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COMPARISON OF ENGINEERING CHANGE CAUSE ANALYSIS IN LITERATURE AND INDUSTRIAL PRACTICE

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ABSTRACT

Engineering changes are a permanent feature of product development. They enable the development of successful and up-to-date products. However, many engineering changes can be avoided or at least anticipated by deriving preventing measures from identified underlying causes. Cause analysis procedures of engineering changes presented in literature aim to identify technical and organizational causes behind a change as soon as the necessity for a change was recognized. The examination of six cause analysis examples from industrial practice shows that cause analysis in industry is additionally used to investigate the reasons for a change. Furthermore, cause analysis in practice is not only conducted ad-hoc when a change is required, but also retrospectively in project reviews. A comparison of procedures and methods described in literature and gained from practice indicates different classifications for cause analyses regarding their initial situation and purposes. It further reveals which procedure steps and methods are useful and where more methodological support is needed. Hence, a foundation for the development of specific cause analysis procedures is given.

Keywords: engineering change, cause analysis, design process, organisation of product development

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1 INTRODUCTION

Engineering changes (ECs, also referred to as just 'change' in this paper) are a permanent feature of product development. Defined as "alterations made to parts, drawings or software that have already been released during the product design process" (Jarratt et al., 2011), ECs can be wanted and are necessary for the development of products that meet changed customer requirements, market trends and up-to-date technologies. At the same time, there are unwanted ECs, which are caused by e.g. design errors or unforeseen requirements (Jarratt et al., 2005). According to Huang and Mak (1999), the adequate and efficient management of ECs is a crucial factor to maintain the agility of a company. Competitiveness can be increased significantly by a proper handling of ECs, whereas a failed handling can lead to loss of time and money (Huang and Mak, 1999). One important strategy in engineering change management (ECM) is the avoidance of engineering changes (Fricke et al., 2000).

Deubzer et al. (2005) see the highest potential for the avoidance of unwanted changes in the identification of change causes. They identified in their study that 56% of ECs are caused by errors, of which 39% could have been avoided (cf. Figure 1). Also wanted changes (e.g. to meet new requirements) bear the potential to be avoided or at least anticipated by investigating the causes that led to the late recognition of the target deviation. In industrial practice, however, cause analysis is conducted insufficiently or not at all because of high time pressure. Hence, not the causes but just the symptoms of an engineering change are resolved (Aßmann, 2000; Gerst and Stetter, 1998). When the underlying change causes remain unknown and the real problem is not eliminated, its severity can even rise and similar problems in future cannot be avoided (Gerst and Stetter, 1998).

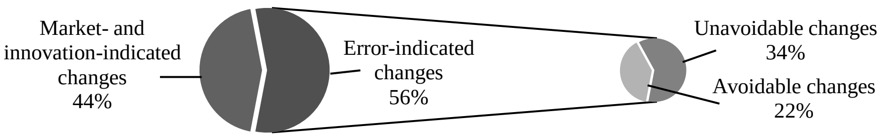

Figure 1. Breakdown of change classifications according to Deubzer et al. (2005).

This paper aims to investigate which procedures and methods for EC cause analysis (CA) are provided in literature and which are actually used in industrial practice. Further, implications for research and industrial practice shall be derived by a comparison of the results. After introducing some background information of this research in Section 2, relevant terms about the causalities of ECs are defined in Section 3. Section 4 presents the results from a literature research about EC cause analysis, examines examples for CA in industrial practices, compares both perspectives and discusses implications in the end. Finally, a summary and outlook is given in Section 5.

2 BACKGROUND OF RESEARCH

2.1 Motivation

The Collaborative Research Centre (SFB 768) – 'Managing cycles in innovation processes – Integrated development of product-service-systems based on technical products' aims to provide support for the controlling of influenceable cycles and interdependencies within the life cycle of a complex product. The management of engineering changes is one focus area within this research project, since engineering changes and iterations can be seen as specific types of cycles in design processes (Langer et al., 2012a). In order to investigate current practice, the biggest challenges and potential strategies in ECM we conducted surveys with industry in three different countries (Chucholowski et al., 2012; Langer et al., 2012b; Maier and Langer, 2011). Subsequent to the survey in Germany, we invited survey participants to a workshop where survey results were discussed. Based on interest in more chances for discussion and knowledge transfer about ECM between researchers and industry partners, we founded a "Workgroup Engineering Change Management" in 2012 which meets three times a year. Companies represented in the workgroup reach from middle-sized enterprises to large-scale enterprises and from suppliers to Original Equipment Manufacturers (OEMs). The main topic of the workgroup's meeting in December 2012 was 'systematic cause analysis for ECs', where CA in industrial practice was discussed.

2.2 Methodology

As a first step, a total of six different examples for cause analyses in industry were analyzed. The examples come from the industry partners that took part in our workgroup meeting in December 2012. Table 1 provides anonymized details about the participants. In workshops we discussed the examples and characterized them by the following attributes: point of time of conduction during design process, purpose, outcome, procedure steps of the analyses and the methods used. The results of the workshop are presented in Section 4.2.

Table 1. Information about participants of the meeting of the "Workgroup Engineering Change Management" in December 2012.

	Company size (employees)	Position in supply chain	Position of representative
A	~ 20.000	OEM	Project Manager, Change Manager
B	~ 45.000	OEM	Chief process manager
C	~ 600	Supplier	Process manager
D	~ 35.000	OEM	Head of change services
E	~ 1.200	Supplier	Head of development

In order to compare industrial practice of CA for engineering changes with the perspectives from literature, a literature research was conducted in a second step. Therefore, the literature data bases Web of Science and Google Scholar have been searched for the keywords 'cause analysis', 'cause analysis method(s)', 'problem analysis' and 'problem solving'. Additionally, the literature that was referenced in relevant search results was searched, as well as already familiar ECM literature (e.g. Deubzer et al., 2005; Eckert et al., 2004; Fricke et al., 2000; Huang and Mak, 1999; Huang et al., 2003; Pikosz and Malmqvist, 1998; Siddiqi et al., 2011; Terwiesch and Loch, 1999).

As results of the research about general cause analysis procedures and methods, so called root cause analysis (RCA) methods and rather general analysis methods were found, whereas most of them are presented very context specific. Hence, the literature perspective on CA presented in Section 4.1 considers engineering change-related literature on the one hand and a selection of relevant general cause analysis literature on the other hand.

3 ENGINEERING CHANGE CAUSALITIES: DEFINITION OF RELEVANT TERMS

Since most literature uses different terms to describe engineering change causalities, definitions for the main terms are given in this section to provide a common understanding for this paper. Especially the term 'cause' can have different meanings in different contexts and the usage and definition in the context of changes varies in literature. Words related to the causality of changes are 'motivation', 'reason', 'underlying cause', 'source', 'initiator' or 'objective' (Aßmann, 2000; Conrat, 1997; Eckert et al., 2004; Köhler, 2009; Vianello and Ahmed-Kristensen, 2012; Jarratt et al., 2011).

Table 2. Overview of definitions for terms regarding the causality of ECs.

Term	Definition
Target deviation	Target deviations are deviations of the actual state from the nominal state which trigger an EC at any point of time in a product lifecycle. **Synonyms**: trigger, technical problem, technical cause, symptom
Initiator	Initiators are domains that indicate or require the change. **Synonym**: source
Reason	Reasons are arguments that motivate the change or objectives pursued by the change. **Synonyms**: objective, motivation
Cause	Causes are circumstances/factors that lead to the target deviation as part of a cause-effect network.
Root cause	Root causes are specific underlying causes that can be reasonably identified and can be controlled by management. It is possible to derive effective recommendations for preventing their recurrence. **Synonyms**: driver, underlying cause, original cause

Table 2 shows an overview of the definitions of different terms regarding the causality of changes used in this paper. An engineering change is always triggered by a target deviation (Conrat, 1997). The domain that requires or indicates an EC is referred to as initiator (Conrat, 1997; Eckert et al., 2004). The change reason argues for the implementation of an EC (Jarratt et al., 2011; Vianello and Ahmed-Kristensen, 2012). It is possible to identify many different circumstances or factors that contribute to the emergence of a change. Every one of them can be seen as a cause and is part of a cause-effect network (Aßmann, 2000). The underlying causes among them are usually referred to by the term 'root cause' in literature (Rooney and Vanden Heuvel, 2004). An illustrative example to explain the difference between causes and root causes is the following: 'severe weather' as a root cause for parts that are not delivered on time is not appropriate, but 'insufficient time buffer for delivery' can be seen as a root cause. The more specific root causes are, the easier it is to generate recommendations towards prevention of recurrence (Rooney and Vanden Heuvel, 2004). This is why CA aims to identify these underlying causes instead of other factors that often only are the symptoms of the real problem (Gerst and Stetter, 1998).

4 CAUSE ANALYSIS IN LITERATURE AND INDUSTRIAL PRACTICE

4.1 Cause analysis in literature

The basic task of cause analysis is not only to find out what happened and how something happened, but also why it happened (Köhler, 2009; Rooney and Vanden Heuvel, 2004). However, searching for the true root causes is not trivial and it is not enough to just think about the problem and to identify simple cause-effect chains, because often a high number of interrelations that build a complex cause-effect network are behind the whole problem (Andersen and Fagerhaug, 2006; Conrat, 1997). Methods and tools for systematic CA support the identification of underlying root causes (Aßmann, 2000; Andersen and Fagerhaug, 2006). There is only little EC-specific methodological support for CA in literature. ECM literature rather just refers to general methods to analyze causes such as Fault Tree Analysis, 5-whys, Fishbone-/Ishikawa-diagram or Kepner/Tregoe-Technique (Köhler, 2009). However, Conrat (1997) and Gerst and Stetter (1998) introduce a detailed description of cause analysis for ECs. Their procedures are presented in the following, before also a procedure from general cause analysis literature and an error diagnosis procedure is presented.

4.1.1 Cause analysis by Conrat

Conrat (1997) suggests to conduct a cause analysis in order to examine whether an EC is avoidable or not. If the change is reckoned as avoidable, the identification of the change cause(s) gives indications for potential improvements that aim to avoid similar changes in future.

His cause analysis for engineering changes is structured in three steps:

Definition of the exact target deviation

Identification of the process which is responsible for the target deviation

Systematic identification of potential improvements

In the first step, the target deviation that triggered the change is investigated. There are three different types of target deviations: 'Modified nominal state', 'deficient nominal state' or 'deficient actual state'. Then, the responsible sub-process is identified in the next step by investigating gradually in which project phase, in which area of responsibility and in which subtask the deviation was either determined or audited insufficiently. When the responsible sub-process is identified, improvements can be derived by looking for 'misfits' between critical tasks in the process and allocated resources on the one hand, and for factors that influenced the emergence of the target deviation on the other hand.

4.1.2 Problem and cause analysis by Gerst and Stetter

Gerst and Stetter (1998) see the cause analysis as part of the task clarification, i.e. the definition of the technical cause or problem as the exact deviation between nominal state and actual state of the product. Still, additionally to the identification of the technical cause, also human-related causes that led to the emergence of the target deviation can be identified with the following procedure:

1. Problem description:
    a. Problem gathering: Collection of all relevant information to clarify the situation
    b. Problem description: Detailed description of the problem
    c. Cause analysis: Information processing and structuring
2. Collection of potential causes: Identification of causes that could have led to the problem
3. Cause selection: Identification of the true cause

The first step considers the whole problem situation in order to identify which actual state differs from which nominal state. Questionnaires and Checklists support the collection of all relevant information and the Kepner/Tregoe-Technique helps to describe the problem situation in detail. Then, the information gets processed and structured by identifying causal correlations with a Fault Tree Analysis or by depicting a cause-effect network. The second step looks at potential causes that lie behind the emergence of the problem situation with the use of methods like Brainstorming, Ishikawa-diagram, or 5-why. Also the previously elaborated Is-/Is-Not comparison as part of the Kepner/Tregoe-Technique, already existing Failure Mode and Effects Analyses (FMEAs) or experiments (Design of Experiments, DoE) indicate potential causes. This collection of potential causes not only aims to technical causes but also to human-related causes. In the last step, the true underlying cause has to be identified among the potential causes. Useful methods besides logical thinking are Is-/Is-Not comparison, Scenario Analysis (If this is the cause, then…) or experiments (eliminate the cause and monitor effects).

4.1.3 Root cause analysis by Rooney and Vanden Heuvel

In order to get to know more about analysis procedures and methods, general cause analysis literature is consulted. The analysis of causalities behind a problem or situation is mostly referred to by 'root cause analysis (RCA)'. Starting point for the analysis is usually an undesirable situation or event. Rooney and Vanden Heuvel (2004), for example, present a RCA in four steps:

1. Data collection: generate complete information and understanding of the event
2. Causal factor charting: organize and analyze the information gathered in a structured chart, identify gaps and deficiencies in knowledge and identify causal factors
3. Root cause identification: identify the underlying root cause(s) for each causal factor
4. Recommendation generation and implementation: generate achievable recommendations for preventing the recurrence of root causes

After collecting, structuring and complementing all information about the problem situation in a so called causal factor chart, critical bits are identified as 'causal factors'. Starting with each causal factor, underlying root causes are recognized with the help of a root cause map, which provides a checklist with typical and different types of root causes. Rooney and Vanden Heuvel (2004) also provide generic recommendations for each root cause.

4.1.4 Error diagnosis by Sutcliffe and Rugg

In the end, every cause can be led back to human failure (Gerst and Stetter, 1998). Hence, a strongly connected topic with cause analysis is error diagnosis from a psychological point of view. Sutcliffe and Rugg (1998) provide a comprehensive work about the emergence of human errors. The emergence of human errors can be diagnosed by the following procedure:

1. Failure observation
2. Understanding the causality of the failure
3. Look at cognitive levels

The first step results in a substantial understanding of the failure and the second step directly looks at human-related causalities such as distraction or mental overload. The investigation of the problem on a cognitive level in the third step indicates improvements from an organizational point of view.

4.1.5 Discussion of procedures and methods for cause analysis found in literature

There are different purposes of cause analysis described in literature. While Conrat (1997) aims to identify deficiencies in process execution, Gerst and Stetter (1998) and Aßmann (2000) focus on the technical problem. Yet at the same time, also human-related causes (Gerst and Stetter, 1998) respectively organizational deficiencies (Aßmann, 2000) are identified. This happens on the one hand as a secondary result (outcome of sub-steps); on the other hand the procedures presented enable to focus the analysis on these deficiencies in the design process.

Literature provides several methods that fulfill different purposes needed in a CA. With respect to the presented procedures and sighted literature, the methods can be classified as follows:

- Creative methods: Acquisition of information and identification of potential causes
- Analytical methods: Analysis of causalities, systematic investigation
- Integrated methods: Combination of acquisition, analysis and visualization

Table 3 shows an overview of all the methods that are mentioned as methods for cause analysis in investigated literature.

Table 3. Overview of methods for cause analysis assigned to the respective references.

Class	Method	References
Creative methods	Thought and discussion	(Gerst and Stetter, 1998)
	Calculation and simulation	(Gerst and Stetter, 1998; Stelzer, 1994)
	Experiment	(Gerst and Stetter, 1998)
	Surveys, Questionnaire	(Aßmann, 2000; Gerst and Stetter, 1998)
	Checklists	(Aßmann, 2000; Gerst and Stetter, 1998)
	Brainstorming	(Gerst and Stetter, 1998)
	Gallery method	(Gerst and Stetter, 1998)
	6-3-5 method	(Gerst and Stetter, 1998)
Analytical methods	Logical thinking	(Gerst and Stetter, 1998)
	5 whys	(Gerst and Stetter, 1998; Köhler, 2009)
	W-questions (what, where, when, who, why , how)	(Kepner and Tregoe, 1992; Sutcliffe and Rugg, 1998)
	Is-/Is-Not comparison	(Gerst and Stetter, 1998; Kepner and Tregoe, 1992; Köhler, 2009)
	Scenario analysis	(Gerst and Stetter, 1998; Stelzer, 1994)
	Root cause map	(Rooney and Vanden Heuvel, 2004)
Integrated methods	Cause-effect network	(Gerst and Stetter, 1998)
	Causal factor charting	(Rooney and Vanden Heuvel, 2004)
	Fishbone-/Ishikawa diagram	(Gerst and Stetter, 1998; Köhler, 2009)
	Fault Tree Analysis	(Gerst and Stetter, 1998; Köhler, 2009)
	Kepner/Tregoe-Technique	(Gerst and Stetter, 1998; Kepner and Tregoe, 1992; Köhler, 2009)

4.2 Cause analysis in industrial practice

4.2.1 Summary of examples collected in the workshop

In the following, the examples for cause analysis of our industry partners are summarized:

1. When testing the pilot lot, an electrical component failed. The technical cause had to be identified in order to resolve the problem.
2. Shortly before the end of the development project a review was done in order to derive lessons learned (i.e. measures to avoid engineering changes in future projects).
3. When testing the pilot lot a user interface component failed. The technical cause had to be identified in order to resolve the problem. As a consequence derived from the failure, functions will be tested before producing the pilot lot in future.
4. A new requirement came up after the design phase had already started. The cause analysis investigated why the requirement was not part of the requirement specification from the beginning.
5. When the design phase had already been finished, a collision of two components was recognized. The cause analysis investigated why it was not adhered to the available installation space. As a consequence derived from the design failure, the high degree of freedom in the used IT-tool was reduced and a procedure for the approval of an engineering change request was introduced.
6. A component of a series product was cost optimized. The testing of the prototype showed that the geometry was not rigid enough, so the optimization was reversed. Cause analysis showed that the simulation already indicated the failure but it was still decided to stick to the optimization. Additionally, the same optimization had already been done and rejected in the past. Consequently, for every part there was defined one responsible engineer as a specialist for the part's history.

4.2.2 Point in time, purpose and outcome of cause analyses

The examples for cause analysis of our industry partners show that CA is conducted in various situations during the product development process and can have different purposes, which is why also the outcome of the analyses is different. Table 4 shows the results of the investigation of the examples.

The classifications by point in time, purpose and outcome are assigned to the respective index of the examples listed in Section 4.2.1.
In two cases, the purpose of the CA was to analyze the observed problem towards its technical cause. However, in one of these cases the CA also resulted in a measure for an organizational improvement that aims to front-load the identification of a comparable target deviation in future. In the other four cases the main purpose of the analysis can be summarized as the identification of processes that are responsible for the target deviation. Subsequently, measures for process-related respectively organizational improvements were derived.
During the discussion of terms and definitions around the causality of engineering changes in the workshop, another purpose of cause analysis was mentioned by the workshop participants: If there is an engineering change request, our industry partners also speak about CA when they investigate the necessity or reason for the change. The analysis aims to question the reason for the initiation of the change in order to support the decision whether to implement the change or not.

Table 4. Classification of cause analysis examples provided by our industry partners.

#	Point in time	Purpose	Outcome
1	Testing (pilot lot)	Identify technical problem	Technical problem resolved
2	End of development project	Identify potential for organizational improvements	List of measures for organizational improvements
3	Testing (pilot lot)	Identify technical problem	Technical problem resolved; Measure for organizational improvement
4	Design phase	Identify why requirement was not part of the requirement specification	Standardized requirement specifications for every product sector
5	After design freeze	Identify why installation space was not abode	Responsible process and design engineer identified; Two measures for organizational improvements
6	Testing (physical prototype)	Identify why an inappropriate optimization was implemented	Responsible process and design engineer identified; Measure for organizational improvement

In summary, three different types of cause analysis can be distinguished:

- Technical cause analysis: Identification of the technical cause (i.e. the definite target deviation) in order to resolve the problem.
- Organizational cause analysis: Identification of organizational misfits that led to the target deviation in order to derive measures for organizational improvements. The improvements shall prevent the emergence or anticipate the identification of comparable target deviations in future projects.
- Analysis of the reason: Analyzing the source of the engineering change request in order to assess the necessity for the change.

4.2.3 Procedures and used methods

The CA procedure steps of every example indicated by the workshop participants are listed in Table 5. Example #2 has to be considered separately since it is the only example where the cause analysis was conducted retrospectively at the end of the development project (cf. Table 4). In order to reduce the analysis effort, change cases have to be prioritized. With the help of a template and by ‘bringing together the right people’ (workshop participant), the underlying causes for every particular example are worked out and lessons learned are derived in a structured discussion. The template provides a structure only by the headlines ‘time course of events regarding the EC’, ‘effects of the EC’, ‘causes of the EC’ and ‘learnings’ which are addressed in the discussion.
The other examples address the step of the cause analysis itself in more detail. Besides example #1, where the buildup of a team is explicitly mentioned in a first step, the examples start with the acquisition of relevant information. In the examples #1, #3, #5 and #6, correlations between particular

bits of information (e.g. product functions, product structure, processes) get detected and further cause-effect chains are investigated afterwards. In the end, measures for the found causes are derived.

Table 5. Cause analysis procedure steps and used methods mentioned by our industry partners assigned to the index of the respective example (cf.Section 4.2.1).

#	**Procedure steps *(used methods)***
1	1. Build a team for the analysis *(Stakeholder analysis)* Define problem (what, where, when, ...) *(Workshops)* Establish test profile to reproduce the problem Determine cause-effect chain *(Fault Tree Analysis)* Build hypotheses for technical causes Prioritize hypotheses *(Expert estimation)* Test hypotheses *(Design of Experiments)* For verified hypothesis: Implement solution
2	1. Create collection of change cases 2. Filter/Prioritize change cases 3. Identify causes for the changes 4. Derive lessons learned *(Structured discussion using templates in all steps)*
3	1. Identify fault *(Brainstorming, FMEA)* 2. Analyze functions *(Functional analysis)* 3. Instruct designers *(Questionnaire, 6-3-5 method, Catalog of tasks)*
4	1. Retrieve examples for requirements specifications (RSs) *(Brainstorming)* 2. Analyze RSs and conduct interviews regarding contents and file format *(Questionnaires, Interviews)* 3. Line up RSs with literature statements *(Literature benchmark)* 4. Derive deficiencies *(Is-/Is-Not comparison)* 5. Derive measures for improvements *(Best practices benchmark)*
5	1. Analyze and acquire information regarding geometry and installation space *(Brainstorming)* 2. Analyze installation space *(Virtual installation space analysis)* 3. Check information flow *(Fault Tree Analysis)* 4. Coordinate part design with the help of an installation space team
6	1. Acquire information *(Brainstorming, simulation)* 2. Evaluate and verify information *(Design of Experiments, Fishbone-diagram)* 3. Conduct cause-effect analysis *(5-why method)* 4. Derive measures

4.3 Comparison of cause analysis in literature and in industrial practice and discussion of implications

Cause analysis procedures described in literature aim to investigate the underlying technical causes and deficiencies in the design process as organizational causes. These purposes are also pursued by industrial CA. The additionally mentioned reason analysis in industry is not directly addressed in literature. Only Aßmann (2000), who does not differentiate the terms ‘cause’ and ‘reason’ explicitly, suggests to do cause analysis in order to classify a change also by its reason.

When these analyses play a role within the design process is not differentiated in literature. In all sighted references the recognition of a target deviation is taken as a starting point for CA. The analysis procedures in most of our industry examples are also conducted right after the recognition of the target deviation before the change is implemented. But one example describes CA in a project review, where prioritized change cases are analyzed towards organizational deficiencies. Summarizing the situations when CA is conducted as described in literature and by our industry partners, three different situations can be distinguished:

- Ad-hoc: When the target deviation is recognized
  - Deficient actual or nominal state
  - Subsequent modified nominal state
- Retrospectively: When the change has already been implemented

If an EC is triggered by a deficient actual or nominal state (e.g. failure of component during testing or error in requirement specification) it is necessary to investigate the technical problem at once (ad-hoc) in order to derive constructive measures. On the contrary, if the nominal state was modified (e.g. a customer changed his mind) there is no technical cause for the problem and only an organizational cause analysis makes sense. In both cases, an analysis of the reason for the change is applicable. The objective of retrospective analyses is to derive organizational measures in order to avoid ECs in future projects. The application of a retrospective cause analysis is not addressed in the investigated literature.

A look at the single procedure steps of CA in literature and in industrial practice reveals a high grade of analogy. All relevant information about the problem is acquired in a first step, before the cause-effect correlations are analyzed. However, the identification of the true root cause among the collected potential causes in the cause-effect network seems to come short in industry. Only example #1 addresses this step. The process for the derivation of measures in a last step is not always (in literature and in industry) seen as part of the cause analysis.

All in all, the methods to support the CA procedures suggested by ECM literature primarily stem from research about problem or cause analysis in general. A high proportion of the methods is actually used in the discussed examples and seems to provide adequate support. Still, there are some companies that do not proceed methodologically for CA but rather just think about the change problem.

5 SUMMARY AND OUTLOOK

The examination of cause analysis literature and industrial practice regarding engineering change management shows that there are three different main purposes:

- **Technical cause analysis**: Identification of the technical problem (exact target deviation)
- **Organizational cause analysis**: Identification of organizational deficiencies
- **Reason analysis**: Identification of the source of the engineering change request and questioning the necessity for the change

The technical cause analysis provides methodological support to generate constructive measures that eliminate the symptoms of the problem, whereas the organizational cause analysis helps to derive measures for organizational improvements which avoid the recurrence of the problem in future. As support for the decision finding, the reason analysis gives an indication whether to implement the requested engineering change or not. The straight distinction of cause analysis purposes is not given in literature although there are fundamental differences in the outcome. Also industry is not aware of the different possible focuses of cause analysis.

Cause analysis in industrial practice is conducted either **ad-hoc** when a target deviation is recognized or **retrospectively** for more than one change case. The retrospective analysis of EC causes is not addressed in literature, although it induces other challenges where methodological support needs to be provided by design research. Since the effort for cause analysis is very high (Gerst and Stetter, 1998), the change examples for deeper analysis have to be prioritized.

Design research needs to provide cause analysis procedures and methods that are matched to the specific purposes and situations appearing in engineering change management practice. Therefore, the classification of purposes and situations presented in this paper has to be verified in further investigations and adapted cause analysis procedures have to be developed.

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