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Communication Approach for the Model-Based Engineering Change Management

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Abstract

Engineering changes play an important role in the product development process. They account for a large proportion of development costs and are often classified as critical. A lack of communication and high system complexity increase the negative effects in engineering change management. The aim of this paper is to support an approach for a targeted communication of change information and the triggering of activities in an agile development environment. The developed approach is presented as an integral part of the model-based methodology "Advanced Engineering Change Impact", implemented using the example of a change case and evaluated through expert interviews.

Keywords: engineering change management; communication concept; model-based systems engineering

1. Introduction

Engineering changes have an important role in the product development process [1]. Engineering changes occur regularly [2] and are often associated with high costs and risks [3]. Typical causes for the occurrence of engineering changes include change propagation, optimization of cost-saving potentials, simplification of the manufacturing process, improvements to the product and careless errors, as well as a lack of communication in the product development process [4]. In particular, avoidable engineering changes are attributed to a lack of communication, misinterpretation or missing information [5]. A study with industry participants also confirms that targeted communication of engineering changes is important in an agile development environment [6]. In systems with high system complexity, engineering changes often lead to high costs [7] and further subsequent changes [8].

Model-based systems engineering is considered a promising approach for dealing with high system complexity [9]. With the help of a central system model, relevant information is captured and made available to various users of the model in needs-based views for analysis and synthesis purposes [10].

However, in order to be able to use model-based approaches for engineering change management, suitable methodologies are required. One methodology that supports the holistic handling of changes is the Advanced Engineering Change Impact Approach - AECIA [6]. This methodology provides support in checking the validity of change requests, in the subsequent analysis of change propagation and change impact and in the consistent communication of change information. While the activities for checking the validity of change requests [11] and analyzing change propagation and change impact are already described in detail and applied in various industrial case studies [12], the activity for communicating change

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information is only initially presented in the context of the overall methodology [6].

The aim of this paper is to present an approach for communicating changes as part of the AECIA methodology and to illustrate this approach using the example of an industrial use case. Finally, an initial evaluation of the extended methodology will be carried out.

2. Field of Action

2.1. Model-Based Systems Engineering

The Model-Based Systems Engineering (MBSE) approach involves the systematic and formalized application of modelling techniques to support activities in the areas of requirements management, design process, analysis and verification and validation processes [13]. In contrast to document-based systems engineering, the model-based approach uses a central system model that links relevant information from the product development process across disciplines and makes it available through needs-based views [10]. The MBSE approach can be applied across all phases of the product creation process. The aim is to encourage a holistic understanding of the system and thereby improve efficiency in the various phases of product engineering [13]. The system model is machine-readable and is represented in an abstract syntax that explicitly supports different MBSE concepts [10].

2.2. Advanced Engineering Change Impact Approach – AECIA

The Advanced Engineering Change Impact Approach (AECIA) is an MBSE-supported methodology for holistic change management [6]. The methodology builds on the activity-based IPEK MBSE methodology [14, 15] and extends it to include the dimension of change management. AECIA includes specific analysis and modeling activities that can be flexibly iterated and executed in any order, as well as an ontology that is used for modeling changes. The central activities of the AECIA framework support checking the validity of change requests, analyzing the impact and propagation of changes and targeted communication of change-relevant information within an agile development environment. While the activities for checking the validity of change requests, the propagation analysis and the impact analysis have already been described in detail, applied to industrial use cases and initially evaluated through expert interviews [11, 12], the procedure for communicating change information is only rudimentarily presented in the context of the overall AECIA methodology and has neither been applied nor evaluated.

AECIA uses different types of change element to model change propagation, which have links both to each other and to the system model, see Fig. 1. A change request defines the starting point of a change propagation. A change request can be linked to any elements of the system model (e.g. logical or functional elements, requirements) via relationships such as change, replace, remove or add. A change issue represents potential problems or knowledge gaps, linked to change requests or alternative solutions by "caused by" relationships, and is associated with affected system elements. An alternative solution proposes answers to problems in change issues, linking to system elements in the same way like change requests, and may cause new change issues.

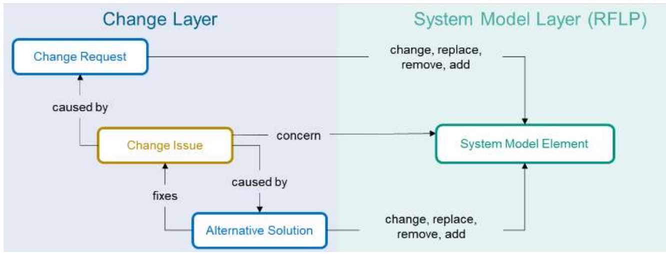

Fig. 1. AECIA element types and relationship types for modeling change propagation [11].

2.3. Model-Based Communication

Communication and transmission of decisions are particularly important because the increasing complexity of development tasks requires strong collaboration among developers [16], [17]. Collected and documented knowledge often needs to be applicable across multiple projects and different organizations. Good documentation promotes communication [18]. Communication is understood as the interrelated behavior of two or more individuals and their interaction with the goal of information transfer and mutual understanding of meanings [19].

Against this backdrop, model-based communication, as an integral part of Model-Based Systems Engineering (MBSE), offers many advantages [13]. It supports the development of complex systems through the use of models instead of traditional document-based methods. This enhances the efficiency and accuracy of system development, enables better traceability, and simplifies integration and communication within projects. MBSE provides various communication opportunities based on models and principles of system development [13]. In addition, a demand-oriented presentation of change information in the form of graphs can help to avoid information overload and thus speed up workflows and decision-making processes [20].

Despite the advantages of MBSE, there is still a lack of concrete approaches in practice to improve communication in development through model-based methods. For instance, a 2021 study found that the multitude of currently used communication channels complicates structured documentation [21]. Another study from 2022, which conducted semi-structured group interviews with experts from various companies, confirmed this problem. A significant deficiency unanimously identified by the respondents is the lack of appropriate tools and methods to systematically document and communicate design decisions [22]. The missing or incomplete communication of design decisions or changes remains a central issue.

3. Research Question and Research Approach

As described in the previous section, targeted communication of information in engineering change management is an important factor for successfully dealing with changes. At the same time, there is a lack of suitable methods for communicating and documenting design decisions. The methodology for model-based change management AECIA presents a holistic approach for managing engineering changes, which also includes activities for communicating changes. However, this activity is not yet explicitly specified and has not yet been applied and evaluated in any real application. In order to close this research gap, the following research questions are answered in this paper:

RQ1: What could an approach for model-based communication of engineering changes look like?

RQ2: How can the developed approach be applied using the example of an engineering change to a commercial dishwasher?

RQ3: What added value is perceived through the application of the approach?

Section 4 addresses the first research question. Therefore, an approach for model-based communication as an integral part of the AECIA methodology is presented and methodically described. Section 5 presents the answer to the second research question. To this end, the approach for model-based communication of change information is applied using the example of an engineering change to a commercial dishwasher from Miele & Cie. Finally, an evaluation of the approach is carried out by Miele experts in the field of systems engineering in section 6, thus answering the third research question.

4. Communication Approach as Part of the AECIA - Methodology

With model-based communication as an integral part of the AECIA methodology, activities for checking validity, propagation and impact analysis can be specifically triggered and controlled in an agile development environment. The trigger item element type is introduced for this purpose. This allows an activity to be recorded and linked to relevant engineering change elements such as change request, change issue or alternative solution. The link between a change element and an element from the system model and the associated stakeholders is used to identify relevant requirements, functions and subsystems as well as the people responsible for them. The trigger items created can be collected in the backlog, prioritized in the next sprint planning and selected for the next sprint. This allows activities to be triggered in a targeted manner and contact persons to be identified. Fig. 2 shows the chain of relevant system elements and the stakeholders responsible for the element using the example of a trigger item that requires the re-evaluation of alternative solution 2 (AS2).

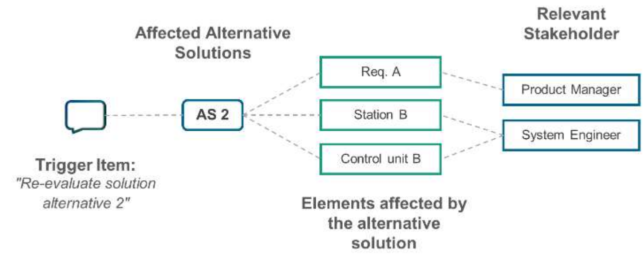

Fig. 2. Exemplary visualization of the chain from a trigger item, the associated alternative solution and the directly affected system model elements and stakeholders

The implementation of the activity for communicating change information can be divided into four sub-activities. This includes activities for analyzing existing trigger items, for creating, changing, removing and linking trigger items and for keeping track of the changes made.

- Analyze existing trigger items to avoid redundant items.
- Create new trigger items, change or remove existing trigger items
- Link trigger items with affected change elements
- Overview of the changed trigger items in order to analyze linked change elements as well as the indirectly linked system model elements and stakeholders

5. Implementation and application of the model-based communication concept using the example of a commercial dishwasher

For the application of the communication approach, the procedure and the developed ontology are implemented in a modeling tool and applied using the example of a commercial dishwasher from Miele & Cie. KG.

A system model of the dishwasher is created as the basis for the case study. Relevant stakeholders, stakeholder needs, the system context of the dishwasher and relevant use cases are identified and modeled. System requirements, functions and subsystems of the dishwasher are then derived and linked.

The four sub-activities for modeling and linking trigger items presented in the last section are mapped in a diagram as a procedure and each sub-activity is linked to a view, e.g. table or matrix, which is intended to support the implementation of the sub-activity, see Fig. 3.

The sub-activities for analyzing existing trigger items and for creating, editing or removing trigger items are performed in a table. All existing trigger items in the model are listed in the first column. The color of a column symbolizes the status of the trigger item and can be changed in the penultimate column. The second column from the left shows change elements that are linked to the trigger item and the third column shows system model elements that are in turn linked to the change elements from the second column.

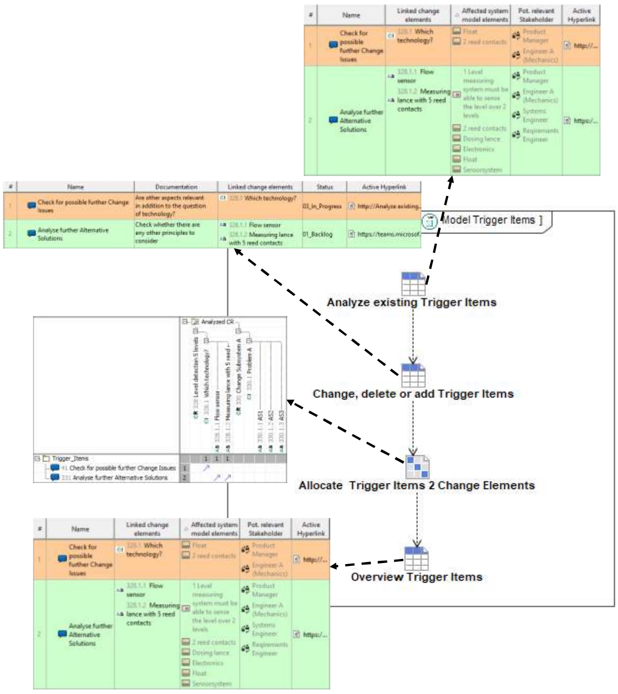

Fig. 3. Subactivities for modeling trigger items for communicating change information implemented in a modeling tool

In the Miele case study, a trigger item is created that requires an analysis of further alternative solutions for measuring the level of detergent in the dishwasher. In Fig. 4. the second column shows alternative solutions that have already been identified and the third column shows the system model elements linked to the alternative solutions, such as requirements and various subsystems. The fourth column lists the stakeholders responsible for the affected system model elements. This allows relevant people to be involved in the prioritization and selection of trigger items for the next sprint. The trigger item for finding further alternative solutions is located in the backlog. This can be changed in the penultimate column using a drop-down menu. The last column contains a link to a task in a project management tool, where other tasks are managed in addition to tasks from the system model.

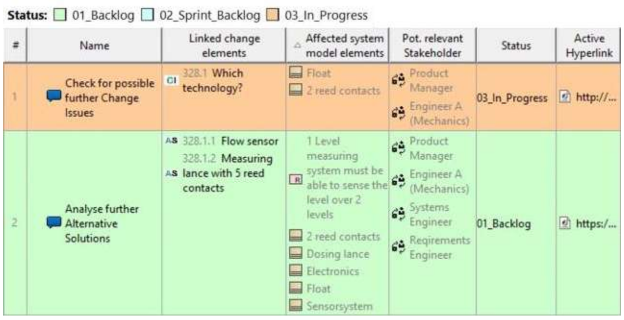

Fig. 4. View (table) for analyzing existing trigger items and for creating, editing and deleting trigger items in the system model

The sub-activity for linking trigger items with change elements such as change request, change issue or alternative solution is supported by a matrix as a view, see Fig. 5. All existing change requests in the model and the associated change issues and alternative solutions are displayed on the horizontal axis. All existing change items in the model are listed on the vertical axis. This allows relevant change elements to be linked directly to a trigger item in the matrix. In the case study considered here, the trigger item for analyzing further alternative solutions was linked to the existing alternative solutions.

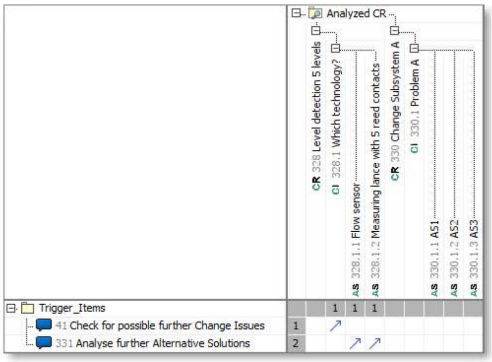

Fig. 5. Matrix implemented in the modeling tool for linking trigger items and change elements

Trigger items can be modeled and managed with the help of the views presented. This allows upcoming tasks in Engineering Change Management to be analyzed, prioritized and selected in a holistic and model-based manner.

6. Evauation of the extended AECIA-Methodology

To evaluate the extended AECIA methodology the case study presented in section 5 was demonstrated to four Miele experts from the areas of PLM, requirements management, MBSE and systems engineering and subsequently evaluated using a semi-structured survey. The experts are not involved in the development of the methodology. Evaluation criteria that can be derived directly from objectives and requirements identified in a previous study [6] are used to evaluate the methodology. The derived evaluation criteria (EC) are summarized in Table 1.

Table 1. Derived Evaluation Criteria (EC) for a Model-Based Engineering Change Management Methodology.

How does the model-based AECIA methodology support...	
EC 1:	the reuse of information from previous product generations?
EC 2:	the assessment of changes with respect to various criteria such as cost, time, quality, development risk, etc.?
EC 3:	the systematic identification of elements potentially affected by changes?
EC 4:	the recording of the change history?
EC 5:	the modeling of problems and knowledge or definition gaps caused by a change?
EC 6:	the agile and iterative execution of analysis and synthesis activities?
EC 7:	the modeling of a change, whether affected model elements should be modified, replaced, removed, or newly added?
EC 8:	the modeling and analysis of change cases without modifying the system model before a change is approved?
EC 9:	the parallel analysis and modeling of multiple cross-domain changes?
EC 10:	the reuse of evaluation criteria from other change cases?

EC 11:	the addition and weighting of evaluation criteria?
EC 12:	the systematic modeling of causes and consequential changes for clear traceability of changes?
EC 13:	the communication of change information in an agile development environment?

The evaluation results in Fig. 6 refer to the derived evaluation criteria in Table 1. This shows the extent to which the AECIA methodology presented, applied to the example of the commercial dishwasher, fulfills the derived evaluation criteria. A Likert scale of 0-3 was used for the evaluation. 0: the methodology does not support at all with regard to an evaluation criterion, 1: the methodology does rather not supported with regard to an evaluation criterion, 2: the methodology supports with regard to an evaluation criterion, 3: the methodology supports very strongly with regard to an evaluation criterion. This scale was chosen to eliminate a neutral response option, encouraging respondents to take a clear stance on the degree of support provided by the methodology.

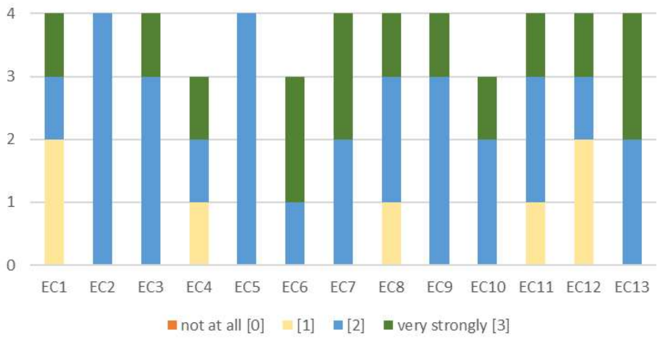

Fig. 6. Results of the survey with regard to the derived evaluation criteria

7. Discussion

The results of the evaluation make it clear that no expert considers the methodology to be completely worthless in the context of Engineering Change Management. In particular, a positive contribution of the methodology is perceived in supporting the communication of change information in agile development environments and in the implementation of agile analysis and synthesis activities. At the same time, the least added value is seen in the areas of reusing information from previous product generations and identifying the causes of change.

However, it should be noted that due to the limited number of participants, the results can only be interpreted as initial indicators of the potential benefits of the methodology. A well-founded evaluation requires further studies with a larger and more diversified sample.

8. Summery and Outlook

Engineering changes play a central role in the product development process, as they account for a significant proportion of development costs and are often considered critical. Poor communication and high system complexity are among the most common causes of engineering changes and can lead to unwanted change propagation and the associated additional costs.

To better manage such challenges in complex systems, model-based methodologies for engineering change management are used. The Advanced Engineering Change Impact Approach (AECIA) is a comprehensive methodology for the holistic handling of changes. This supports the validity check of change requests, the analysis and modeling of change propagation and impact as well as the model-based communication of change information in agile development environments. However, the activities and procedures for communicating changes within the AECIA methodology have not yet been explicitly described or tested in real engineering change cases.

The aim of this paper is to present a procedure and the necessary element and relation types for model-based communication as part of the AECIA methodology. For this purpose, the element type “Trigger Item” is introduced, which can be used to describe change management activities that are to be taken into account when planning the next sprint. System model elements and stakeholders that are relevant for the respective activity can be used to prioritize the trigger items. The proposed communication approach integrates existing change elements of the AECIA methodology and thus forms an integral part of the methodology. With these results, an answer to the first research question was presented.

The developed approach is applied as an example to an industrial dishwasher of the company Miele & Cie. KG using a modeling tool. The results show that the approach can be successfully transferred to real engineering change cases and thus provide an answer to the second research question. A final evaluation by experts from the company provided initial indications of the added value of the approach, particularly with regard to the communication of change information in an agile development environment and the agile implementation of analysis and synthesis activities in change management. This provided an answer to the third research question.

Future work should focus on the greater integration of information from previous product generations and on improving the interfaces to project management tools in order to exploit the full potential of the methodology.

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