caskey, 2003; Jarratt *et al.*, 2011)
Reduce negative impact of engineering changes	(Terwiesch and Loch, 1999);
Efficient implementation of engineering changes	(Terwiesch and Loch, 1999; Aßmann, 2000; Fricke *et al.*, 2000; Jarratt *et al.*, 2011)
Learning from previous engineering changes	(Fricke *et al.*, 2000)

11.3.2 The Initial Engineering Change Reference Process (iECRP)

By merging all different strategies and process steps identified in literature into one process model, a basis for the comparison was derived. The result is a model (iECRP) with five phases:

- Identification of the necessity for a change;
- Preparation of the change (generation of options and their assessment);
- Decision for a change option;
- Operation: implementation of the change;
- Review of change effects.

These phases are on a too abstract level in order to allocate concrete activities within the handling of ECs in industry. Figure 11.1 shows the initial ECRP where every phase is detailed with necessary activities in an ideal procedure of an EC. Since this model was revised in a next step, the detailed description of the phases follows in the next section.

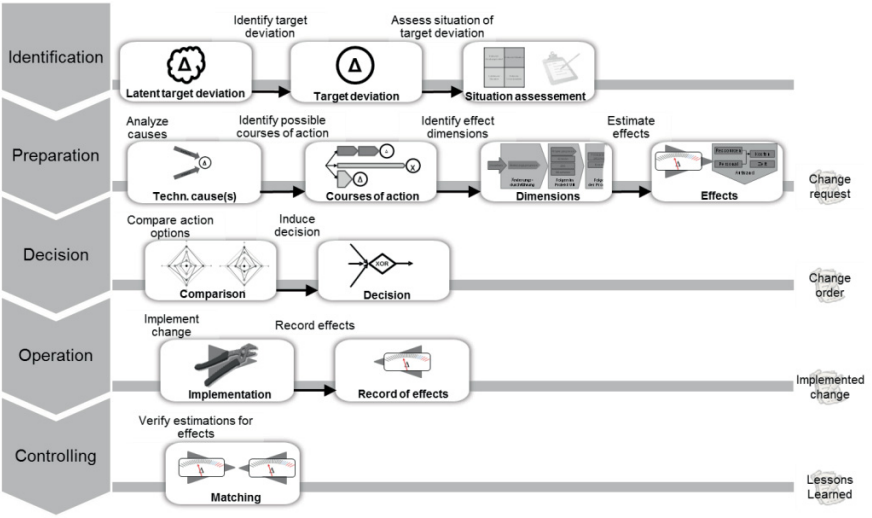

Figure 11.1. Initial model for an engineering change reference process.

11.4 Comparison of Seven Company-Specific Engineering Change Processes

11.4.1 Revision of the ECRP According to the Company-Specific EC Processes

The iECRP based on literature (see Figure 11.1.) was sent preliminary to the meeting to the participants of the industry working group with a description of the iECRP. The representatives of the seven companies then allocated their company-specific ECP to the iECRP in preparation for the working group meeting.

Within the workshop the participants presented consecutively their company-specific ECPs with reference to the phases and process steps of the iECRP. Subsequently a discussion was lead about differences and commonalities of the seven company-specific ECPs.

The allocation of the company-specific EC processes to the iECRP indicated that some revisions would be helpful to reach a better result in the comparison afterwards. Therefore the following points were revised:

- simplification to a purely activity-oriented process model (the results of the activities are depicted by the graphics);
- aggregation of two activities (“Identify effect dimensions” and “estimate effects” to “Identify and estimate effects”);
- expansion of the activity “verify estimations for effects” to ”match results”;
- modelling “Lessons Learned” as a process activity: “draw lessons learned”.

Figure 11.2 depicts the revised ECRP with five phases and eleven process activities. It is of prime importance that the whole process should not be seen as just sequential. There are many loops possible and the sequence of actions depends on the specific context and situation, which are investigated in the identification phase.

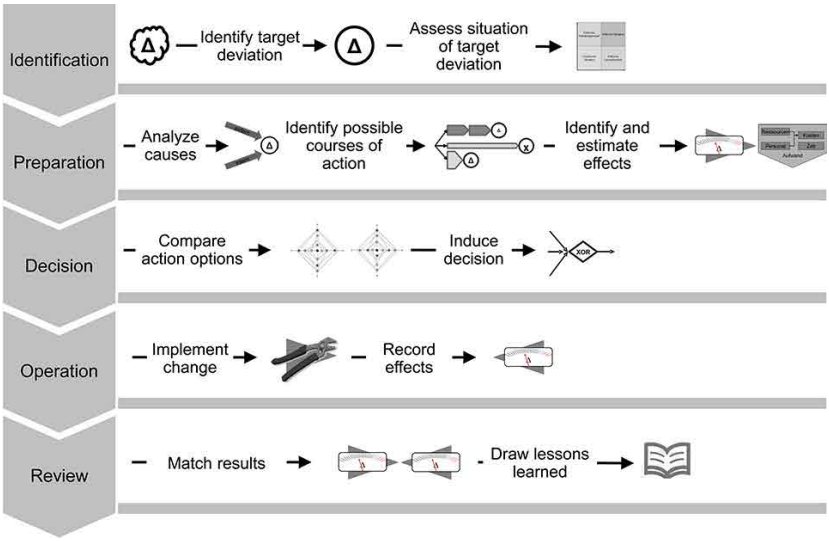

Figure 11.2. Revised ECRP according to the company-specific EC processes

The identification of the target deviation and the assessment of the situation regarding the necessity to change and boundary conditions are focus of the first phase (identification). Here, the further procedure is defined roughly. Within the following preparation phase, more information is gathered. Among with a cause analysis in order to identify the technical cause behind the target deviation, several courses of action are elaborated. For each course of action, the dimensions and extents of resulting effects are estimated. The result of the preparation phase is an engineering change request (ECR) that describes the target deviation, the underlying technical cause, potential solutions and related effects. Based on the ECR, a decision has to be made in the next phase whether there will be a change at all and if so, what solution should be implemented. The result of the decision phase is an engineering change order (ECO). During the operation phase, all actions described in the ECO are executed. The effects of the change have to be recorded

during implementation in order to derive lessons learned in the closing controlling phase, where estimated change effects are compared to actual effects. Hence, the quality of predictions for change effects can be enhanced. The following section presents the comparison of the company-specific ECPs, allocated in our ECRP.

11.4.2 Comparison of Company-Specific ECPs

The seven company-specific ECPs were compared against the revised ECRP which consists of five phases and eleven process activities. The ECRP is represented in Table 11.4. In a first step of the comparison it was analyzed whether the particular process activities are part of the companies' ECP (see Table 11.4, column: "Quantity of companies"). In a second step the core differences within process activities of particular ECPs were determined (see Table 11.4, column: "Core differences").

Table 11.4. Results of the comparison of seven company-specific ECPs against our ECRP

	Process activities (ECRP)		Company							Core differences within company-specific process activites
			1	2	3	4	5	6	7	
Identification		Identify target deviations	●	●	●	●	●	●	●	-
		Assess situation of target deviation	●	●	●	●	●	●	●	Companies have different criteria and procedures to assess target deviations.
Preparation		Analyze causes	○	○	○	○	○	○	●	-
		Identify possible courses of action	●	●	●	●	●	●	●	Only two companies generate more than one course of action.
		Identify and estimate effects	●	●	●	●	●	●	●	Companies take different effects into accout, which have to be estimated.
Decision		Compare action options	●	●	●	●	●	●	●	Two companies decide between alternatives. The others have "go/no-go" decisions.
		Induce decision	●	●	●	●	●	●	●	Single- or multi-stage decisions are possible.
Operation		Implement change	●	●	●	●	●	●	●	"Just do it" – The activity depends on the

	Process activities (ECRP)		Company							Core differences within company-specific process activites
			1	2	3	4	5	6	7	
										specific EC and company surroundings.
		Record effects	○	○	○	○	○	○	○	-
Controlling		Match results	○	●	●	○	●	○	●	Different conditions are matched by companies: - objectives achieved? - estimations correct? - assumptions occurred?
		Draw lessons learned	●	○	●	○	○	○	○	-

Legend: ● Company with process activity ○ Company without process activity

11.4.3 Findings and Discussion

The comparison of the seven company-specific ECPs indicated that the "identification phase" is very important for ECPs and especially the phases "preparation" and "controlling" differ strongly within the seven companies and between academia and practice.

Within the **"identification phase"** the following process activities are determined for the specific situation of the change. Therefore, first the situation and deviation is assessed by the companies. Hereby the point of time within the development process when the deviation is detected is very important. Three out of seven companies differentiate between changes occuring in the planning phase, in the development or production phase or in the phase of product care. Furthermore, one company takes into account if the change affects a complex product or process and also if the customer has to be informed.

The **"preparation phase"** in which causes for target-deviations have to be identified as well as possible courses of action is less emphasized within the companies. Only one out of seven companies has "analyze causes" as a process activity in their ECP and only two companies generate more than one course of action in order to eliminate the target-deviation. Due to increasing time pressure, companies often detail, assess and document only one course of action, which is then captured in a change request. In the following decision phase it will be decided whether the change request will be implemented or not. The decision then is a "go/no-go" decision instead of a decision between alternatives. In discussion with participants of the working group about the preparation phase it becomes apparent that the companies are not sure which effort is appropriate for the preparation phase, i.e. how much time they are allowed to spent in order to find a solution to eliminate the target-deviation. In the foreground there was lead a discussion about the effort-benefit ratio. Besides that, none of the companies

documents alternative courses of actions, which were established in the preparation phase. They are not captured in the change request. The ECRP includes this activity and the working group agreed on the potential of this process activity.

Furthermore the **"controlling phase"** differs strongly between the companies and the established ECRP. Within the process activity "match results" the EC is examined retrospectively: two companies check whether the objectives of the EC were achieved and therefore the target-deviation was eliminated, one company checks whether the estimations have been correct and one company checks whether the proposed assumptions have become true (e.g. sales volume for a product). Then only two out of seven companies draw "Lessons Learned" after a closed EC to generate knowledge out of the findings and preserve the knowledge that has been gained during the ECP. The representatives of this two companies which draw lessons learned admitted that they draw lessons learned for some critical ECs but without a structured documentation and procedure and also the distribution of the gained knowledge is not organized.

With regard to the **whole EC process** and the quantities of companies which perform the particular process activities it can be assumed that most of the companies focus on activities which are really necessary to implement ECs. Activities which do not lead or contribute directly to an elimination of the target-deviation or have any benefit for the specific EC are not part of the ECP. Therefore often only one course of action is prepared, assessed and documented within the change request, which leads then to an easy "go/no-go" decision but not necessarily to the best possible solution. Furthermore, no profound controlling is done after a change is implemented so that it cannot be assessed whether the decision was right as well as all assumptions which have been made during the process. Companies thereby abstain from the strategy "learning" out of ECs.

11.5 Conclusion and Outlook

Literature provides numerous similar ECPs on a very high and abstract level. However, these processes lack of detail to apply them as a reference process in order to compare company-specific EC processes. So within this work first an ECRP was developed which is more detailed and profound then the processes already presented in literature.

This ECRP was the basis for a subsequent comparison of seven company-specific EC processes to determine the state of EC processes in industry. The focus within this study was on standard process activities and their differences.

The main findings are that most of the companies generate, document and assess only one course of action instead of several in preparation for an EC decision. Furthermore, the process activities after an EC was already implemented are very poor emphasized in industry. But these phases and activities are the basis for a process improvement of EC- and development processes because it can be identified whether the ECP was successful or not. Also the strategy learning depends on the late phases and a review of the EC in total and retrospectively. In conclusion, industry is currently abstaining from the potential to improve and

increase the effectiveness and efficiency of the EC- and development processes by intensifying the late phases and extend the field of courses of actions.

In a next step methods and tools to assess change effects in order to support the decision making will be developed. Thereby, decisions within the phase identification for situation analysis purposes as well as decisions within the phase decision upon courses of actions are addressed. Furthermore, these methods and tools promise an improvement of the effort-benefit ratio, which is vital challenge in industry when estimating the effort to put in the elimination of target-deviations. A subsequent goal is to develop an approach for the strategy learning within ECPs and the evaluation of the benefit of this strategy.

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