A Knowledge Management Approach to Support Concurrent Engineering in Wiring Harness Development

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Abstract. Engineers are confronted with the challenge of processing an increasing amount of data within a continuous shrinking time frame. Due to the fact that it is usually not possible for engineers with the current methods to distribute the knowledge gained accordingly resulting in knowledge being lost in due course of the product life cycle. Especially with products such as the automotive wiring harness, which is highly complex and subject to a large amount of changes, this can lead to missing data, inconsistencies and repeated errors during the product life cycle. One approach to support engineers is the use of a knowledge management system, capturing knowledge during the development process, identifying possible use cases and integrating them into the corresponding data sets. This paper gives an overview of current problems in the cross model concurrent engineering of automotive wiring harnesses. Based on these, the specific requirements for virtual geometry development of the wiring harness using CAD are derived and compared to the state of the art. Furthermore, an approach for a knowledge management system for CAD data fulfilling the corresponding requirements is described. Thereby, the individual steps are listed to be carried out for the realization of this system.

Keywords: Knowledge management · Knowledge transfer · Knowledge reuse · Computer aided design (CAD) · Concurrent engineering

1 Introduction

Increasing competition forces the industry to bring more and more products to the market in a shorter period of time. In order to save costs, platforms are formed on which as many product variants as possible can be developed in parallel [1]. In addition, various process steps of the product life cycle are executed concurrently to reduce the time required. Therefore, traditional sequential process steps, such as producing prototypes, must be started early before the digital data freeze. As a result, individual workflows take place in parallel. Since this does not involve working with the final state of information, each change triggers a correction loop, resulting in considerable

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additional work and correspondingly high communication effort [2]. Due to this, engineers are challenged with processing an increasing amount of data in a continuously shrinking time frame. Among other things, this makes it often impossible for engineers to distribute acquired knowledge appropriately. This results in a large amount of knowledge being lost in course of development and therefore errors are may be repeated. This loss is a huge challenge in engineering change management (ECM) [3].

A particular challenge in this context is the automotive wiring harness, where new change requests arise daily due to the high dependency during the development process [4]. Thus, the following questions need to be answered:

- What challenges arise from the current wiring harness development process?
- What requirements must be met to generate complete and consistent data sets?
- How can knowledge gained during the development process be efficiently transferred to potential reusers?

This paper is organized as follows: Sect. 2 describes the current development process of automotive wiring harnesses. Section 3 reviews the state of the art of knowledge management systems (KMS) for Computer Aided Design (CAD) data. Section 4 points out the challenges of the wiring harness development and derives the research gap. Section 5 describes the approach for a KMS for wiring harness CAD data. Section 6 concludes this paper and presents an outlook on future work.

2 The Wiring Harness Development Process

An automotive wiring harness development process begins with the creation of the system design. In this process, the individual electronic components, such as sensors and electronic control units, are defined and logically connected to each other. With this information, the routing paths and attachment points are designed as a 3D CAD model. Simultaneously with the installation space modeling, the circuit diagram is created. In the latter the individual wires are assigned to the corresponding routing paths and, among other attributes, the material and diameter of the individual wires are defined. This information is used to calculate the maximum bundle diameters for the laying paths. Subsequently, these are transferred into the CAD model with an additional markup to account for production fluctuations and future functional scopes. Finally, the CAD model, the schematic and the component database are combined to create the 2D production drawing, unifying all geometric and electrological information and enhancing it with production relevant information, such as tolerances.

In practice the drawing has to be created manually with high expenditure of time and money. However, the 3D master method adapted to the boundary conditions of the wiring harness by Neckenich et al. [5–8] could change this manual process in the long term and reduce these effort. In this method, the complete digital product description is merged into a so called 3D master model. This is a data container, which essentially contains a complete description of the wiring harness based on the XML (Extensible Markup Language) format, as well as its geometry in the standardized JT (Jupiter Tessellation) format. Using the appropriate tool, a drawing can be automatically generated from the data container. In order for the 3D master method to work reliably, a complete and consistent set of data must be guaranteed.

Despite the fact that more and more product characteristics can be tested with CAD models, physical mockups (PMU) are still required for selected development phases for validation purposes. The production of a first PMU can take several months in the automotive industry. A particularly high level of effort is required for the wiring harness, which cannot be produced automatically due to the large number of variants and its flexible structure [9]. In order to ensure on schedule installation of a wiring harness into a PMU, it is necessary to start creating the drawing and subsequently manufacturing the wiring harness before the digital data freeze of the specific development phase (see Fig. 1). It should be noted that the corresponding lead time can vary depending on the supply chain. For example, wiring harnesses for seats have to be produced earlier, as they have to be made available to the seat supplier in advance, so they can be delivered to the automotive manufacturer as part of the fully assembled seat.

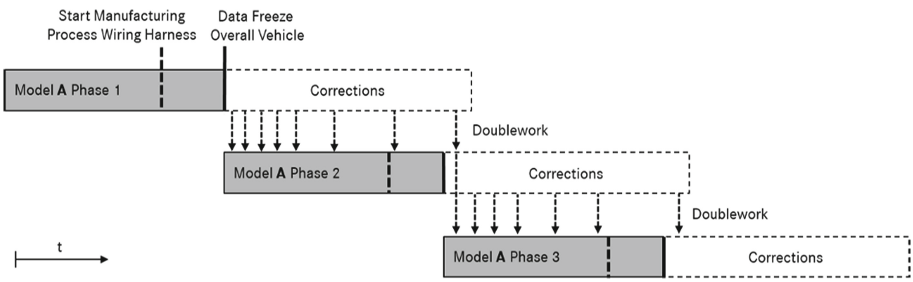

Fig. 1. Exemplary timeline of a single model wiring harness development process

The high dependency of the wiring harness leads to the fact that changes to other components usually cause an adaptation of the wiring harness [10]. Combined with its flexible structure and limited installation space, this leads to the fact that the wiring harness is usually the last component to be changed in a development phase [4]. This induces the necessity of making a large number of adjustments after the early start of drawing creation and, more importantly, after the freeze date of a development phase. In addition, further corrective measures arise during production and assembly, which must be integrated back into the CAD model and the drawing in order to ensure data consistency between the digital and physical state [11]. Since these adjustments can also be relevant for the following development phases, they must be carried out multiple times for the corresponding data sets. If parts of the wiring harness are used in several vehicle models, this redundant maintenance effort is multiplied (see Fig. 2).

Due to the high time pressure these changes are often only implemented in the latest development phase in the CAD model and circuit diagram. In the original digital data sets corresponding to the PMU these are only documented by manual adaptation of the drawing or separate documents. In addition, engineers may not have the ability to adjust frozen data due to the specific product data management (PDM) system and company rules.

Another aspect that increases the complexity and effort of the wiring harness development is the early consideration of already known future changes. For example, the release of a new electronic control unit is fixed several months before its deployment date and needs to be taken into account in the corresponding development phases at an early stage. This results in several more data sets to be maintained simultaneously [12].

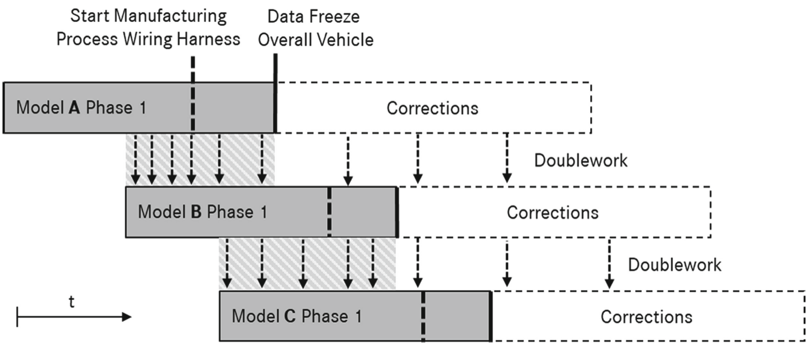

Fig. 2. Exemplary timeline of a cross model wiring harness development process

Despite continual improvements in the field of the wiring harness development, commercial CAD software like Siemens NX and Dassault Systemes CATIA have not improved their ability to support partial reuse and change management. Even though CAD systems provide reuse libraries for certain parts such as fixings, splices and labels, the individual wire paths must be designed manually. Although most systems provide the user with a copy and paste functions for features, these functions are rarely used as the corresponding process has to be done manually and the inserted features cannot always be consistently implemented into the target CAD model.

3 Knowledge Management

In order to prevent the loss of knowledge and to maximize the benefits of acquired knowledge, a large amount of research has already been carried out in the field of knowledge management (KM). Depending on the perspective, knowledge can have a variety of meanings. For example, knowledge can be documented in the form of data and information. Alternatively, knowledge can enable engineers to perform processes or to operate in a situation specific manner [13]. Looking at the development of a CAD model, knowledge can be captured and transferred in different ways. Several commercial CAD systems like Dassault Systemes SolidWorks enable the user to add annotations that can be used to capture the design intent and can be passed on to subsequent processes [14].

In their work, Schacht and Maedche [15] provide an overview of a variety of KM methodologies and combine them into their own process. This process consists of five different phases (see Fig. 3).

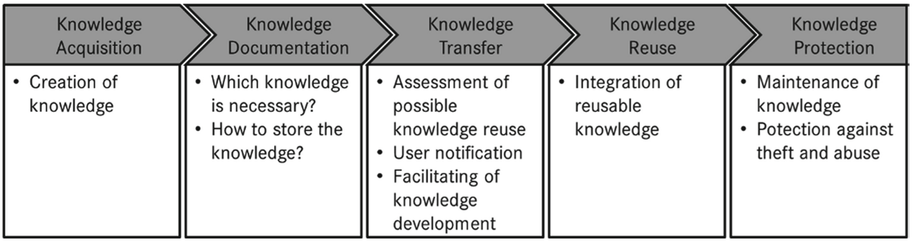

Fig. 3. KM process aligned to Schacht and Maedche [15]

The starting point is the acquisition of knowledge (phase one), in the course of which, for example, the construction of a CAD model takes place. Subsequently, the gained knowledge has to be documented and stored (phase two). For the following knowledge transfer it is crucial to capture the intention of the knowledge creation [16]. Therefore, the relevant information has to be extracted and stored in a suitable form [15].

The third phase (knowledge transfer) forms the core of the KM. In this phase, it is important to find possible use cases for the reuse of the acquired knowledge, to make responsible persons aware of a possible knowledge transfer and to make it easier for them to access the knowledge. Once a suitable candidate has been found, the relevant information must be integrated into the candidate's knowledge base (phase four). The last phase (knowledge protection) aims to maintain and protect the gained knowledge from theft or misuse [15].

Since knowledge is a very multifaceted term, the implementation of a KMS depends on the knowledge to be reused, the desired scope of use and the software application used. Commercial CAD systems like Siemens NX, Dassault Systemes CATIA and SolidWorks store knowledge in CAD files that can only be accessed through the same system and its application programming interface (API) [17]. For this reason most KM approaches for CAD rely on the API of these systems.

One approach to integrate achieved knowledge into the development process with CAD is to make it available during the generation of new knowledge as a supporting function and consequently to accelerate this process. For example, Sung et al. [18, 19] developed the COSTAR cable harness design system, which allows users to design wiring harnesses in virtual reality (VR). During the design process, all user activities and decisions are documented, which enables the developed system to calculate patterns. Based on this data, the user can be offered situational support during further design processes. So far, all these methods have been dismissed by potential users due to the increased effort required for knowledge acquisition. Another possibility for the direct integration of generated knowledge is the research of Bai et al. [20, 21]. In their approach, feature based design patterns of a CAD model with high cohesion, low coupling and moderate complexity are extracted and coupled with matching attributes. The extracted patterns are sorted according to their frequency of use and provided to the user as a template for the design based upon the attributes entered by the user.

The work of Chen et al. [22] represents another approach for implementing a KM process. In their approach, a conceptual assembly structure is created at the beginning of the development process based on the required scope of functions according to the top down principle. The individual subassemblies and components are then built up in three levels with an increasing degree of detail. Due to the same structural design of the components and assemblies, Chen et al. [22] are able to transfer individual information of features, parameters, kinematic links and geometries from the abstract level to the detailed level with their method. Pan et al. [23] use a similar method. Their approach is to automatize almost the entire detailing of a component. To do so, an abstract geometry with the desired boundary conditions is designed to match the structure of an existing detailed component, allowing the individual faces to be linked. Using this link, it is possible to transfer the individual features to abstract geometry. Pan et al. [24] were able to extend this method to the transfer of features for entire assemblies by including kinematic links.

In further research, the advantages of a partially implemented KM are shown. For example, the Multi CAD API manager developed by Cho et al. [25, 26] can be used to automatically extract the relevant information from a CAD model. By using an additional tool called KAFA, this information can then be formalized and stored in an XML file. Subsequently, the generated file can be compared with other data sets. Effects of changes can thus be recognized and processed more quickly. Another approach is taken in the research of Toepfer et al. [27–29]. In their approach, the individual systems and relationships are modeled using the Systems Modeling Language (SysML) and linked directly to the PDM system. By storing the model parameters in XML files, they can be retrieved directly in the PDM system. In addition, this method also allows immediate notification of the affected users as a result of a change in data sets.

Heber and Groll [30] go one step further. Using the principles of model based systems engineering (MBSE), all systems are modeled and their individual elements are linked via Uniform Resource Locators (URL) to various PDM systems or product life cycle management (PLM) systems across companies. In case of a change, the corresponding metadata, such as CAD models, are distributed to the linked systems by forming blocks. In addition to the metadata, these blocks contain additional meta information, such as Uniform Resource Identifiers (URI), which are used for precise assignment in the systems. The main advantage of this method is that all users affected by a change can be informed immediately. Thus, they can directly approve or reject a change or make adjustments before the data set is released in the corresponding PDM system.

4 Research Gap

In order to be able to develop wiring harnesses with increasingly reduced development periods, an increasing amount of simulations and methods such as the 3D master method have to be used. These require complete and consistent CAD data for any development phase confronting engineers with the following challenges:

- An increasing amount of data must be coordinated and processed in a continuously shrinking time frame
- The completeness of the data has to be realized by executing redundant processes efficiently
- Synergies between all data sets have to be detected and gained knowledge needs to be transferred in order to prevent repeating errors

To meet these challenges the use of a KMS for CAD data deemed to be a solution. This should support engineers to identify synergies and make redundant design processes in a CAD system more efficient. Thereby it extends existing ECM methods for the in-change stage according to Hamraz [31].

Because of the unique structure of the wiring harness, the high frequency of changes, the complexity and the variations between the individual CAD models, this system must meet certain requirements. Since normally only partial areas of a wiring harness correspond to those of other CAD models, the individual models can differ completely in structure and content except for this specific area. Depending on the area of a wiring harness, different data sets are possible for the reuse of the gained knowledge. In order to be able to identify the relevant ones, all areas of all possible wiring harnesses must be compared quickly and automatically. To be able to notify the responsible persons and for documentation purposes, an explicit and generally comprehensible description of the change should be provided. Since an exact redesign of the wire routing in other CAD models is very time consuming, it should also be possible to integrate the corresponding adjustments by supporting the user or, ideally, in an automated way.

Table 1. Approaches of KM for CAD data ranged in to the process of [15]

Research	Knowledge documentation	Knowledge transfer	Knowledge reuse
[14]	Annotations with design intention in cad model		
[18, 19]	User's actions in XML file	Activity pattern are matched with ones in the database	Assistance by displaying context related instruction
[20, 21]	Feature patterns	Adding attributes to the feature patterns	Feature patterns are suggested based on attributes
[22]	CAD models with increasing level of details	Linking of similar features, parameter, kinematic links and geometry	Linked Elements are transferred from the abstract level to the detailed level
[23, 24]	CAD model	Linking of similar faces, kinematic links	Automatic adaptation of the features to the abstract model
[25, 26]	Parameter in XML file	Comparison with defined data sets	
[27–29]	Parameter in XML file	System relationships are defined via SysML. User notification of changes	
[30]	Metadata (e.g. CAD model)	Systems are linked via URL to PDM/PLM systems. Metadata are distributed as blocks	

In comparison with the current state of the art from Sect. 3, none of them meet all the requirements of the wiring harness development. The approaches in which knowledge is reused (see Table 1) are rather unsuitable for the large amount of changes and the partial transfer of changes to subareas of a CAD model. In addition, none of the systems can provide indications to data sets that might be suitable for reuse. [25–30] provide promising approaches for the detection of changes and affected data sets, but do not offer any approaches for the automatic integration of this knowledge into other data sets.

5 Approach for a Knowledge Management System in the Wiring Harness Development

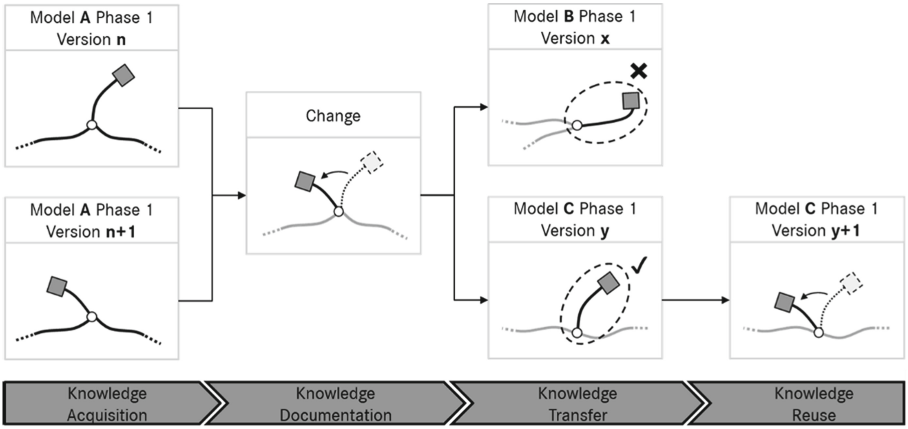

Fig. 4. Principle of a KMS for CAD data of wiring harnesses

In the following, an approach is shown how a KMS aligned to the method of [15] could look like in order to fulfill the above mentioned requirements of the wiring harness development (see Fig. 4). Due to the large amount of modifications, the system aims for an immediate reuse of the acquired knowledge, which is why a long term preservation and protection is omitted.

The starting point of the KM process workflow (see Fig. 5) is the change request and the following implementation of a change in a CAD model. In order to be able to automatically recognize changes made in a CAD model, it is necessary to identify the elements that build up a wiring harness model in a CAD system (e.g. Siemens NX). Then, a suitable medium must be selected that can store all relevant attributes of the CAD model, for example, the coordinates of each routing point. A possible solution for this would be the XML format, which was also used by [25–29] and is already generated in the context of the 3D master process by [5–8].

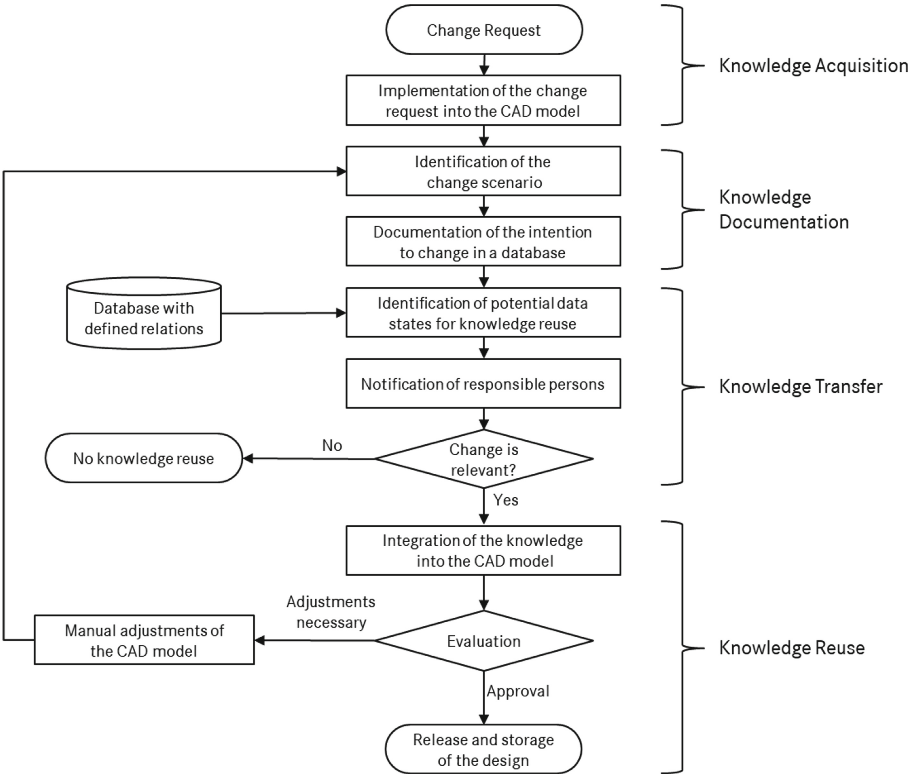

Fig. 5. Process workflow of a KMS for CAD data for the wiring harness development

Subsequently, all change scenarios must be registered, which can be carried out by the engineer in the CAD system on a wiring harness. For example, changing the routing path of a wire or moving a connector. Based on these scenarios, it must be analyzed which specific data changes in the XML as a result of the change process. By programming a corresponding algorithm, it should be possible to automatically recognize each change scenario that has been carried out by comparing the XML files from before and after the change to the associated CAD model. The changed data must then be saved in a separate XML file along with a description of the respective change scenario defined in the algorithm.

In order to be able to automatically detect potential reusers on the basis of the detected changes, all theoretically possible data sets must initially be linked with each other. For example, a tool based on the principle of [27–29] might be a solution for this purpose, in which individual points of the CAD model are parameterized for all models. By updating the database automatically after a change is made, it is possible to determine which data sets had been consistent with the changed area before the adjustment and could therefore be considered for a reuse of the knowledge. Subsequently, the responsible persons have to be informed via a function. Based on the change intention, this person can determine whether or not a possible integration of the gained knowledge is relevant. If so the modification has to be integrated into the corresponding CAD model. Therefore, the modification data have to be transferred from the stored XML file into the XML file of the potential reuser. Afterwards, this file has to be converted into a CAD model, which can be modified or accepted by the user.

6 Conclusion and Outlook

Incomplete and inconsistent data, the overlooking of synergies between product variants, as well as the lack of transfer of previously acquired knowledge lead to unnecessary correction loops due to increasing time pressure in the development of automotive wiring harnesses. In order to meet the requirements of high data quality, engineers must be supported in recognizing synergies and redundant processes have to be managed efficiently.

A possible solution was identified in the realization and use of a KMS for CAD data. The specific requirements of the automotive wiring harness development were defined for the system and compared with the state of the art. An approach to the process workflow of a corresponding system was presented based on the fact that XML files derived from CAD models are compared before and after the changes. The relevance and applicability of the captured change are then automatically checked for linked data sets and, if applicable, a correspondingly modified CAD model is presented to the responsible person. Finally, the individual steps were listed, which need to be executed for the implementation of the KMS. In future work, these steps will be carried out and validated at an automotive manufacturer.

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