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Improving engineering change management by introducing a standardised description for engineering changes for the automotive wiring harness

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Abstract

Engineering change management is a key part in the development of products that requires a lot of resources and time. A key problem is the lack of a shared ontology to describe engineering changes. This creates problems, additional effort and hinders the digitalisation of the engineering change management. This is especially true for the development of the automotive wiring harness where a low degree of automation together with the occurrence of many changes in a multi-variant system poses a big challenge. A description that is unambiguous, comprehensive and coherent is needed. The research presented in this paper tackles this problem. A standardised description for the engineering change management for the automotive wiring harness is introduced in this publication. The authors outline the approach that has been used to create a systematic description. The validation of the standardised description is based on two approaches: a case study of a development project and an ongoing development project. The validation shows that 94% of all engineering changes can be described in the proposed standardised way. Concepts where the standardised descriptions can be used to improve the engineering change process are outlined at the end of the paper. The paper thereby presents a way that directly improves the engineering change process and the product development process. It enables the further improvement of the engineering change management by providing a basis for an automatic processing, evaluation and implementation of engineering changes.

Keywords: Engineering Change Management, Standardised Engineering Change Description, Automotive Wiring Harness, Product Development

1. Introduction

The successful development of products is made possible by receiving all necessary information. This also applies to the engineering change management, which is an important part of the product development process. However, there is no structured form to describe engineering changes. That leads to mistakes, errors, additional efforts and prevents the digitalisation of methods and workflows that can support engineers. The automotive wiring harness is especially affected by this lack of clarity. It is the nervous system of a car, connects all combinations of electrical and electronic components and supplies them with information and energy. The characteristics of the wiring harness such as high customisability result in high numbers of engineering changes. Engineering changes increase the quality with each development generation but also require more time and effort compared to other systems [1]. Reasons are incomplete or badly worded descriptions that result in poor data quality, rework and problems in following steps [2]. This paper aims at solving this problem. A standardised description for engineering changes of the automotive wiring harness is introduced. It is supplemented by the approach that was taken

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to create it. The standardised change description is validated based on development projects at an OEM. Methods and concepts that improve the engineering change management are outlined. They are based on the standardised description.

2. State of the art

2.1. Engineering Change Management

Products are developed in generations [3]. This also applies to the automotive wiring harness where several engineering generations are created during the development process. Those are embodied by artifacts such as prototypes [4]. Variations of reference system elements that form this process can be described as engineering changes. They are an integral part and main driver of the development process. Engineering changes are defined as: “changes and/or modifications to released structure, behavior, function, or the relations between functions and behavior, or behavior and structure of a technical artefact” [5]. Engineering change management describes the process of dealing with engineering changes, which consists of the emergence, identification, creation of solutions, assessment, implementation and review of engineering changes [6]. The process is supported by systems, tools and defined workflows and connected to other systems [7]. The information are conveyed via documents, drawings, pictures and other data formats. Engineering change management is in constant development following the five principles of less, earlier, effective, efficient and better that aim at improving the engineering change process [8].

2.2. Description Models in Engineering Change Management

A common description enables a shared understanding, helps to communicate and share relevant information. This idea is known as an ontology which is a structured “conceptualizations […] in terms of a set of entities […] and their relationships [that] provide uniform frameworks to identify differences and similarities that would otherwise be obscured” [9]. One publication focuses on the wiring harness. It proposes a data format that should contain classes with attributes with current and target values and is based on past changes. However, the content as well as the approach remain completely generic [10]. Other ontologies and description models from engineering change management focus on structures of systems. They describe the different domains of a system in order to trace and evaluate the spread of engineering changes. Components, attributes, functions, substances and interactions of the structures are used for the description [11]. Other approaches classify engineering changes by relevant general themes such as effects, influencing factors, general properties and objects [12]. Those classifications are also aimed at improving the evaluation of change propagation. The systems that help to process engineering changes also collect data. The information they contain is derived from previous paper based processes [7]. The data contains meta-information of engineering changes and added documents like drawings to provide additional information [13]. However, this information is unstructured and requires effort for a correct interpretation. Communication in written or spoken form can be difficult as well and is a source for errors due to the differences between individuals. Among the differences are the professional and private background, level and type of experience and language skill. That leads to different mental models and a loss of information on technical aspects of engineering changes [14].

2.3. Automotive Wiring Harness

The automotive wiring harness is a central part of the electrical/electronic architecture. It connects all systems and components and ensures the transfer and supply of information and energy. The wiring harness can be described in different levels, which represent different domains and stages in the development process. Those are the functional scope, functional architecture, network architecture and the components [15]. The information from these domains are stored in the wiring diagrams (logic), 3D-Models (geometry) and 2D-Drawings (release relevant) [16]. Additional information regarding the production or assembly can be found in the 2D drawing (see Fig 1). New approaches try to store all information in a 3D-Master model [17].
A lot of engineering changes occur in the development process of the wiring harness [1]. This is due to the flexibility of the wiring harness and the fact that it spans through the whole car. The manual manufacturing process causes long preparation times in production and procurement [18]. Therefore, design freezes are scheduled earlier in the development process than for other components which leads to additional changes when these components are altered. It is also a highly customised system with many variants due to different customer specific features that influence the whole vehicle [16,19,20].

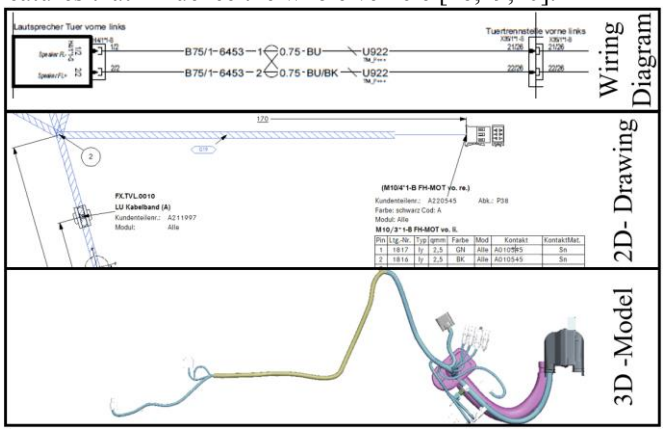

Fig. 1. Domains in the wiring harness development process

3. Need for research

3.1. Problems and Challenges concerning the engineering change management with regards to the wiring harness

Engineering change management currently requires a lot of effort and resources. The development of automotive wiring harnesses is a field where change management is especially challenging and seen as the biggest weakness [1]. Especially the manual effort, discontinuity of data and processes, low degree of digitalization and complexity are seen as problematic

[1,2]. Those problems affect companies along the entire value chain [21]. Research shows that the problems are linked to poor data quality, lack of communication, ambiguous descriptions and bad workflows [2]. This results in bad process continuity and information deficiencies [22]. The lack of digital and machine-readable descriptions is pointed out as a general problem in engineering change management that prevents the improvement and utilization of existing methods [23].

3.2. Research gap and research questions

A standardised description, model or framework for descriptions of engineering changes does not exist based on comprehensive literature reviews and a review focused on the time after [5,6,24]. The lack of a standardised description leads to fragmented shared mental models between engineers and results in a mismatch between available and needed information [14]. Existing descriptions focus either on broad topics [12] or systems that are changed but not on the individual engineering change [11]. The concepts, which propose standardised data models and reference processes, focus on general structures and exchange formats and not on the technical aspect of the change [13]. The data formats used to document the engineering changes range from free-text, excel tables, PowerPoint slides or other attachments to different kinds of PDM software [7]. Those documents are filled based on the engineer's individual experiences, knowledge, preferences and language abilities, which can lead to ambiguous descriptions in texts or drawings [14]. The process in the wiring harness development requires the engineers to fill the systems manually. The importance of a standardised description is highlighted by different members in the industry [21]. Understanding and clearly defining a single engineering change is the foundation for supporting the mentioned activities in the development process. Solving the mentioned problems is the first and most important step to improve engineering change management overall. Especially, when the numbers of changes and time required dealing with changes in the wiring harness environment is considered.

Developing and introducing a standardised description that is readable by people and programs is the solution for the mentioned problems. It would improve the current processes, enable the digitalisation and thereby support the industry. The research questions provide the frame for this publication.

- How does a standardised description of engineering changes for the development of an automotive wiring harness that supports engineers in the development process look like?
- What are the steps that have to be taken to create a structured engineering change description?
- How can the proposed standardised engineering change description be used to improve the engineering change management?

4. Methodology

The research of this publication follows the Design Research Methodology [25]. The main points are the conceptualisation, creation, implementation and validation of the standardised description of engineering changes as well as the initial exploration of possible applications. Figure 2 shows how the research is structured. The research clarification is based on a critical review [26]. It outlines the field of research and provides the resources for the following chapters. The standardised description of engineering changes as well as the steps taken to create it are based on the current literature, an analysis of the wiring harness and its data formats, a retrospective analysis of documented changes and discussions with experts from different domains. The case study and the pilot project were used to validate the standardised engineering change description. The case study is a retrospective analysis from the development of the door module wiring harness. It was analysed whether the documented engineering changes that occurred can be described in the standardised format.

A software prototype was used to support engineers in the creation of engineering change descriptions during the pilot project. The descriptions were created by selecting attributes from defined lists. Those attributes were combined and exported as complete descriptions, using the structure of the standardised engineering change description. The engineers were part of the development team that worked on the automotive wiring harness of a mid-sized car. The data was collected through four interviews with another group of development engineers that are responsible for the engineering changes. The interview contained single-choice questions as well as open questions. The results of both studies are analysed and discussed and provide the basis for the evaluation of the standardised description. A generic engineering change process was used to outline how different methods and approaches can improve the engineering change management.

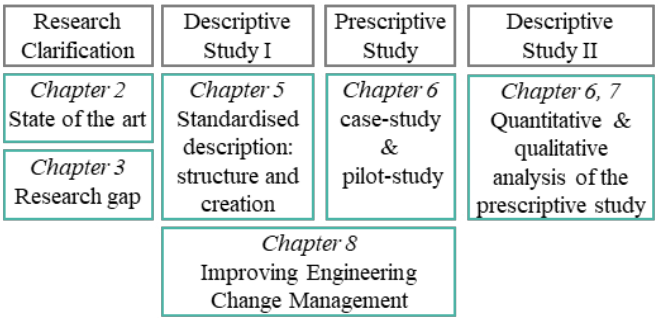

Fig. 2. Methodological approach

5. Development of a new standardised description for engineering changes for the automotive wiring harness

5.1. Introduction of the developed standardised description

The standardised change description contains all elements that are necessary to understand and process engineering changes. It describes changes in an understandable, unambiguous and consistent manner. Figure 3 shows the structure of a standardised description. The first set of elements refer and identify the object that is changed. Those are the class, the name and a unique ID. The second set of elements is used to describe the technical aspect of the change, which the object undergoes. The type of change is the first element and can be either add, remove, replace and change. Replace refers to a

change of the IDs. Change refers to an alteration of attributes. In order to describe this alteration the type of attribute, its current value and desired value are additional elements necessary for the description. The location of the object forms the third set of elements. It consists of either one or two positions and the corresponding displacement or distance if it exists. The positions contains coordinates or other referenced objects. The fourth and last group of elements is meta-information. This can link the engineering change to other engineering changes, indicate the temporal integration in the process and the affected system or configuration. This last part is not necessary for the engineering change itself, but for the organisation of it. All elements combined create the ontology for engineering changes. The content of the elements is always a pre-defined list. This list can be separate or linked to a database with cross-references, which allows elements to be pre-filled or checked. This ensures a consistent use of terms and words. It enables an automatic translation by linking the words to the corresponding term from other languages. The description is structured in a way that ensures the readability by humans and by machines. The description for the human readable form is supplemented by auxiliary words, which can be defined for the specific change. The machine-readable form also contains the mentioned elements. An XML created according to the structure in Figure 3 can be translated to show the change in a human-readable format.

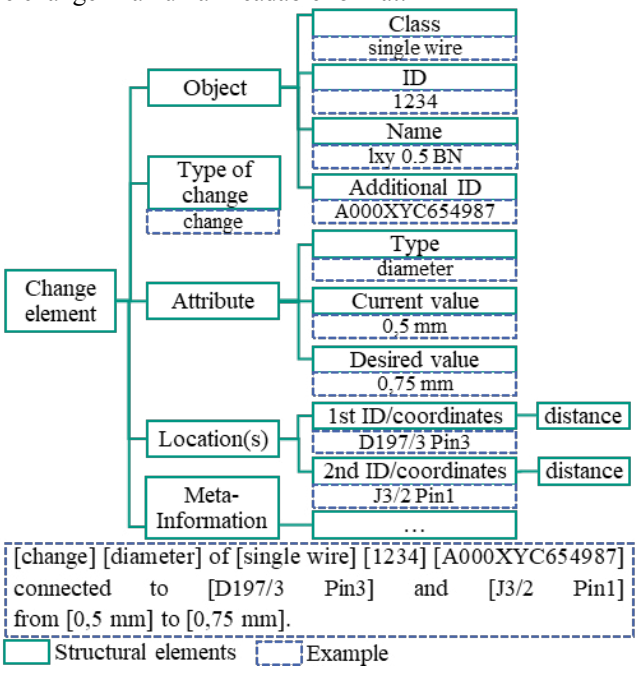

Fig. 3. Newly developed structure for a standardised description of engineering changes with an example depicted in human-readable form

5.2. Creation of a standardised change description

The process of creating the standardised engineering change description is shown in Figure 4. The steps can be understood as an iterative process. The wiring harness is analysed and broken down systematically to identify all relevant objects and attributes in the different domains. The domains are depicted in Figure 1 and are the functional & electro-logical domain, the 3D domain and the manufacturing & production domain. The result is compiled into a tree diagram that shows all attributes of the objects that can be changed. Figure 4 shows an excerpt of this structure. This structure is supplemented by additional information like location and meta-information in the next step.

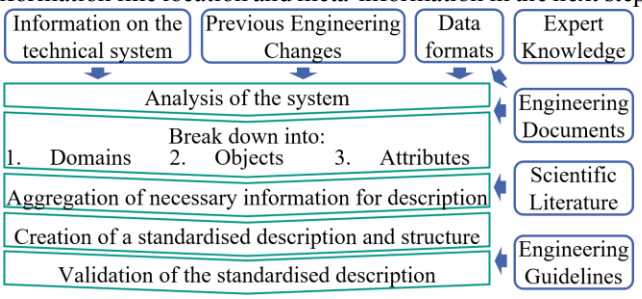

Fig. 4. Introduced approach to create a standardised description

Starting with the attributes all documented changes were compiled and analysed focusing on information that engineers need to describe and understand a change. An example would be the change of the diameter of a wire. The location of the wire is an important information in this context. Another example would be the change of a fixing were the location of that element is important. Analysing the information and combining the changes of the different domains results in a standardised engineering change description that contains all relevant information. The information sources used for every step are shown in Figure 5.

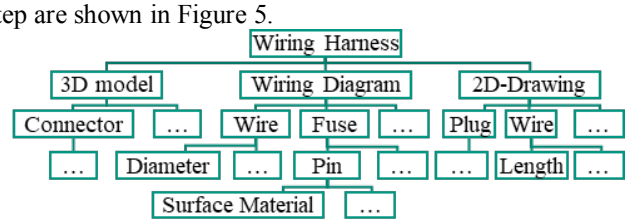

Fig. 5. Created structure for objects & attributes of engineering changes

6. Validation of the standardised change description

A case study of a development project and a pilot project in a development process are used to validate the developed standardised description. The aim was to confirm its applicability and success. The case study has been conducted to find out whether the description is suitable to describe real engineering changes. The share of engineering changes that could not be described and the reason why this is the case were of interest. The results of the analysis are shown in Figure 6. Most changes (94%) can be described in the standardised structure. Some of these changes (9%) were non-technical. This refers to changes of the target date or corrections in the 2D drawing.

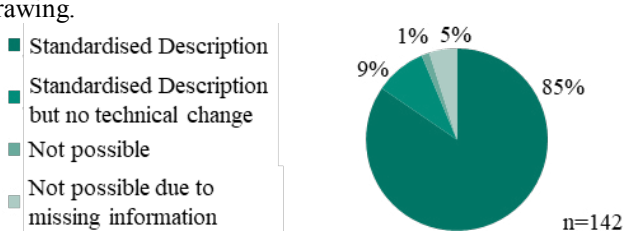

Fig. 6. Share of engineering changes from the case study of a wiring harness that can be depicted in the standardised description

Six percent of all considered changes cannot be described in the standardised form. The majority of those changes (5%) are lacking information. This is a consequence of bad data quality in the documentation especially when the changes are only change ideas. The one percent refers to complex routing changes that are too complex to describe with the structure provided. A graphic representation is especially helpful in those cases where a short verbal description is not sufficient. The pilot study has been conducted during the development process of the wiring harness of a car model. The engineers used a pre-defined input dialog to create the descriptions. The descriptions have afterwards been used for the communication with the responsible engineers. Some descriptions were altered or amended by drawings. The descriptions have been evaluated by interviewing the engineers that dealt with most of these engineering changes. Figure 7 shows the results of the single-choice questions. Most interview partners stated that some engineering changes cannot be described arguing that those are to complex or extensive changes. The degree to which it improved depended on the experience, cooperation and interaction between engineers. The engineers said that the difference to normal descriptions from well-trained engineers is not so big but that it helps people who do not have much experience. The experts said the creation of the descriptions has to be easy and intuitive to eliminate additional effort.

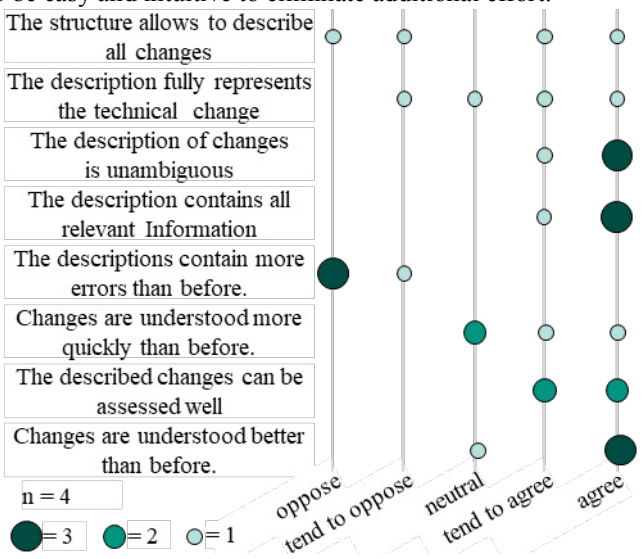

Fig. 7. Findings from interviews from a pilot development project

7. Discussion on the standardised description of engineering changes

The first study shows that the majority of engineering changes can be fully described in the standardised form. Thereby confirming the underlying assumption that a structure exists that provides the basis for a complete and unambiguous description. Some changes require an elaborate explanation due to their geometrical complexity. Hence, they can be described in the standardised form but only to a certain degree because a complete description would be too long and not improve the change process. The interviews of the engineers confirmed that some engineering changes could not be described even though some of them did not encounter these changes. This is supported by the rarity of this type of engineering change that only accounts for 1% of changes. For complex changes, drawings and other attachments should be used to support the standardised description. The interviews from the second study underline the applicability of the description in a real life setting. The engineers stated that the description is complete, comprehensive and stated that it reduced errors and allowed them to accelerate their activities. The newly developed structure for descriptions is helpful for the engineers. It can therefore be called successful. It improves the process by making it quicker and reducing errors. This will result in the reduction correction loops and thereby the number of engineering changes. The new standardised description can be digitalised based on the structure in Figure 3. It provides the basis the automatic classification of engineering changes, their evaluation and processing.

8. Improving engineering change management

The standardised description is essential for the digitalisation and automation of the engineering change management. Subsequent potential improvements of the process are shown in Figure 8. They can accelerate the change process, make it more effective, efficient and reduce the total number of engineering changes. The process on the left depicts a generic engineering change process. The green box represents the standardised description and its impact on the process. The dashed lines and boxes illustrate additional improvements of the change process. The first box represents the automatic description of changes in different tools. An automatic classification and evaluation of changes based is shown in box 2. The next one represents the automatic implementation of engineering changes in the next development generation [27].

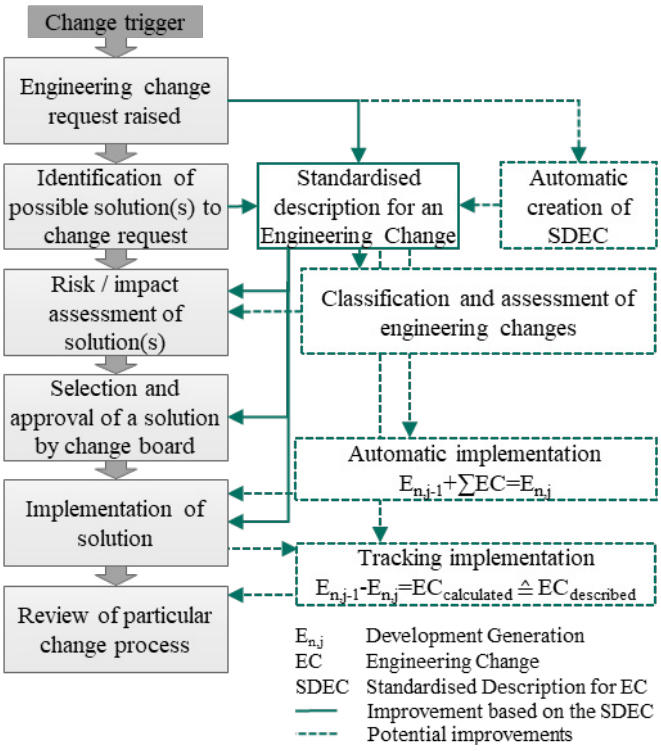

Fig. 8. Potential improvement of the generic engineering change process [6] based on the newly developed standardised engineering change description

The last box shows how the implementation could be tracked by describing engineering changes and comparing them to the automatic description based on the latest digital version of the system.

9. Outlook

The standardised description of engineering changes proved to support the engineering change management. The clearer definition leads to a better and quicker understanding of engineering changes, which has a positive impact on the activities of the engineering change management. Further research should look at the implementation of the standardised description into the development process of automotive wiring harnesses and other fields considering existing models and technologies. Moreover, future work should focus on the complex geometrical changes to find descriptions for those scenarios. The approach should be applied on other technical systems to confirm the assumptions that this approach works for other systems. Additional improvements like the automatic evaluation, which are based on the standardised description, should be investigated because they hold the potential to deal with changes more effective and efficiently. Especially the variations of the PGE – Product Generation Engineering that could help to classify and evaluate engineering changes [3,28]. Evaluating the relationship, interaction and change propagation between engineering changes can be easier with the data from the standardised descriptions [23].

Author Contributions

Moritz Altner performed conceptualisation, methodology, analysis, investigation & writing original draft and editing. Hans Redinger performed conceptualisation & methodology. Eder Kevin performed an investigation of occurring 3D changes & review. Benjamin Valeh performed the investigation of the case study. Jonas Neckenich performed writing – review & editing. Simon Rapp performed writing – review & editing. Roland Winter performed supervision. Albert Albers performed supervision.

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