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ENHANCEMENT OF AN MBSE-SUPPORTED METHODOLOGY FOR MANAGING ENGINEERING CHANGES USING THE EXAMPLE OF A MACHINE TOOL

***A. Martin*[1]**, *F. Weidinger*[2], *M. Greinert*[3], *S. Wagenmann*[2], *A. Albers*[1]
[1]*IPEK – Institute of Product Engineering at Karlsruhe Institute of Technology (KIT)*
Karlsruhe, Germany
[2]*TRUMPF Machine Tools SE + Co.KG, Ditzingen, Germany*
[3]*Two Pillars GmbH, Paderborn, Germany*

ABSTRACT

Engineering changes are often classified as critical and lead to high costs. The reason for this is the high system complexity. To deal with high complexity, MBSE can be used as an approach. However, in order to be able to operate model-based engineering change management, suitable approaches are required. The Advanced Engineering Change Impact Approach - AECIA presents a holistic methodology for model-based change management by supporting change request validity checking, change propagation and change impact analysis, and change information communication in an agile development environment. In this publication, the methodology is extended to include a procedure for checking the validity of change requests, applied to a real change case using a machine tool as an example, and initially evaluated.

Index Terms – Model-Based Systems Engineering (MBSE), Engineering Change Management

1. INTRODUCTION

Engineering changes are a key part of the product development process [1]. They occur frequently [2] and define 70 to 80 % of the final costs of a product [3]. The high complexity of today's systems is a significant cost driver [4, 5]. Thereby, engineering changes take up about a quarter of the development costs [6]. In addition, the complexity of the system-in-development and the complexity of the organization are also major challenges in engineering change management. [7][8]. Thus, one third of all changes in the company are classified as critical [6].
Model-Based Systems Engineering - MBSE offers an approach for dealing with high system complexity. It supports traceability, consistency and availability of information in the development of highly complex systems. [9]
Existing methods support propagation and impact analysis of engineering changes, but there is a lack of approaches that support early check of the validity of change requests, which is important for engineering change management [10]. The objective of this publication is to present an approach for checking the validity of change requests based on the Advanced Engineering Change Impact Approach - AECIA [10], and to apply and evaluate the AECIA methodology using a machine tool change case as an example. The results of this publication are based on the work in the BMBF-funded project MoSyS. Within the project, human-centered approaches and tools are elaborated to be used for the development of complex socio-technical System of Systems.

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2. STATE OF RESEARCH

2.1 Model-Based Systems Engineering

Model-Based Systems Engineering (MBSE) is a formalized approach for the creation of cross-domain system models which support the product development in all product life cycles in the areas of requirements management, verification and validation as well as analysis and synthesis [11]. In doing so, unconnected, document-based information from product development is to be transferred into a consistent and networked system model [12]. In this way, coping with high system complexity is to be supported and communication between all stakeholders is to be improved [12].

The modeling language, the modeling tool and the modeling method form the three pillars on which MBSE is based. The language defines element types and the relationship types between elements. The method describes the procedure for creating consistent models and is defined by the modeling method. The modeling tool is used to generate the actual system model using the modeling language and the modeling method. [13]

The System Modeling Language (SysML) is often used as the modeling language. SysML extends the Unified Modeling Language (UML) and is able to describe the structure, behavior and requirements of a system with a total of nine diagram types. [12]

2.2 Engineering Change Management

The term Engineering Change (EC) is defined differently in the literature, particularly regarding the scope of the change object and the timeframe within the product development process [14]. According to Langer [15], an engineering change refers to a transformation in product models that have already been released for further development and production. Executing an engineering change involves allocating time and resources to the change process and the associated modifications in product properties.

While an engineering change focuses on altering a system or system model, the term Engineering Change Management (ECM) encompasses all activities involved in planning, managing, and controlling engineering changes throughout the entire product lifecycle, from concept selection to production and service [14].

There is a wide range of methods covering the topic of engineering change management. Clarkson et al. [16] present with the Change Prediction Model an approach for the analysis of change propagation risk. Pasqual and de Weck [17] introduce with the Multilayer Network Model a way to model network-based change propagation on the product and organization level. Albers et al. [18] present an approach for predicting the effort and risk of engineering changes using the example of an automotive harness. They use the model of PGE - Product Generation Engineering [19] to characterize technical changes as variations of reference system elements by using "carryover", "attribute" and "principle" variations. These variations are used to derive a trend in terms of effort and risk. Li et al [20] use a time-based mathematical model to characterize the sequential process of change propagation. They use a motorcycle engine as an example and present an algorithm that determines the shortest path for time-efficient change propagation in engineering tasks. Cheng and Chu [21] use a weighted product network that includes parts, subassemblies, or subsystems to evaluate the impact of changes. They consider three change indices: degree of changeability, range changeability, and intermediate changeability. By evaluating the change impact, critical components of a system can be identified to initiate accelerated and cost-effective development of design solutions

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In addition, there are numerous MBSE-based approaches that support the analysis of risk, change propagation, and impact. Stürmlinger et al. [22] utilize the PGE model to analyze the impact and risks associated with potential changes in a product production system. They model dependencies between product function, features, and the associated production system in a SysML model, investigating change propagation and new development shares. The objective is to support decision-making in integrated product and production system design based on risks, change propagation, and new development shares. Meissner et al. [23] propose an approach that leverages Model-Based Systems Engineering (MBSE) at the parameter level to support engineering change management. They estimate the impact of engineering changes by establishing connections between system parameters and domain-specific models, focusing on a material change in the A-pillar of a vehicle. Additionally, they suggest the possibility of supporting semi-automatic change execution to reduce execution time. Wilms et al. [24] introduce an approach for creating ECM product models using MBSE, along with a process for describing the creation of ECM product models in different ECM process phases. Wang et al. [25] present a scenario-based process for consistently modifying elements in a SysML model, utilizing the views of function, structure, and requirements for propagation analysis.

The Advanced Engineering Change Impact Approach - AECIA, which was developed in the research project MoSyS, represents an MBSE-supported methodology for holistic change management in contrast to the previously mentioned approaches.
The structure of the approach builds on the activity-based IPEK MBSE framework [26] and extends it to include the level of engineering change management. AECIA includes specific analysis and modeling activities that can be flexibly iterated and performed in any order. As illustrated in Figure 1, the main activities presented in the AECIA framework support change request validity checking, propagation and impact analysis of changes, and targeted communication of change-related information in an agile development environment.

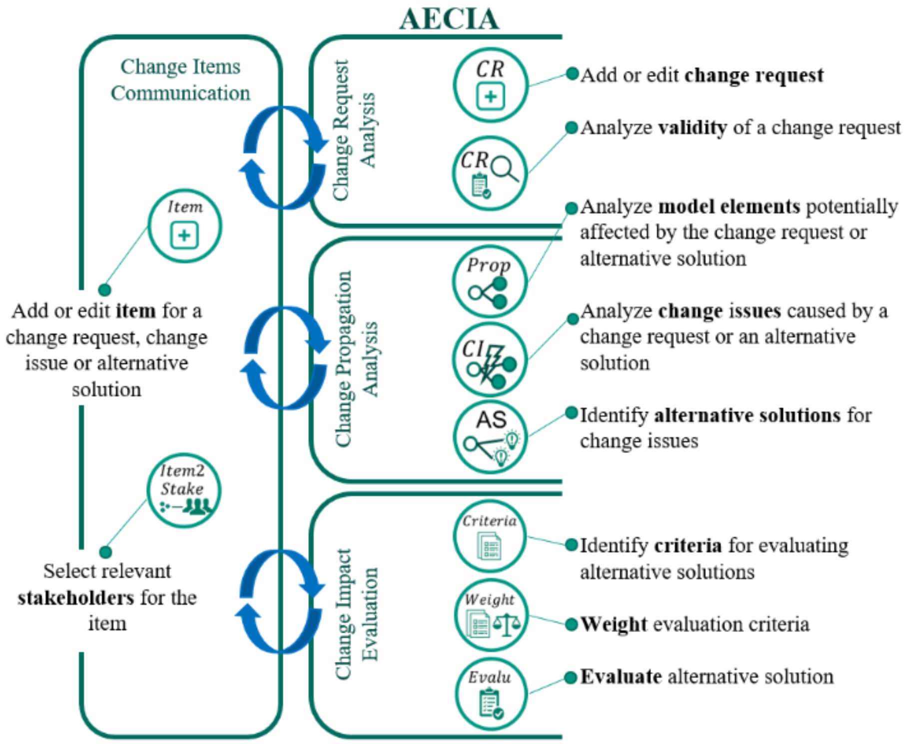

Figure 1: Advance Engineering Change Impact Approach Framework [10]

Considering that technical change cases can also be considered as problems, the above main activities are based on the SPALTEN problem solving process [10]. The SPALTEN

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methodology is a universal approach to problem solving that consists of the steps of situation analysis, problem isolation, search for alternative solutions, pre-selection of solutions, scope analysis, decision making, and recapitulation and learning [27].
The element types change request, change issue and alternative solution are used for modeling and analyzing change propagation, see Figure 2. With the change request element type, the initial change request is modeled and linked with the relationship types changes, replaces, removes or creates to one or more system model elements, such as logical element, functional element, requirement, etc. The change issue element type is used to model potential problems, knowledge gaps, or definition gaps. A change issue can result from one or more change requests or alternative solutions and is linked to them by a "caused by" relationship. In addition, a change issue is associated with one or more system elements that are affected by the specific change issue. The element type alternative solution describes a possible answer to the problem described in the change issue. An alternative solution is linked to the affected system model elements just like a change request, but can also cause new change issues. [10]

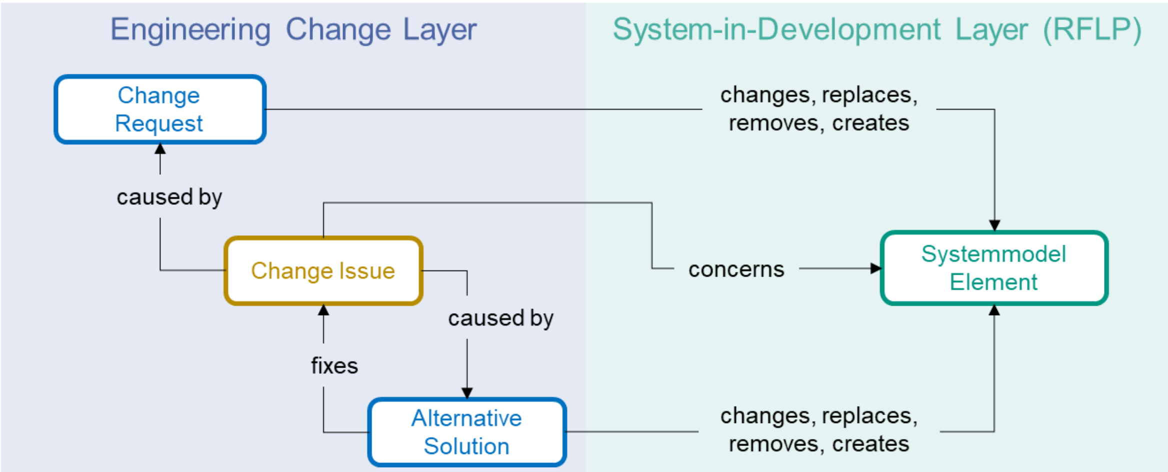

Figure 2: Element types and relationship types for implementing change propagation, based on [10]

Although the model-based methodology AECIA - Advanced Engineering Change Impact Approach shows a holistic approach for dealing with engineering changes, no explicit procedure is presented, especially for the main activity to check the validity of change requests. Furthermore, the approach is neither implemented in a modeling tool nor applied and evaluated on a real change case. In conclusion, the initially identified requirements for the methodology have not been evaluated for relevance in development practice.

3. RESEARCH DESIGN

3.1 Research Questions

To address the research gaps identified in the previous section, the following research question will be answered:

1. What are the relevant requirements in model-based engineering change management in the development of machine tools?

2. How can a methodical procedure model for checking validity look like that addresses the previously identified requirements and can be integrated into the AECIA methodology?

3. How can the evolved AECIA methodology be implemented in an MBSE tool to support the analysis of a machine tool change case?

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4. How does the evolved AECIA methodology improve the management of engineering changes?

3.2 Research Approach

In order to answer the stated research questions, a prioritization and extension of objectives and requirements for a model-based methodology for engineering change management in the development environment of a machine tool manufacturer is presented in Section 4. Then, in the next section, we present a methodological approach for checking the validity of change requests and its integration into the AECIA methodology. In the next step, we demonstrate the implementation of the enhanced AECIA methodology as well as the application of the methodology to a change case using the example of a TRUMPF SE + Co. KG machine tool in the modeling tool iQUAVIS. Finally, the implemented methodology is initially evaluated in order to get a first impression of the added value of the methodology.
The BMBF-funded research project MoSyS and the product development environment of the machine tool manufacturer TRUMPF SE + Co. KG serve as the research environment.

The research project MoSyS-Human-Oriented Design of Complex Systems of Systems involves 18 project partners from research and industry pursuing the objective of providing targeted support for the development of highly complex socio-technical systems and thus helping to shape the engineering work of tomorrow. In the project, human-oriented methods, aids and IT tools are being developed for an innovative Advanced Systems Engineering. A partner in the MoSyS project is the internationally operating high-tech company TRUMPF SE + Co KG. The company is world market and technology leader for machine tools and laser applications in industrial manufacturing. As a high-tech company in a pioneering position, TRUMPF works on topics including smart factory, digitalization, artificial intelligence and Industry 4.0. The product portfolio is based on individual product lines derived from the various technologies: Laser, punching and bending applications. In addition, TRUMPF offers automation solutions with different degrees of automation for various types of machine tools.

4. EVALUATION OF OBJECTIVES AND REQUIREMENTS

4.1 Survey structure

First, we prioritize and supplement relevant objectives and requirements for a model-based methodology. For this purpose, we draw on requirements that have been identified in the MoSyS project and already published [10]. Referring to this basis, objectives and requirements for further prioritization and supplementation are listed in Table 1.

To carry out the prioritization and supplementation of the objectives and requirements listed in Table 1, semi-structural surveys are conducted employees from TRUMPF SE + Co. KG Development. The survey participants are not actively involved in the development of the methodology.

The survey asks for the job title, work experience in the current job, and previous knowledge in the areas of Model-Based Systems Engineering and Engineering Change Management of the participants.
Subsequently, participants rate the relevance of the objectives and requirements for a model-based methodology in Engineering Change Management listed in table 1. Four Likert scale responses are possible, ranging from [1] = "the requirement is not relevant for a model-based

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methodology in engineering change management" to [4] =" the requirement is very relevant for a model-based methodology in engineering change management".
In addition, participants of the survey have the possibility to add further objectives and requirements in a text field.

Table 1: Requirements for a model-based engineering change management methodology according to [10]

	The model-based change management methodology should...
Requirement 1	support parallel analysis and modeling of multiple cross-functional changes.
Requirement 2	support in the evaluation of changes with respect to various criteria, such as cost, time, quality, development risk, etc.
Requirement 3	assist in systematically modeling causes and consequence changes for clear change traceability.
Requirement 4	support in identifying stakeholders relevant to the change case.
Requirement 5	support a systematic identification of elements potentially affected by changes.
Requirement 6	support the reuse of information from previous product generations.
Requirement 7	assist in modeling a change to determine whether affected model elements will be modified, replaced, removed, or added.
Requirement 8	support modeling and analysis of change cases without changing the system model (before a change is released).
Requirement 9	support the recording of change history
Requirement 10	assist in the reuse of evaluation criteria from other change cases.
Requirement 11	support the addition and weighting of evaluation criteria.
Requirement 12	support agile and iterative execution of analysis and synthesis activities.
Requirement 13	support the communication of change information in an agile development environment.
Requirement 14	support in modeling issues and knowledge or definition gaps caused by a change.
Requirement 15	assist in checking the validity of the change request.

4.2 Survey results

A total of 17 people participated in the survey. Participants indicated various job titles, including architect, domain architect, mechanical architect, development engineer, development designer, design manager, project manager, process/application consultant (PLM/SAP), systems engineer/SW developer, and systems engineer. Eight persons reported working in their current job between 1 and 5 years, five persons have 5 to 10 years of work experience, and four persons have more than 10 years of work experience.
In terms of knowledge of Model-Based Systems Engineering (MBSE), eight people reported having no prior knowledge, three people have little prior knowledge, five people have good prior knowledge, and one person has expert knowledge of MBSE.
In Engineering Change Management (ECM), two people indicated having no prior knowledge, five people have low prior knowledge, eight people have good prior knowledge, and two people have expert knowledge in ECM.

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Figure 3 consolidates all responses to the evaluation of the relevance of the requirements from Table 1 and sorts them according to the average evaluation from left to right.

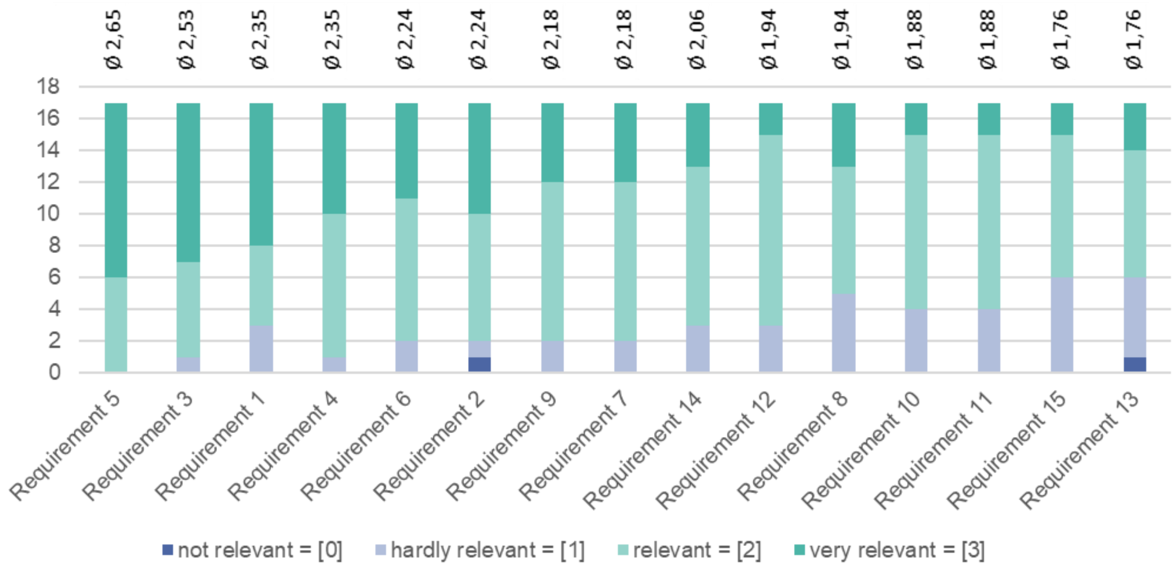

Figure 3: Resposes sorted in descending order to assess the relevance of requirements for a model-based methodology in ECM

The survey responses show that requirements 5 and 3 in particular are rated as especially relevant. Thus, support in the systematic identification of potentially affected elements as well as in the systematic modeling of causes and subsequent changes for transparent change tracking is considered relevant by most participants.

On average, no objective or requirement is rated as barely relevant or not relevant, which allows us to assume that the listed requirements are considered relevant for most participants.

In addition to the rating, some participants add the following aspects to the list of objectives and requirements:

- Enable connection of changes along the RFLP chain.
- Intuitive application, easily accessible, understandable, and easy to learn.
- Support for interactions with other sub-processes, such as requirements management, testing, or development process organization.
- Support for reasoning in the selection of alternative solutions.

5. ENHANCEMENT OF THE AECIA METHODOLOGY

The model-based methodology Advanced Engineering Change Impact Approach - AECIA presented in section 2 is used as the foundation for extension to include change request validity checking activities. The goal here is to validate the scope of the change request and thereby find a valid starting point for the further steps, such as the propagation and impact analysis. The steps presented below for checking the validity of a change request are assigned to the activity "analyze validity of a change request" in the activity group "change request analysis", see Figure 1. The procedure for checking the validity of change requests is being developed in several iterations in the MoSyS project. In addition to the relevant activities, the necessary elements, relationships and views are to be derived. The procedure can be divided into two areas: "the why-cone" and "the no-solution-was-forgotten-fork". In "the why-cone", the cause of a change request and the obligation to implement the cause are analyzed. At "the no-solution-was-forgotten-fork ", it is checked whether there are other alternative solutions for the identified

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cause. This ensures that the solution space of a change request is not restricted too much in advance and possible solution alternatives are neglected.

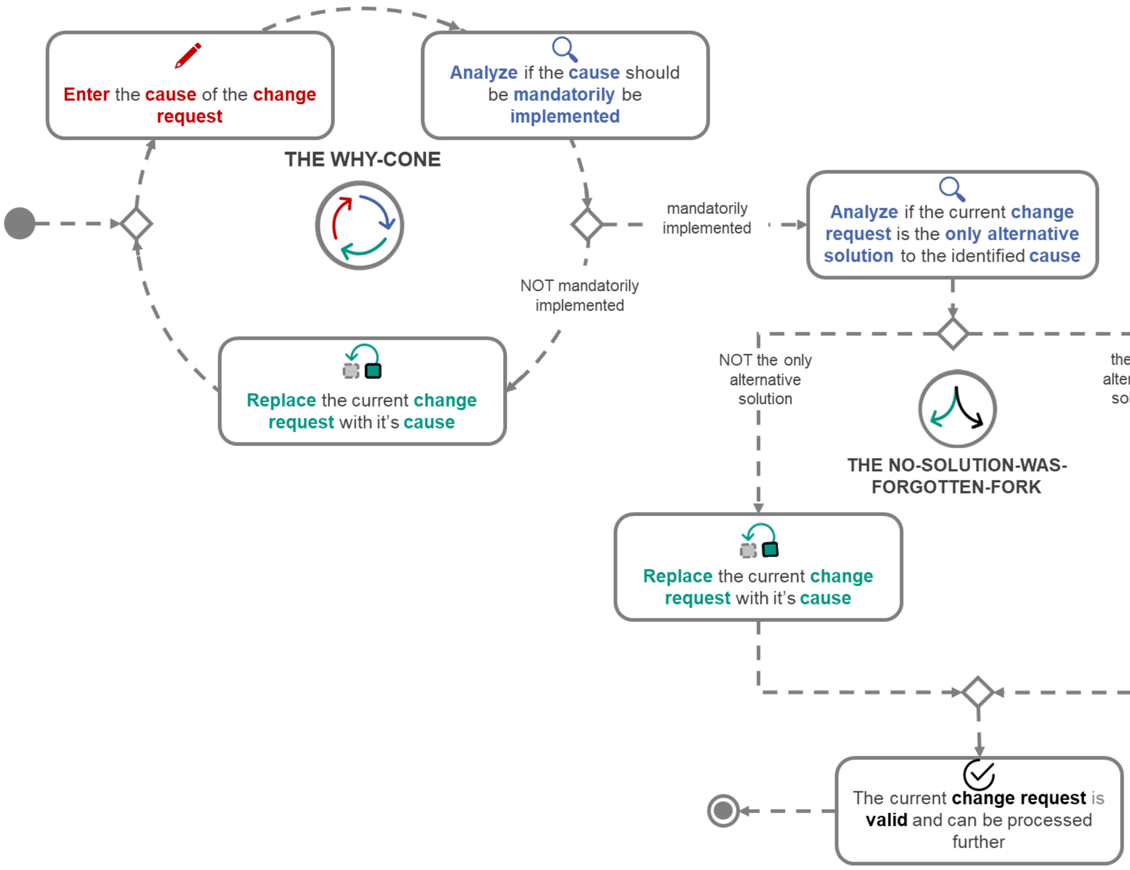

Figure 4: Methodical procedure for checking the validity of change requests

Using a fictitious change request as an example, we apply the procedure shown in Figure 4 with all sub-activities. To do this, we analyze the change request "Increase battery size by X %" for an e-scooter. In the first step, we identify and document the cause of the change request. In this case, the cause is "the increase of the electrical capacity by X Wh". In the second step, we check whether the identified cause should be mandatorily implemented. We find that it is not, so we replace the original change request "increasing the size of the battery" with "increasing the electrical capacity". With that, we have gone through the why-cone once and proceed to identify the cause for the new change request. Now we identify and capture the cause for the change request "increase in electrical capacity". In this case, the cause is "Increase range by X%". Next, we check if the increase in range is mandatory to be implemented. In our fictitious example, this is the case, for example due to a management requirement. With this, we leave the Why-Cone and check with the next activity whether there are other alternative solutions for the current cause "increase in range", apart from "increase of electrical capacity". We answer this question in the yes, because also a weight reduction, an improvement of the efficiency of the powertrain or a reduction of the drag coefficient could lead to an increased range. Thus, in the next step, we replace the current change request "increase in capacity" with its cause "increase in range" and complete the change request validity check. The starting point for further analyses of change propagation and impact is shifted in this fictitious case from the change in battery size to the increase in range. In this way, we ensure that the solution space is not too narrow from the beginning and that alternative solutions are not passed over.

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6. CASE STUDY

6.1 Separation station

In order to apply the AECIA methodology shown in the last section to a real system, the separation station from the product portfolio of the machine tool manufacturer TRUMPF SE + Co. KG is used. It is a subsystem of the loading and unloading unit of the automation solution for punch-laser machines. It is located next to the stack of sheets and ensures that raw sheets that stick together are separated before they are transported by the automation solution to the machine and processed there.

Figure 5: Automation solution for loading and unloading manufactured sheet metal parts with a gripping unit

6.2 System model of the seperation station

For the system modeling of the separation station and the implementation of the enhanced methodology AECIA, the modeling tool iQUAVIS is used. iQUAVIS is an MBSE modeling platform developed by Information Services International-Dentsu (ISID) in Japan. In German-speaking countries, consulting, sales and development are carried out by Two Pillars GmbH.
In contrast to SysML-based modeling tools, iQUAVIS has its own metamodel. This allows the modeling of complex systems but also other aspects like business processes, organizations and data flows. For the representation of requirements, functions, structural elements and tasks (in the following summarized as model elements) iQUAVIS offers the following views:

- Trees: Allow to break down model elements as well as visualize and analyze dependencies between them.
- Worksheets: Allow the representation of model elements in tabular form.
- Matrices: Allow the comparison and linking of model elements.
- Function Block Diagrams: Allow modeling of inputs, outputs, and functional flows for functions, as well as their assignment to structural elements.
- Element block diagrams: Enable the modeling of inputs and outputs for structural elements as well as their relationships to each other, the so-called mechatronic sketch.
- Sequence and state diagrams: Offer further possibilities to specify the system behavior.
- Classic project management views: Flowchart diagrams, Gantt charts, resource allocation diagrams, and process sheets can be created to manage projects.

When creating the system model of the TRUMPF separation station, we modeled different artifacts, see Figure 6. Requirements for assembly as well as associated assembly processes are

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included. In addition, both functional and non-functional requirements for the separation station are created at different system levels. Functions of the system on different abstraction levels as well as logical elements, which represent subsystems of the separation station, are modeled. Functions and logical elements necessary for them are linked in the model. In addition, functional requirements are linked to functions and non-functional requirements are linked to logical elements. This provides us with a basis that is used for the further propagation and impact analysis of engineering changes.

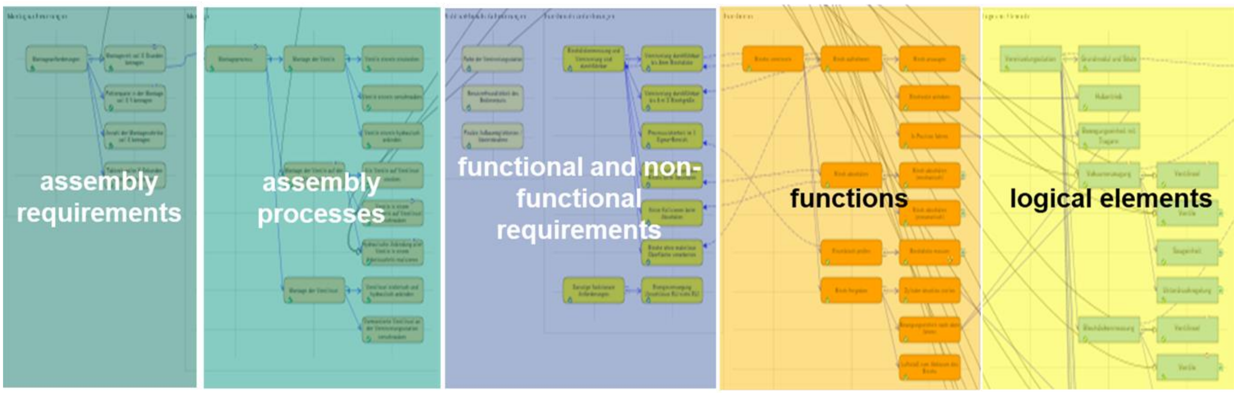

Figure 6: Section of a tree diagram for decomposition and linking of system model elements of the separation station

6.3 Implementierung der weiterentwickelten AECIA-Methodik

For the implementation of the AECIA methodology, the main activities "change request validity check", "change propagation analysis" and "change impact analysis" are used. The main activity for communicating change information is not the subject of this publication and is therefore not implemented. Figure 7 shows the reduced framework with the three main activities on the right.

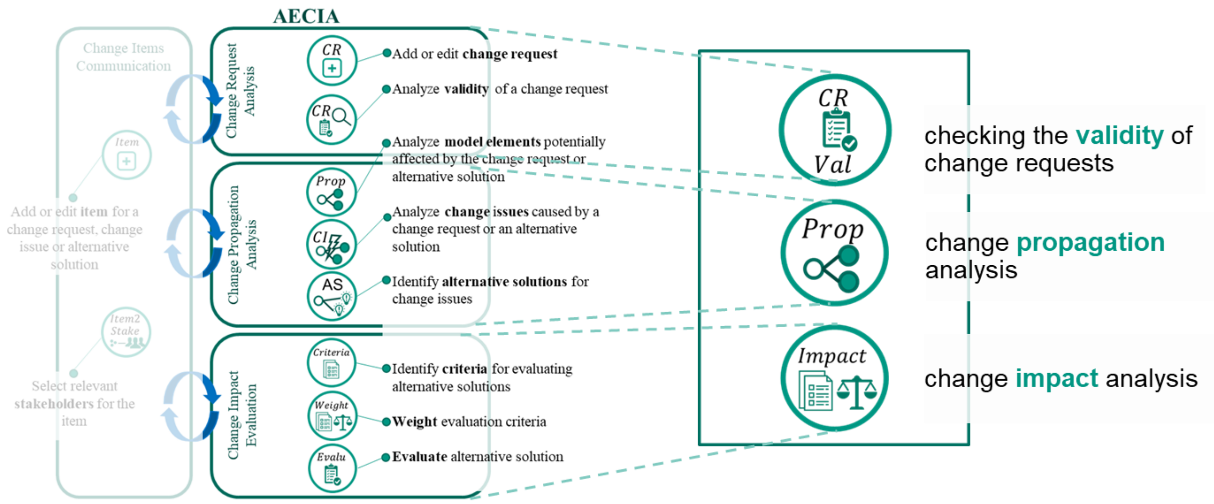

Figure 7: Reduced AECIA framework (right) for the implementation of the case study

Each main activity is linked to a function block diagram in which further sub-activities are located, see Figure 8. Each sub-activity is in turn linked to a diagram that can support the execution of the sub-activity. Both analysis and synthesis activities can be performed. Each sub-activity also has a blue video icon that is linked to a short screencast that explains the respective sub-activity using an example. This allows activities to be learned or refreshed as needed and appropriate to the situation.

In the main activity for checking the validity of change requests, sub-activities are implemented, which are presented in Section 5. In the main activity for change propagation analysis, sub-activities for modeling change issues, alternative solutions, and connection to the system model are implemented following [10]. In the main activity for change impact analysis, sub-activities are implemented following [10] to support the creation and weighting of evaluation criteria as well as the evaluation of individual alternative solutions in terms of the selected evaluation criteria. In addition, variation type and the origin of the reference system based on the model of the SGE [19] as well as the complexity of an alternative solution can be defined in order to evaluate the engineering risk.

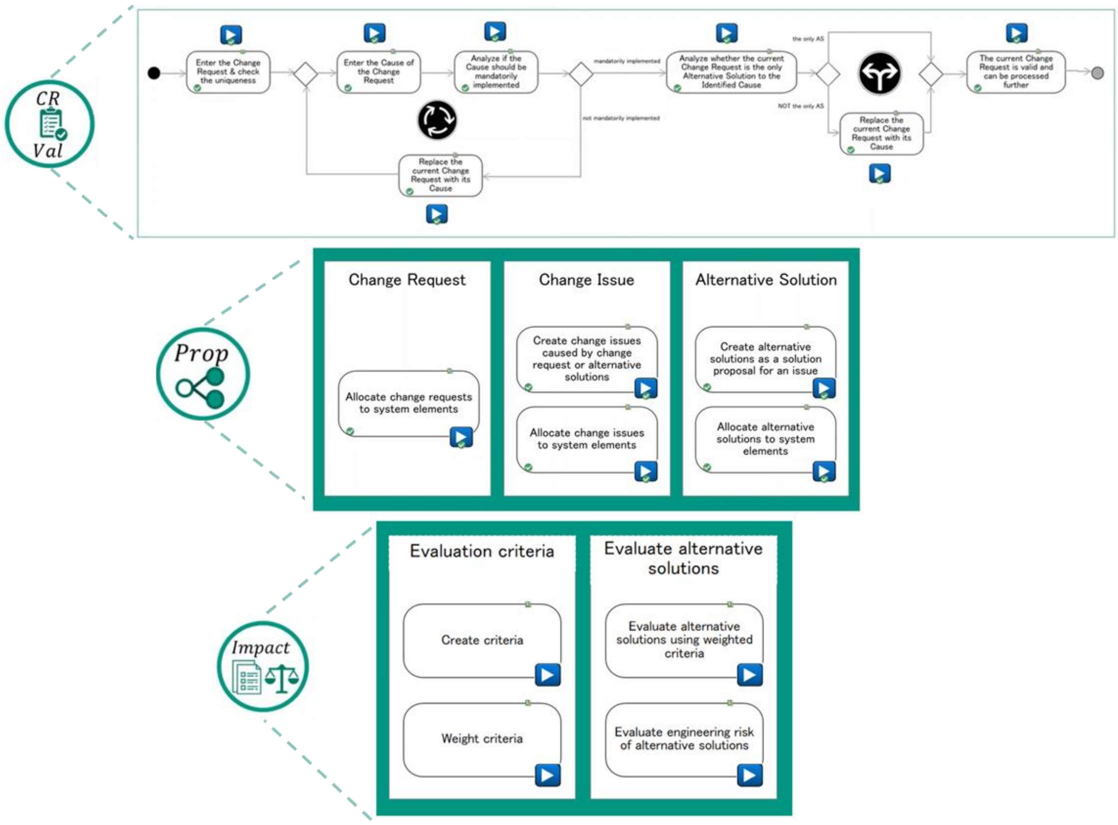

Figure 8: Overview of the implemented main activities and included sub-activities

For this case study, the change request "Reduce the assembly time of the separation station by at least X %" is investigated. First, we analyze the validity of the change request and apply the procedure shown in Figure 9. For this we create the change request as a model element in the tree diagram and analyze its cause: "Increase of productivity". In the next step, we examine whether the cause should be mandatorily implemented, which is the case. With this, we leave the Why gyro and in the next step we investigate whether there are other alternative solutions for the identified cause. The analysis shows that no other alternative solutions are found, confirming the validity of the change request and thus providing the starting point for further propagation and impact analysis. We model the change request, the change cause and their connection in the tree diagram in the engineering change layer, see Figure 9.
In the next step, we examine the propagation of the change request following the procedure in [10]. For this purpose, we link the change request to the affected assembly requirement that demands the maximum duration for the assembly. Then, all system model elements that are related to this assembly requirement are analyzed. This includes all assembly processes that specify the duration of the assembly. Considering this problem space, we model the issue "Which process needs to be optimized to reduce assembly time by X%" and link it to the change request. This shows that the change issue is triggered by the change request. Then, several alternative solutions are identified and modeled. The alternative solutions are linked to both the

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causing change issue and affected elements of the system model. For example, an alternative solution is to optimize the assembly of valves by pre-assembling them on a valve terminal. This alternative solution in turn triggers new change issues, which in turn are solved by alternative solutions. For example, it is necessary to decide which communication standard should be selected for controlling the valves. Change issues and alternative solutions are modeled alternately in a tree diagram, see Figure 9, which shows both the causes of the respective change issues and alternative solutions and the system model elements affected. The system model is not changed in the process and thus the propagation of several changes can be modeled and analyzed in parallel.

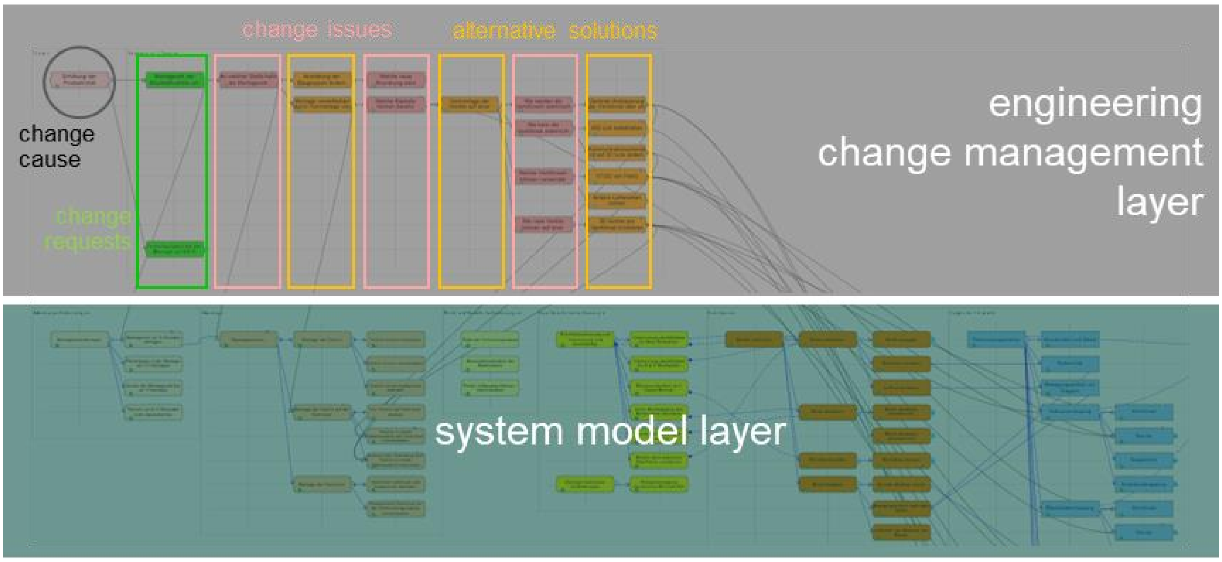

Figure 9: Tree diagram showing change propagation and system elements affected by change requests, change issues, and alternative solutions

After initial change propagation has been performed and initial alternative solutions have been identified, we can analyze the impact following [10]. For this purpose, we use the worksheet in Figure 10 to implement a Pugh Matrix. While the alternative solutions identified in the propagation analysis are automatically arranged horizontally, evaluation criteria can be newly added or reused from previously conducted impact analyses and arranged vertically. In addition, evaluation criteria can be weighted. Next, we evaluate the two alternative solutions that propose the use of different communication standards. In the evaluation, the values from 1="very bad" to 5="very good" can be selected. These are multiplied by the respective weight factor of the evaluation criterion and added up. The higher the value of the overall result, the better the evaluation of an alternative solution with regard to the selected criteria. However, the evaluation only serves as a support for choosing an appropriate solution and does not take away the

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decision. In addition to the criteria-based analysis, an evaluation of the engineering risk, as described in section 6.3, is conducted on a separate worksheet.

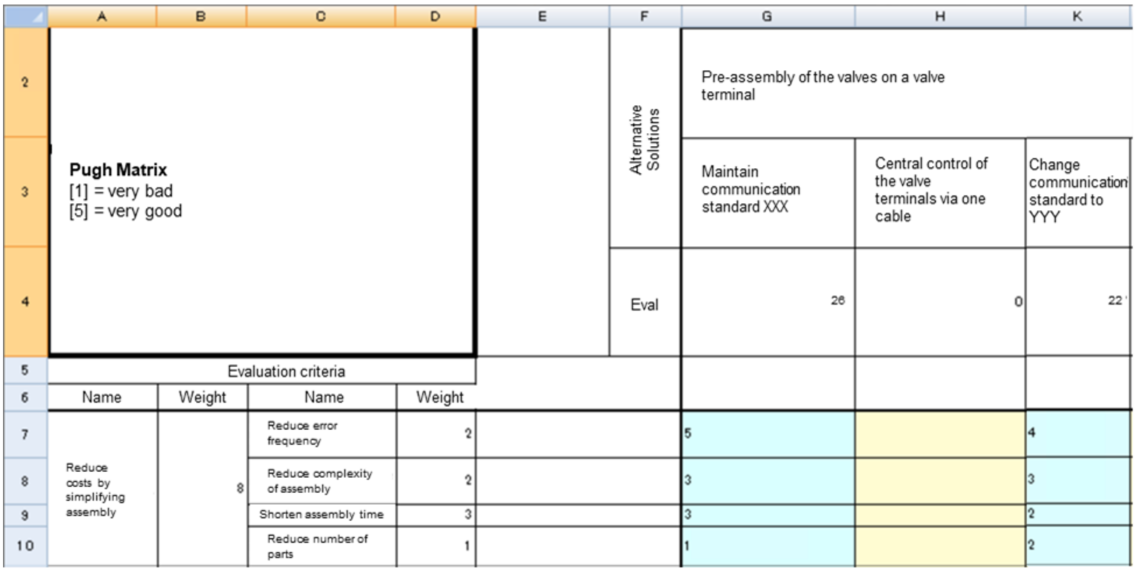

Figure 10: Implemented Pugh matrix to conduct impact analysis

In the case study presented, a change request is analyzed holistically using the example of a separation station by checking the validity of the change request, then modeling the propagation of the change using change issues and alternative solutions, and finally evaluating the impact of the alternative solutions found. The activities shown can be performed any number of times and in any order.

7. EVALUATION OF THE ENHANCED AECIA METHODOLOGY

7.1 Survey structure

In order to identify the first signs that indicate an added value of the enhanced methodology, the case study presented in the last section will be presented to several TRUMPF employees and then evaluated in a semi-structured survey.

The evaluation criteria for the survey are derived based on, the requirements prioritized in section 4 and summarized in Table 2. Since the case study does not consider the main activity for communicating changes, the survey does not list evaluation criteria that relate to this activity.

Table 2: Overview of derived criteria for the evaluation of the AECIA methodology

Evaluation Criteria	**How does model-based methodology support...**
Criterion 1	the reuse of information from previous product generations?
Criterion 2	the evaluation of changes based on various criteria such as cost, time, quality, development risk, etc.?
Criterion 3	the systematic identification of elements potentially affected by changes?
Criterion 4	capturing the change history?
Criterion 5	modeling problems and knowledge or definition gaps caused by a change?
Criterion 6	agile and iterative execution of analysis and synthesis activities?
Criterion 7	modeling a change, determining whether affected model elements should be modified, replaced, removed, or added?

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Criterion 8	modeling and analyzing change cases without modifying the system model (before change approval)?
Criterion 9	parallel analysis and modeling of multiple cross-domain changes?
Criterion 10	the reuse of evaluation criteria from other change cases?
Criterion 11	the addition and weighting of evaluation criteria?
Criterion 12	validating change requests systematically?
Criterion 13	systematic modeling of causes and consequential changes for clear traceability of changes?

Similar to the survey used to prioritize the objectives and requirements for a model-based methodology for engineering change management, this survey asks about job title, work experience, and prior knowledge of MBSE and ECM.
Afterwards, the participants evaluate the presented AECIA methodology using the evaluation criteria listed in Table 2. Here, four answer options can be given according to the Likert scale from [1] = "the methodology does not support at all" to [4] =" the methodology supports very strongly".
In addition, there is the possibility to add additional comments on the evaluation of the methodology in a text field. The participants of the survey are not involved in the development of the AECIA

7.2 Survey results

A total of 5 TRUMPF employees participated in the survey. The following job titles are given: Developer, Doctoral Student, Architect, Development Engineer. One participant has more than 10 years, one between 5-10 years, and the remaining participants between 1-5 years of professional experience in their current profession.
In the area of Model-Based Systems Engineering (MBSE), two participants reported low knowledge and three participants reported good knowledge.
In the area of Engineering Change Managements (ECM), one person indicates having no prior knowledge, three people have low prior knowledge, and one person has good prior knowledge.
According to the participants, the methodology can support especially in the systematic modeling of causes and consequential changes and can thus support in the analysis of change propagation. In addition, support is also perceived in the reuse of evaluation criteria in impact analysis and in the use of information from previous product generations. The least support is noted in the agile execution of analysis and synthesis activities, and in modeling whether a system model element is changed, removed, replaced, or added. For the remaining criteria, such

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as analyzing the validity of a change request, support is perceived. This points to a first indication of added value of the methodology.

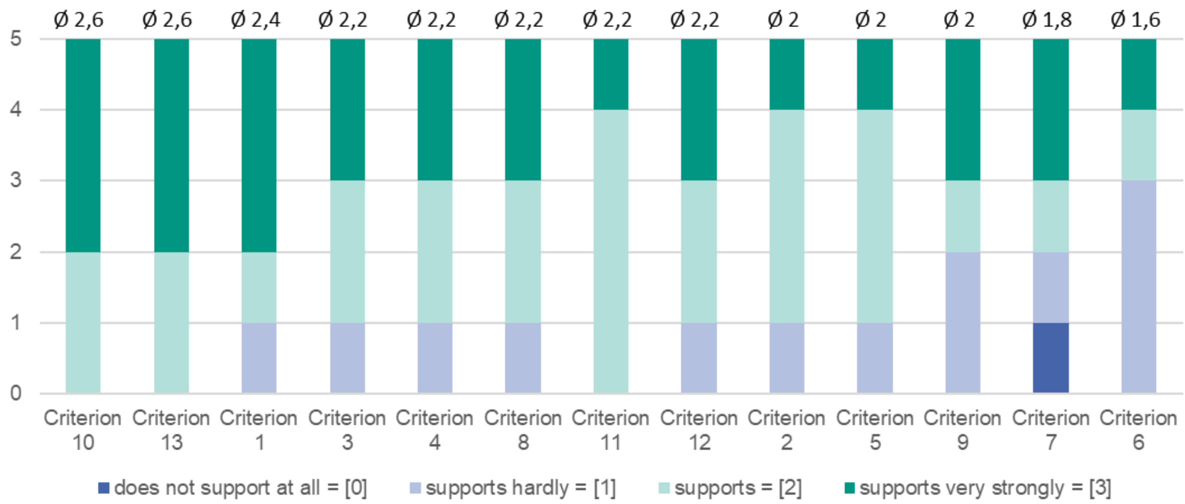

Figure 11: Responses sorted in descending order for the evaluation of the AECIA methodology

8. STATEMT OF CONTRIBUTION AND DISCUSSION

In industrial practice, engineering changes consume significant resources. The increasing complexity of highly networked systems is seen as one of the causes. Model-based systems engineering is seen as a potential approach to managing this complexity.
A model-based approach for a holistic handling of engineering changes is the Advanced Engineering Change Impact Approach - AECIA. However, this methodology has not been implemented on a change case on a real system. Furthermore, the methodology does not describe a detailed procedure for checking the validity of change requests. To address this research gap, this paper prioritizes requirements for a model-based methodology in a survey. Then, a procedural model for testing validity is presented and integrated into the AECIA methodology. In the next step, the enhanced methodology is implemented in a modeling tool and applied to the change case of a machine tool. Finally, an initial evaluation of the further developed methodology is performed.
It could be shown that the identified requirements are relevant in the development environment of a machine tool manufacturer. Furthermore, it was demonstrated how the procedure for checking the validity of change requests can be integrated into the AECIA methodology. In conclusion, an initial evaluation has been able to identify first indications that suggest the added value of the methodology.
However, it must be noted that the results shown were identified in the investigated engineering environment of a machine tool manufacturer and are therefore not generally valid. In addition, the results of the surveys can only be understood as initial impressions, since the number of participants is small.

9. OUTLOOK

The model-based methodology AECIA will be continuously enhanced. In particular, the activities around propagation and impact analysis as well as the communication of change information will be more focused in the future and applied to different industry applications using different modeling tools.

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CONTACTS

A. Martin	email: alex.martin@kit.edu
F. Weidinger	email: felicia.weidinger@trumpf.com
M. Greinert	email: matthias.greinert@two-pillars.de
S. Wagenmann	email: steffen.wagenmann@trumpf.com
Univ.-Prof. Dr.-Ing. Dr. h. c. Albert Albers	email: albert.albers@kit.edu

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