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DIGITAL SUPPORT OF WIRING HARNESS DEVELOPMENT (BASED ON THE 3D MASTER METHOD)

Neckenich, Jonas (1); Winter, Roland (1); Vielhaber, Michael (2)
1: Daimler AG, Germany; 2: Saarland University, Germany

Abstract

The challenges for designing and developing automotives increase and create the need for a change in developing processes. One solution to support digital processes in today's developing processes is the 3D master method. Advantages and disadvantages of the 3D master method are analyzed in comparison to 2D drawings. The implementation of 3D master method as a digital support for the development processes of wiring harnesses is described and new methods which are needed for a complete integration of 3D master method into wiring harness development processes are presented.

Keywords: Computer aided design (CAD), Design engineering, Design methods, Design process, Mechatronics

Contact:
Jonas Neckenich
Daimler AG
RD/EKL
Germany
jonas.neckenich@daimler.com

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1 PROBLEM DEFINITION

Throughout the last years, there have been several changes in the automotive industry. More restrictive regulations regarding fuel consumption and emissions result in an increasing complexity of cars. At the same time growing customer expectations about safety and comfort must be met. The consequence is an increasing amount of electrical systems in cars, the need for signaling lines, power cables and ground wires rises significantly. The car market has gained access to the global market, which leads to the fact that new model series are no longer built only on one continent, but are produced locally directly in the target markets. For the purpose of remaining successful in competition, new model types are developed and new derivatives enlarge the product range of all car manufactures. In addition, development times are shortened and possibilities for cost savings are identified and implemented.

In order to face rising challenges in development, a review of current processes and methods is necessary. In an increasing digital world interfaces between different processes have to be simplified and redundancies must be avoided. To ensure this, the digital support of the different development departments has to be advanced. One solution to face this challenge is the use of the 3D master method. Regarding wiring harness development, this requires a concept for designing and releasing wiring harnesses in a realistic, complete digital mock-up (DMU). Consequently, the following research questions arise: Which data is needed for the concept? Which processes have to be performed? Which new methods are essential for the implementation of the concept? How can the concept be turned into tools?

This paper starts with the presentation of the state of the art of using 2D drawings in industrial development. Chapter 3 develops the use of 3D master method and summarizes the main aspects. Chapter 4 shows the current deficits in a combined 2D/3D digital world. Chapter 5 describes a concept for the implementation of 3D master method in digital wiring harness development of Mercedes-Benz Cars (MBC). This concept is compiled in the context of a dissertation.

2 USING 2D DRAWINGS AS MAIN INFORMATION OBJECT

Many parts of today's industry use 2D paper drawings. They are main information objects and the most relevant documents in the development and product documentation process. Their central data content is based on the supply of dimensions, tolerances, annotations, parts lists, references to standards and other manufacturing-relevant information. A detailed analysis of the design supports the understanding of the manufacturing and usage of the shown product. Thus, the detailed representation of the product is essential for all downstream processes in manufacturing, quality control, delivery chain and assembling (Dassault Systems, 2013) (PROSTEP AG, 2012) (Paffenholz, 2009).

2.1 Challenges and problems

Within digital development processes, the design and release of 2D drawings implicate some challenges. Besides the digital computer-aided design (CAD) model, it is necessary to develop an associated technical design drawing on the one hand. On the other hand, one has to maintain the drawing in parallel during the life cycle of the product (Kitsios and Haslauer, 2014). The proper interpretation and application of design contents affect the correct und accurate manufacturing of a product. Additionally, technical drawings and parts lists form the central components of technical product documentation. They do not only document complex changes and release processes, but also provide a knowledge base and may not be neglected for issues of product liability.

Affected by the only two-dimensional representation of complex geometrical facts and the integration of a wide range of information, drawings may lead, however, to misunderstandings. Those misconceptions arise in errors in design as well as higher manufacturing and error follow-up costs (Dassault Systems, 2013). Reasons for this are both the complexity of the shown information and the often insufficient representation or misinterpretation of shown views and sections (Alemanni, Destefanis and Vezzetti, 2011). The knowledge stored in two-dimensional drawings cannot be processed automatically, because filtering or reprocessing of the contained data is not possible and an analysis can only be done visually (Kitsios and Haslauer, 2014) (Paffenholz, 2009) (Wan *et al.*, 2014).

The switch-over between 3D CAD environment and two-dimensional drawings that is needed for changes is based on an often appearing incompatibility between both kinds of representation. The duplication of efforts towards the maintenance of 3D model and 2D drawing increases the error probability and results in higher expenditure of time and costs (Dassault Systems, 2013) (Paffenholz, 2009) (Wan *et al.*, 2014).

2.2 2D drawings in today's wiring harness development process

In the wiring harness development process of Mercedes-Benz Cars (MBC) two-dimensional drawings are basic elements of the technical product documentation and thus main information objects. All release-relevant information can be found in the drawings.

The 2D drawings gather both geometrical and logical information. Positions of connector housings and routes are extracted from the CAD model, logical information is taken from the wiring diagram, respectively the wiring list. In the further process geometrical and logical information is detailed and fixing positions are defined. Moreover annotations, manufacturing and assembly references are added.

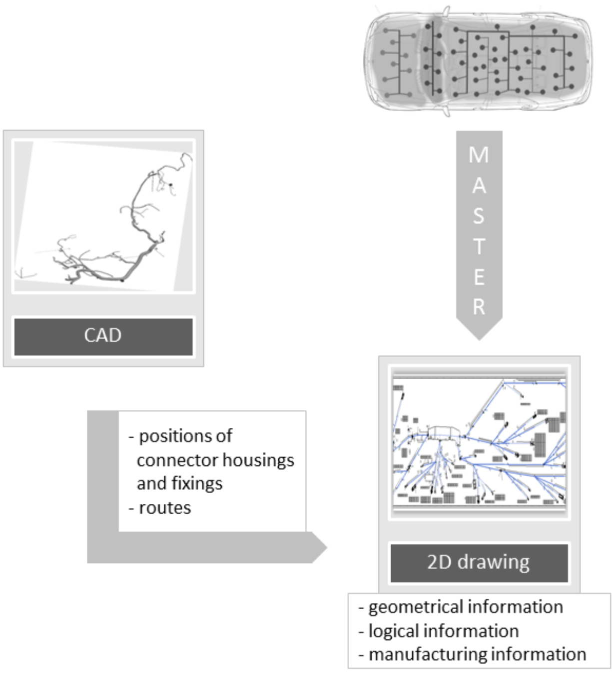

Figure 1. Using 2D master drawings in digital wiring harness development process

MBC has been using 2D master drawings in the wiring harness development process for some years now. In the past each harness module had its drawing, nowadays master drawings summarize all modules of an installation space in one single drawing. This approach makes it possible to centrally obtain all information of the wiring harness of a particular installation space, independently from the specific equipment. The disadvantage of this approach is found in the fact that the combination of all shown modules represents a disproportionate extent, which will never be built in reality.

This centralization of information enables the use of one main information object for each installation space. In addition to the two-dimensional data management, the 3D CAD model defines a space reservation, which does not contain any further information besides the geometrical information of routes. The consequent need for an alignment between 2D and 3D continually leads to a discrepancy between data. The diameters, which are reflected by space reservations, often lack the necessary plausibility and reality, since they include further supplements for possible facelift changes in addition to the disproportionate representation. Furthermore, neither the DMU wiring harness is configurable nor are all relevant components entirely digitally represented.

The complexity of the wiring harness can be seen in the approval drawing which includes all possible variants and necessary information. The representation of the whole installation space refuses the opportunity for a quick overview, due to the variety of release-relevant data. Thus, the 2D paper drawing of a particular installation space of an upper-range sedan can become about two meters high and 30 meters wide.

For a reduction in complexity and for digital data processing in wiring harness development of MBC, the Harness Container for Viewing (HCV) is used. This format contains all necessary information of a specific wiring harness, among others a drawing in SVG format as well as the associated harness description list (KBL). An appropriate software tool combines both KBL and SVG files and enables the intuitive visualization of the existing information. As a consequence either individual modules or connections can be selected and the associated information can be visualized directly.

2.3 Summary of the main problems

Two-dimensional drawings are main information objects in most industrial areas. The central issues that result from using 2D drawings can be summarized as follows:

- Double data management in 2D drawing and 3D CAD model leads to increasing maintenance efforts as well as higher error potentials.
- Complexity of shown information results in confusion and misunderstanding.
- The abundance of the represented information cannot be filtered custom-designed. Likewise, an automated subsequent processing of the integrated information is not possible.
- 3D CAD models contain either no or incomprehensible information and have a discrepancy to associated 2D drawings.
- Essential characteristics and attributes such as configurability and actuality are missing in 3D CAD models, affected by the focus on using 2D drawings as main information objects.

3 THE 3D MASTER METHOD

The preceding chapter has described the basis of representation of objects in 2D drawings. Now the 3D master method is specified in detail. Therefore, an overview of the method is provided and goals as well as requirements are defined. Afterward, practical implementations of the method are considered and analyzed. The end of the section summarizes the most important facts of the 3D master method.

3.1 Introduction

The 3D master method enables an entirely digital product description and, thus, the drawing-less designing and documenting in product development. All information, which has been integrated into the key elements of technical product documentation, is stored within the 3D model, such as the contents of two-dimensional paper drawing and parts list. Apart from geometry, this data contains all semantic data concerning characteristics and functionality of included objects that are needed in downstream processes (Kitsios and Haslauer, 2014) (Mbang *et al.*, 2003) (Paffenholz, 2009). Indicated dimensions, tolerance indications, geometry design, annotations, manufacturing information and parts lists can directly be attached to the 3D model (Dassault Systems, 2013) (Wan *et al.*, 2014). Gröne (2013) describes the central idea of 3D master method as “drawing-less production process, in which all manufacturing-relevant information is summarized in ‘one source’”. Thus, the 3D master model is the central data source and controls the entire manufacturing process (Modern Machine Shop, 2010).
In order to bundle the variety and complexity of data resulting from the realization of the single-source principle, different layers of information are generated. These layers provide a need-oriented content structure and can be used optimally during the downstream processes. Geometrical information forms the first layer. It represents the description of the product’s dimensions and tolerances. Additionally, views and sections that are crucial for downstream processes are included. The technological information is the second level of the product descriptive data. Quality-referred, material-referred, surface-referred or other applicable contents are integrated by reference texts, diagrams, manufacturing additions or different two-dimensional components. The last layer contains organizational information, such as issue- and parts-related information. This process-relevant data is usually archived and administered in a product data management system (PDM system) (Brill, 2008) (Kitsios and Haslauer, 2014) (Krause, 2008) (Paffenholz, 2009) (Sailer, 2011).

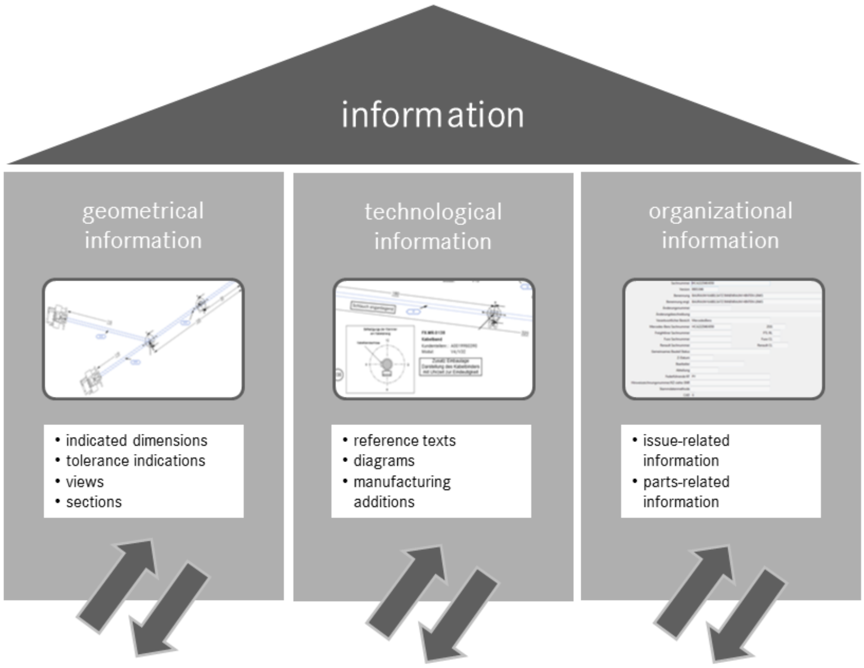

Figure 2. Information layers for 3D master

The benefit of introducing the 3D master method is multifaceted. First, it is evident that all relevant information can be made available to all participants collected in one central data source. The custom-designed structuring enables each data customer to receive precisely the information he needs (Sailer, 2011). Using the 3D model as the reference source demands an exclusive object for all relevant product data. All specifying information of the product is only administered and changed directly in the 3D model, which becomes "the one and only reference document" (Alemanni, Destefanis and Vezzetti, 2011) for all processes. All information can be analyzed directly in the 3D data since it is digital and therefore machine-readable for all downstream processes. Thus, the two-dimensional drawing is redundant and can be omitted (Kitsios and Haslauer, 2014) (Ramsteiner *et al.*, 2011).

The digital master does not only provide information for downstream processes, but also enables the replication of the product specification for variants. The respective data customer can extend the existing information without additional efforts (Dassault Systems, 2013) (Kitsios and Haslauer, 2014).

The illustration of a product in the three-dimensional space as well as in several data layers allows to present manufacturing information more intuitively and to avoid misunderstandings by a more realistic representation (Wan *et al.*, 2014). Paffenholz (2009) refers to a study that establishes "3D information depending on the type of component can be assimilated 20-30% faster than 2D information".

A continuous development with the 3D master method reduces necessary maintenance efforts for several sources and thus error potential during the development process by omitting the required alignment between 2D drawing and 3D model. The associativity of data and processes is bundled and thereby reduced, redundant data management is avoided and data is consistently held (Alemanni, Destefanis and Vezzetti, 2011) (Kitsios and Haslauer, 2014) (Paffenholz, 2009) (Schmelzle, 2014). As the major impact on effort reduction, Kitsios and Haslauer (2014) describe that "engineering drawings are no longer a component of the release extent". As a result, the data compilation is accelerated and component approval is facilitated.

This results in savings of efforts and costs and increases quality and efficiency of the development process, both for the producer and the supplier. Not only efforts of preparing engineering drawings are omitted, but also the efforts during the technical description of the product are reduced, because the required data can usually be generated faster in a 3D model. Work for the preparation of views and sections are no longer needed and geometry definition as well as providing manufacturing information can be parallelized (Kitsios and Haslauer, 2014) (Paffenholz, Spiegelberger and Stengel, 2008). Technical designers can save their efforts for specifying the drawings and even the printing and filing of paper drawings can be avoided (PROSTEP AG, 2012). Schmelzle (2014) describes the "improved communication and co-operation between design, manufacturing and all project stakeholders" as

another substantial factor that results from the single-source principle. He refers to the additional monetary values of advantages in kinds of realized savings in a pilot project.
The conversion of a process based on drawings to a process without drawings does not change the process as such, but its function; nevertheless, it has to meet certain further requirements. The developed 3D master model becomes main information object and replaces 2D drawing and parts list. Therefore, support processes such as visualization, change processes and long-term archiving have to be adapted. Also, suppliers have to be able to take part in the process and – at least for a transitional period – the compatibility between 3D master and the development process with 2D drawings must be ensured. Simultaneously existing tool structures have to be extended and existing filtering and search functions to control function-oriented views, characteristic indicators as well as master data must be used or completed (Fecht, 2015) (Gröne, 2013) (Paffenholz, 2009).

3.2 Product Manufacturing Information (PMI)

PMI is information that is attached to a 3D object in order to set and administer product and manufacturing information digitally. Hereby 3D objects can be equipped with additional information such as indicated dimensions or tolerance indications because PMI data is appended directly to the appropriate geometry. Thereby, it represents a container that does not only include the nominal geometry, but all further relevant data such as material properties, process specifications or parts lists, which are needed for downstream processes. Thus, PMI enables a consistent use of digital tools in the entire product development process and is an important key factor to omit 2D drawings (Katzenbach, 2015) (Krause, 2008) (PROSTEP AG, 2012) (Ramsteiner *et al.*, 2011) (Yares, 2012).

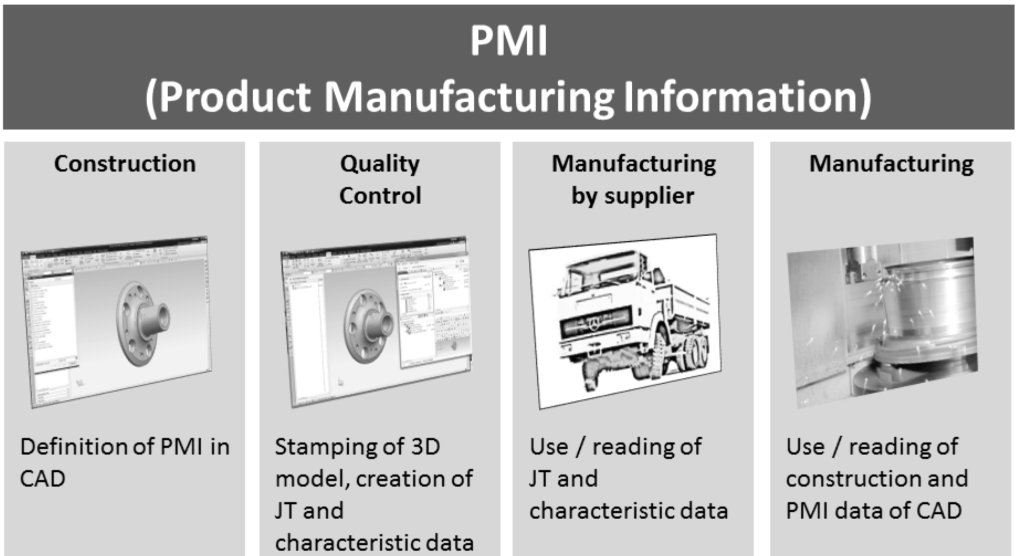

Figure 3. Use of PMI in development processes (similar to Ramsteiner et al., (2011))

3.3 Implementation

The increasing advance of digital development in the past years has led to the test of new methods in different real implementations. The following section provides an overview of completed or current projects that implement 3D master method.

3.3.1 The e3D process

Paffenholz (2009) has developed the designated "e3D process". This process essentially corresponds to the development process of the 3D master method. Creating small prototypes validated this process and tested the implementation of partial method aspects. As a result, Paffenholz (2009) concludes that "a first objective evidence for the feasibility of the concept and the fundamental operability of the developed e3D product development process" has been attained.
Afterward, Paffenholz (2009) validates the prototypes in the context of a case study of a wiring harness development process. As primary goals of the case study, he refers to the admission of manufacturing information in the model as well as the administration of components belonging to

assemblies within the PDM system. A mechatronic integrated system has to be analyzed by the integration of the mechanical and electrical elements and information. Therefore, Paffenholz (2009) accomplishes a theoretical view of the wiring harness life cycle and divides the approaches into the approach of development and the approach of manufacturing. He concludes that a general implementation of the "drawing-free" methodology for the wiring harness development process is possible, although implementation might be much more complicated than for individual parts, but it might gain a higher benefit.

3.3.2 Original Equipment Manufacturer (OEM)

Considerable car manufacturers already use the 3D master method. BMW introduced the "drawing-less" design and release in a project for drive train and chassis as well as the complete body. In 2009, the first step for 3D Master was done by introducing product definitions without drawings. Some of these project results have been included in the above description of 3D master method (Kitsios and Haslauer, 2014). Riascos *et al.* (2015) refer to the use of 3D master models at VW for the concept development of cars. Johnson Controls tested 3D master method in different areas such as molding, welding and quality control. First experiences seem to be good, but the effort for implementation was high (Fecht, 2015).

The aerospace industry has also launched the 3D master method in specific areas. Airbus uses digital CAD models as main information objects for all data customers in the product development process. According to Klauke (2006) "all decisions are based on the digital mock-up". Boeing puts more effort into the use of intelligent, digital three-dimensional CAD models rather than two-dimensional drawings (Modern Machine Shop, 2010). Siemens (2012) correspond to an example of a project in aircraft design, replacing all two-dimensional paper drawings by the introduction of 3D master method and simultaneously reducing the expenditure of time for design and mold making significantly.

3.3.3 Mercedes-Benz Cars (MBC)

Design and development without drawings was firstly used at MBC in 1998. In the context of a pilot project in body-in-white at MBC the entirely digital development was tested. Meanwhile, development with 3D master method has been additionally introduced in selected areas of both interior and exterior work and powertrain development.

For drawing-less design in body-in-white a structured start model is used, which has been implemented in all manufacturing methods and with regard to the manufacturing process. Substantial key factors are master data and weight management as well as the production and documentation of fasteners. Programmed macros enable an individual view control, which visualize needed information depending on the data customer. In the meantime, 3D master method has been launched into all areas of body-in-white, only add-on parts of suppliers are still approved by drawings. First experiences have shown time savings for development of up to 20% (Krause, 2012).

Interior and exterior work develops and releases selected supplier parts of particular model series without drawings. Basic elements are provided by the administration of geometry-referred data and views as well as component-spreading references by using well-known geometry. Variant dependence and master data information are visualized by a PDM system (Sailer, 2011).

Pilot projects in powertrain tried to show the feasibility of 3D master method at selected components with complex geometry and manufacturing information. Therefore, the automatic data transfer from drawing to model and further on to a variant component was tested with a cylinder head in the first step. The second step was conducted by parameterizing data of different objects of a transmission. This trial proved that the produced information can be used in downstream processes. Positive feedback from those pilot projects led to the fact that 3D master method is now productively used in different ranges of powertrains. Beside the data set of forge tools, selected objects for energy conversion processes in fuel cell development are now designed without drawings. Additionally, the serial production of complex cross members investigates the effects of using only digital data for the co-operation of different assembling sections by the example of the integral support (Gröne, 2013).

3.4 Summary

3D master method pursues the approach of an entirely digital product description. The 3D master model is used as main information object for all downstream processes and replaces parts lists and 2D drawings as key elements of technical product description. The custom-designed structuring of data

enables downstream processes to extract needed information appropriately. Redundant data management is avoided by pursuing the single-source principle. The digital supply of all information causes an automated subsequent processing of implemented data by downstream processes. The complexity of the total process as well as the efforts for maintenance and change management are significantly reduced by omitting the 2D drawings. Additionally, a more intuitive approach to the model is offered to data users, as three-dimensional visualization enables the model to be more realistic than a drawing.
The use of Product Manufacturing Information (PMI) enables the integration of manufacturing information in the 3D model. PMI is already used in numerous implementations of 3D master method for complete digital information integration and representation.

4 DEFICITS OF THE CURRENT PROCESS

Two-dimensional master drawings form the key element of technical product documentation in the development of current wiring harnesses. All modules of a particular installation space are shown in one drawing, which has an appropriate complexity. The combination of all shown modules represents a disproportionate extent, which will never be built in reality. The drawing contains all possible information for different data customers and quickly becomes confusing by adding changes. The direct assignment of a represented wiring harness segment to the associated 3D CAD model is not possible. Changes are predominately maintained in drawings, which leads to a discrepancy between drawing and 3D model. The diameters, which are reflected by space reservations, often lack the necessary plausibility and reality, since they include further supplements for possible facelift changes in addition to the disproportionate representation. Furthermore, neither the DMU wiring harness is configurable, nor are all relevant components fully digitally represented. New solutions by means of the Harness Container for Viewing and the advancement of digital viewers only reduce the effects of the problem, yet not the root cause.

5 3D MASTER CONCEPT FOR WIRING HARNESS DEVELOPMENT

A solution to the described problem can be found in the digital support of wiring harness development with the 3D master method. Many arising problems can be solved by the implementation of 3D master method as well as the direct derivative of all information from only one digital data source. This concept of the integration of 3D master method into the wiring harness development process at MBC is developed at present in the context of a dissertation.

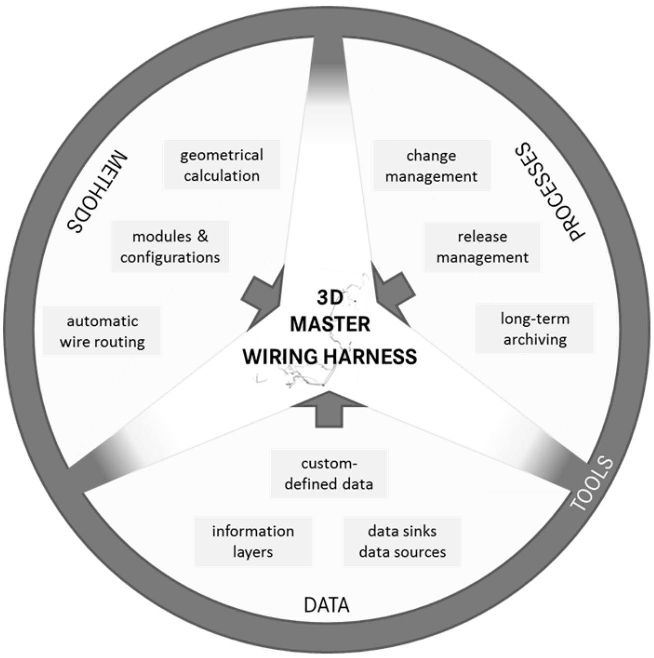

Figure 4. 3D master concept for wiring harness development

Key elements of each concept are the integration of data, processes, methods and tools. Data constitutes any kind of information that is used during the wiring harness development process. Processes represent any activities and actions which run after a given operational sequence. Methods are components of processes and represent ways of working, standardized approaches and techniques. Tools support managing, administrating and using data with defined methods within a process.
In a first step, all existing data is analyzed and clustered regarding its occurrence in the product life cycle and during the development process. Apart from data sources and data sinks, it is defined which data has to be present at which time and in which density. Furthermore, it is considered which data has to be enriched with additional information in which stage of the development process. The different kinds of information are divided into several information layers. These layers also differentiate steps of data definition. Afterward, relevant aspects of data customers are defined in order to provide a custom-designed database. Therefore, each data attribute is assigned to these elements.
Moreover, all existing processes that are needed for wiring harness development are investigated, analyzing which changes and new processes are required for the introduction of 3D master method. Necessary steps for change management are regarded, release processes are defined and a new process for the long-term archiving of the digital 3D master wiring harness models is developed. Additionally, interfaces for suppliers are regarded and established in order to assure the process-consistent development of wiring harness with 3D master method.
The close-to-reality representation in a complete DMU model requires further methods, which are developed in the context of the dissertation. In order to ensure the realistic computation of geometrical characteristics, new approaches are provided for weight, cross section and length calculation. In the early design stage declarations of weight are simply estimated or empirical values. They are only replaced by the material measured weight in the context of the localization. With the support of a yet to develop method, it should be possible to give better statements about the expected weight of the wiring harness in earlier design stages, based on an intelligent DMU model. Several formulas can calculate cross sections of round, elliptical and rectangular wires. These are validated and combined with the supplements for further design changes in order to achieve a uniform, verified formula. This is to be able to give a better and more realistic prediction of expected cross section changes for future model series. KBL format differentiates types of length (DMU length, production length, supplement length). In order to increase the significance of the virtual length (DMU length), a formula will be developed that considers length supplements depending on both the associated cross section and the used bending radius. For the realistic representation of wiring harness components, new methods for automatic routing of connections by wiring lists have to be developed in order to enable importing wiring diagrams in a 3D CAD environment. This includes the consideration of electrical classes as well as separation codes, which describe, for instance, a necessary separation of antenna and signal cables from the point of view of electromagnetic compatibility (EMC). Moreover, a new approach for defining customized modules as well as associated configurations has to be found that provide a realistic, configurable representation of wiring harnesses in DMU. Thus, it is made possible that a realistic minimal and maximum cross section can be indicated for each segment of the wiring harness.
Furthermore, it requires new plausibility checks for the quality confirmation of developed DMU models. These checks will verify and validate the applied methods as well as ensure the consistency of the used data.
Besides developing the 3D master concept, existing CAD tools are compared in order to assure the optimal implementation of the concept and to enhance existing tools meeting the demand. Therefore, gradual requirements are generated from the developed methods and their implementation in the different software tools is compared.

6 CONCLUSION AND OUTLOOK

Increasing complexity of electrical and electronic components pushes present development processes to its limits. Simultaneously, two-dimensional approval drawings obstruct the way to an entirely digital product description. The advantages of development without drawings have been described and the deficits of the current processes have been shown. Wiring harness development of Mercedes-Benz Cars will be able to get along without paper drawings by using 3D master method. Needed steps to achieve this goal as well as new supporting methods for a more realistic representation of wiring harness components have been described in this paper.

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