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AN APPROACH FOR MORE EFFICIENT VARIANT DESIGN PROCESSES

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ABSTRACT

Today, as a result of a steady increasing pressure to reduce costs for being competitive in the automotive supply industry, the majority of the products are designed by adaption of already existing products to new requirements. In the embodiment design phase, engineers take CAD models as the design base and adapt those to the new requirements. Due to the fact that the same models are used in different generations of product variants, the models are getting more and more complex and unstructured. Thereby the effort for adaptation increases. By using parametric design this effort can be reduced significantly.
In addition to the optimization of the embodiment design process, further capability for cost reduction can be found in the design process. Mandatory analyses, like the FMEA, have to be redone completely within every variant, although the main product remains similar. In order to reduce the effort, the FMEA has to be standardized.
In the following, the presented approach shows how the approximation of parametric models in the embodiment design phase can be enhanced by using function structures and parameters derived from the FMEA execution in order to shorten the time needed for the variant design process.

Keywords: Variant Design Process, FMEA, Embodiment design, CAD

1 INTRODUCTION

In times of globalization, the strategic aim of every supplier has to be the cost leadership without neglecting the product quality and the adherence to delivery dates [1]. In domains, such as body and exterior, economic growth is not expected in the automotive supply industry [2]. Due to the worldwide economic crisis, Original Equipment Manufacturers (OEM) and suppliers are facing a further increasing pressure on development costs. The OEMs are able to deal with this problem by shifting the development effort to the suppliers. [3] Therefore, the suppliers have to improve their development processes in order to reduce the development costs.
In the mentioned domains, the products designed by one supplier are fulfilling the same main function, e.g. “Keep the bonnet closed” for a bonnet locking system. The applied physical principles realizing the functions remain similar as well. Just the geometric layout of functional elements and the shape of those are different. Therefore, in the automotive supply industry, the products are designed by variant design [4]. From projects in this field, it is known that the variant design process is based on adaptation of already existing product variants. Normally the engineer selects the product variant with which he is most familiar; therefore, the most recent product is the common choice as initial point of engineering design. As the engineer uses this design model repeatedly, the CAD models are getting more complex with every new product variant development. The part’s features which are getting dispensable during the advancement of the design process often remain in the CAD model. These features still exist in later product generations. As a result, the manufacturing process of the parts is more expensive. The increasing number of elements in sketches complicates the handling of the models, leading to longer development times.
The first aim is to make the handling of the CAD models easier and therefore to reduce the time spent for development. In the 80s, in the Automotive Industry the customer orientation increased. In order to detect problems early in the design process and to take the right measures, the Failure Mode and Effects Analysis (FMEA) was introduced [5]. Today, the FMEA execution accompanies the whole design process [6]. For every new product variant, the FMEA has to be redone completely, even though the product itself basically remains the same.

The second aim is to decrease the effort spent for the execution of the FMEA in order to reduce the expenses in the design process.
This paper describes how the time spend in the embodiment design phase of a product variant can be reduced by using parametric and direct modeling techniques in the CAD system. Further, it is shown how the design process is improved by introducing standardized system elements in the FMEA as well as reusing data out of the FMEA in the embodiment design phase. An introduction into the application of FMEA in automotive industry is given first.

2 BASICS

2.1 Bonnet locking systems

As mentioned before, the approach presented in the following is applicable for products developed by variant design. In chapter 4, the bonnet locking system is used as a case study for presenting the application of this approach. In chapter 2 and 3, examples are shown using the bonnet locking system for explanation purposes. The bonnet locking system consists of the lower part shown in Figure 1 and a striker which engages in the catch bolt. Bonnet locking systems are fulfilling the function of keeping the bonnet in a secure position. The function is always fulfilled with the identical mechanical solution principle: The assembly's core consists of a ratchet brace and a catch bolt mounted in a housing (Figure 1).

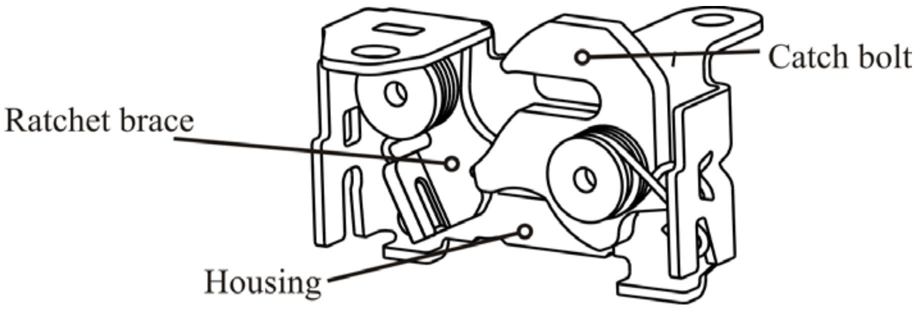

Figure 1. Bonnet locking system, lower part

2.2 Execution of System-FMEA-Product

The System-FMEA-Product is applied throughout the whole design process. As a preventive reliability method, possible system failures can already be detected in the design process. In this context, the system is defined as each technical entity, which can be divided into system elements. [7]
According to the guideline provided by the German Association of the Automotive Industry (VDA), the System-FMEA-Product is executed in the following five steps:

1. System Elements and system structure
2. Functions and Function structure
3. Failure Analysis
4. Risk Assessment
5. Optimization. [6]

Due to convenience in the following the term "System-FMEA-Product" is set equal to "FMEA".

2.2.1 System Elements and system structure

In step 1 of the FMEA procedure the interfaces of the system are determined before the structure of the whole system is worked out. The top element represents the considered system. On the lower levels the system elements can either be sub-assemblies or parts. The number of levels for setting up this system structure is arbitrary. [6]

2.2.2 Functions and Function structure

Functions describe the relationship between the inputs and the outputs of the system [8]. In the next step, the functions of all system elements are determined beginning with the complete system. The system implements the main function; the functions realized by the sub-assemblies contribute to the main function (Figure 2) [7]. Taking the functions into account exclusively, a hierarchical function structure is derived. Considering the collocation to the system elements as well, a product architecture is set up. The product architecture is the scheme by which the functions of the product are collocated to physical elements [9], e.g. sub-assemblies, parts or features.

2.2.3Failure analysis

Based on the functions, a failure analysis is carried out for each system element. By doing this failure analysis all failure functions are detected, which lead to an insufficient fulfillment of the associated function and the superior function as corollary (Figure 2). For abstract functions such as the top function, failure functions can be determined by negation of the function itself. Failure functions of components are defined as physical failure modes such as fracture, wear-out, jams, clamps [7], and insufficient manufacturing.

In the majority of cases the superior failure function is caused by a failure of subordinated system element. Therefore the failure analysis has to be carried out until the lowest system element is reached. Insufficient manufactured parts lead to failure of a function or an insufficient fulfillment of the selfsame function. Therefore, a systematic search of failure functions on part level is carried out by checking every relevant geometric parameter of the examined part.

Geometric parameters in this context can be either thicknesses or angles but also distances between surfaces (chapter 2.6). For example, a failure of a geometric parameter can be a wrong wire diameter of a spring leading to a spring stiffness being too strong which causes a malfunction of the whole system. The FMEA requires a systematic analysis of the product. By doing this analysis, a complete list of geometric parameters is derived. These geometric parameters are reused in the embodiment design phase.

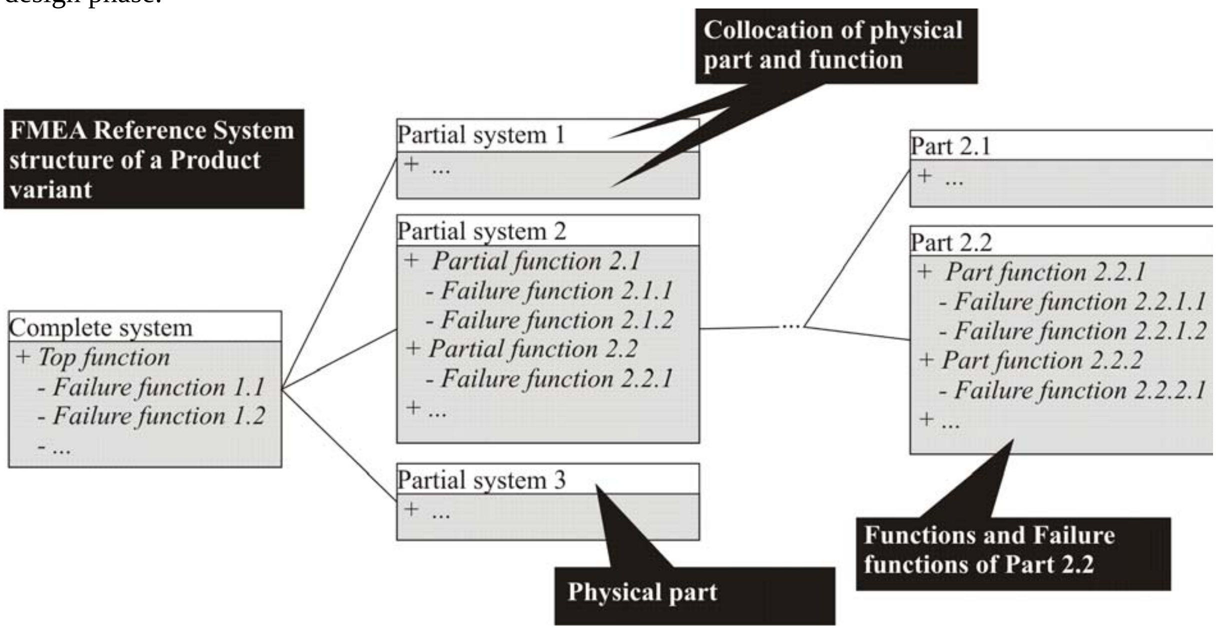

Figure 2. FMEA of product

2.2.4Risk assessment and Optimization

After the definition of the failure functions the risk assessment is executed. For every failure function severity rating, occurrence rating and detection rating are determined and the risk priority number (RPN) is calculated by multiplication. Based on the RPN, a decision is made whether an optimization is necessary. [5]

2.3 Standardization of FMEA

In variant design the effort necessary for execution of the FMEA is easily reducible by standardization. Due to a similar system structure using the same physical principles fulfilling the same functions, the structure of the risk assessment remains constant among the product variants. Based on already existing product variants, standardized elements for each single system element are introduced in the FMEA. Each system element contains a reference set of functions, failure functions. The reference set concludes all functions and failure functions being realized in least one product variant.

In case of a new product variant development it is checked which functions are part of the new variant and which ones are omitted, based on the reference variant of the FMEA (Figure 3). If a new function has to be implemented, it is added to the reference set.
When implementing a new function in the product variant, it has to be checked, which system elements must be changed for this new function. For these system elements steps 1-5 have to be redone. The other system elements only need step 4 and 5 to be redone, leading to a significant effort reduction in the FMEA execution. In this manner it is reasonable to implement standardized elements early.

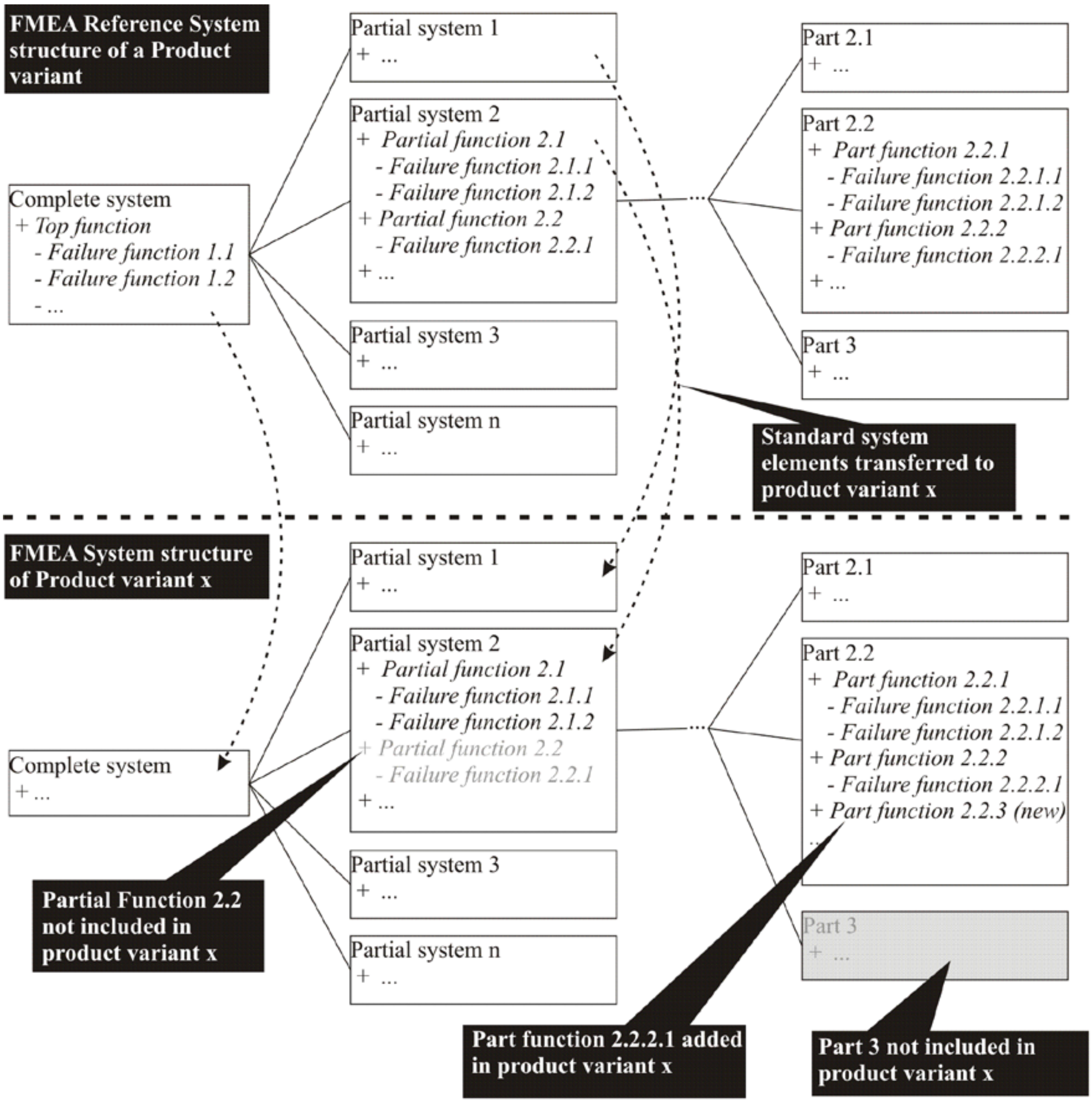

Figure 3. FMEA in variant product design

2.4 Embodiment design

2.4.1Feature

Features are physical elements of a part fulfilling part functions, e.g. the upper arm or the boring. While the layout of the assembly is identical, the layout of the parts features might vary, such as the position of the stop in the opened state (Figure 4).

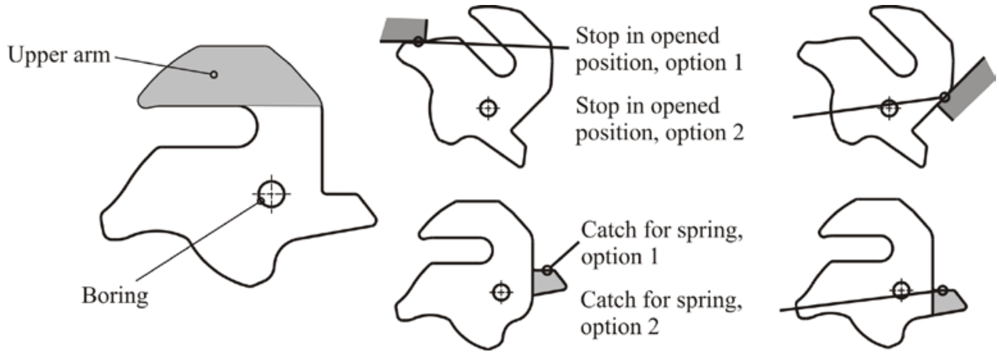

Figure 4. Examples for features of the catch bolt

2.4.2Geometric Elements and Skeleton model

Geometric Elements are planes, axes, points, or coordinate systems in the CAD model. A skeleton model is a part-file which contains only geometric elements. Each geometric element represents an item of the product. For example planes are representing surfaces and axes are representing axes of rotation (Figure 5). The positions of those geometric elements are defined by parameters.

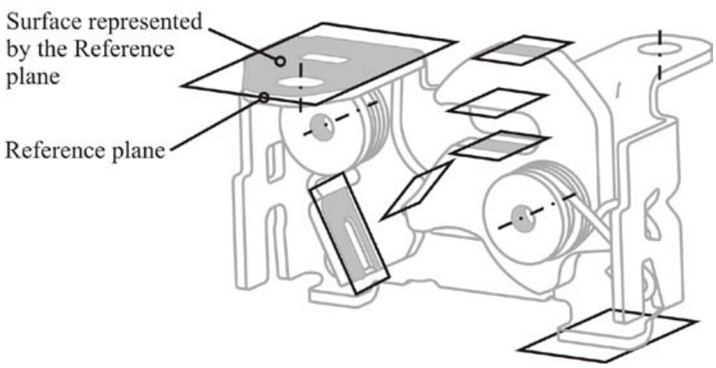

Figure 5. Skeleton model (The product model is not part of the skeleton model.)

2.4.3Parameter

Geometric parameters are user-defined variables to adjust the CAD model. Those variables represent dimensions like a length or an angle. The embodiment design process is normally initiated by defining the main geometrical sizes of the product, either directly given by the specifications or determined by the engineer. The aim is to define the dimensions in the product model only once. When the dimensions are modified, the model is adjusted according to these parameters. Examples for dimensions being parameters are shown in Figure 6.
The different layouts of the features (Figure 4) are also determinable by parameters. In that case the parameter to be determined is “Stop of catch bolt in opened position” and the settable value is either “option 1” or “option 2”.
While an adaptation of a geometric parameter causes no new failure analysis during the FMEA execution (chapter 2.2, steps 1 to 3), a new layout of the features requires the system structure, the functions, and the failure functions to be checked. Risk assessment and the optimization have to be revised anyway.

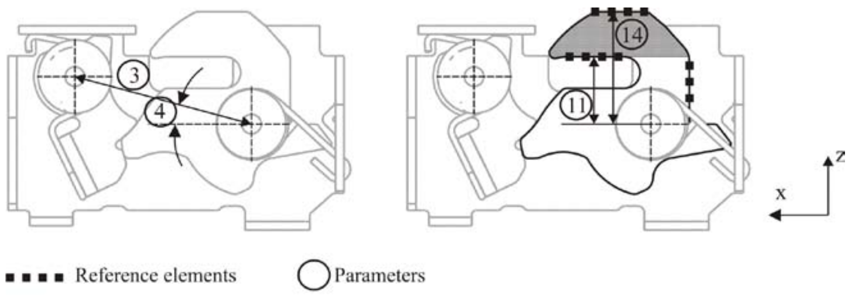

Figure 6. Extract of Parameters

3 APPROACH

In the Automotive Industry, the effort spend for developing products by variant design can be significantly reduced without reducing the quality of the product, if a continuous use of product data is established. Due to a standardization of the FMEA, a reference function structure and a reference set of geometric parameters exist. In case a reference function structure or reference set of geometric parameters have to be established, a similarity analysis has to be carried out. The establishment is done similar to the creation of a reference product structure [10].

In case of a new order, the system FMEA is executed. Based on the reference set of functions, those functions are selected which need to be realized in this particular variant. The functions are determined by the engineer based on the requirements list provided by the OEM. An approach to how the engineer can be supported in the selection of the required functions is worked out in the PONNGA project [11].

The solution presented here is based on three layers (Figure 7). The first layer contains the function structure derived out of the FMEA. Based on the selection of the functions, parameters and geometric elements related to these functions are activated or deactivated. Therefore, in the skeleton model only those geometric elements are provided which are needed to design this particular product variant, eliminating features related to the deactivated geometric elements. This clearly arranges the CAD model and reduces the complexity of the product.

Layer 2 represents the skeleton model including the geometric elements and the parameters. Each parameter is either collocated to one dimension determining the position of a geometric element or it manipulates a part directly, e.g. the thickness definition of a sheet metal part.

The features and parts situated in layer 3 are basically defined by the parameters and geometric elements of the skeleton model. The geometric elements not being determined by the parameters are modeled directly in the CAD part by adding further elements, such as fillets and rounds.

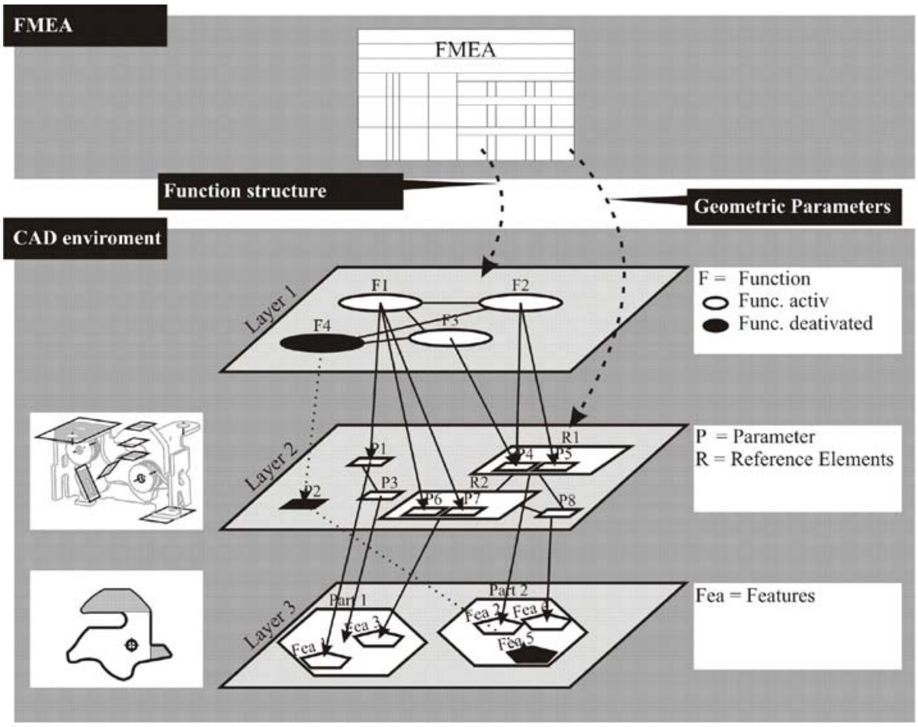

Figure 7. Layer representation

3.1 Setting up the approach

The first step to realize this approach is to set up a product architecture, consisting of the function structure and the feature structure. The product architecture is elaborated based on all existing product variants. By going through all existing product variants, each part is examined for realized features. Each feature being realized in at least one product version is collocated to the part function out of the reference system structure of the FMEA. This collocation of function to feature represents this product architecture (Figure 8). Out of the reference system structure, the set of geometric parameters is taken and collocated to the features which are determined before.

In the application of the approach, the required partial functions are selected; the no longer required partial functions are deselected (layer 1). Automatically, the related geometric elements and parameters are deactivated (layer 2), disabling the embodiment design of the related features (layer 3).

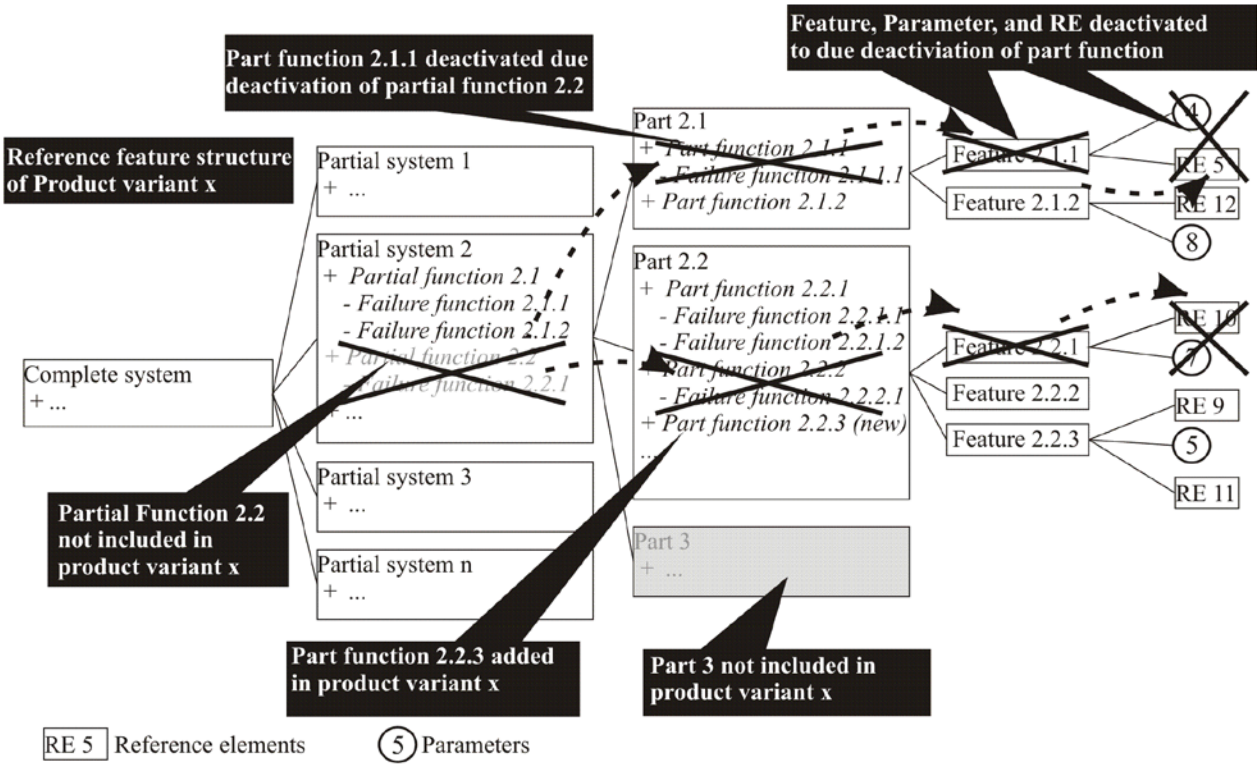

Figure 8. Establishment of the Product architecture

3.2 Part modeling

In the CAD-system, the parts are modeled using the selected geometric elements. All geometric elements belonging to one particular part are transferred from the skeleton model to a separate part file. The basic geometry is designed using the geometric elements. The final shape of the part is created by using the direct modeling techniques (Figure 9).

The linkage between the geometric elements in the skeleton model and the part-files still exists. When an update of the assembly's geometry is necessary, the update will be made in the skeleton model. The part files are automatically adjusted.

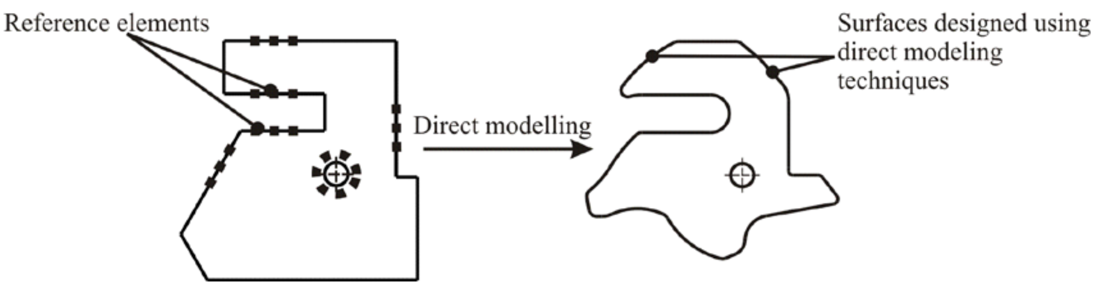

Figure 9. Part modeling

4 CASE STUDY

In the Automotive industry, OEMs order a new system by providing the supplier specifications containing requirements. Normally the specifications are copied from a previous version and edited afterwards. Basically the requirements remain mostly similar. An example is shown in Figure 10.

Based on the provided specifications the development is initiated. The system FMEA is executed continuously in the design phase. Due to the similar requirements, the System structure and the functions of each system element remain similar, too. In order to reduce the effort for the FMEA, standardized system elements are elaborated containing a reference set of functions and failure functions. The engineer is able to decide which functions are needed to fulfill the requirements of the new order. All unnecessary functions are omitted; new functions have to be added. (Figure 10) An example is shown in Figure 11. Certain bonnet locking systems require a high stiffness. The engineer is able to determine whether the housing requires additional elements to achieve the higher stiffness (Figure 11). If the regarding of the stiffness is not required, the related function of the housing is deactivated.

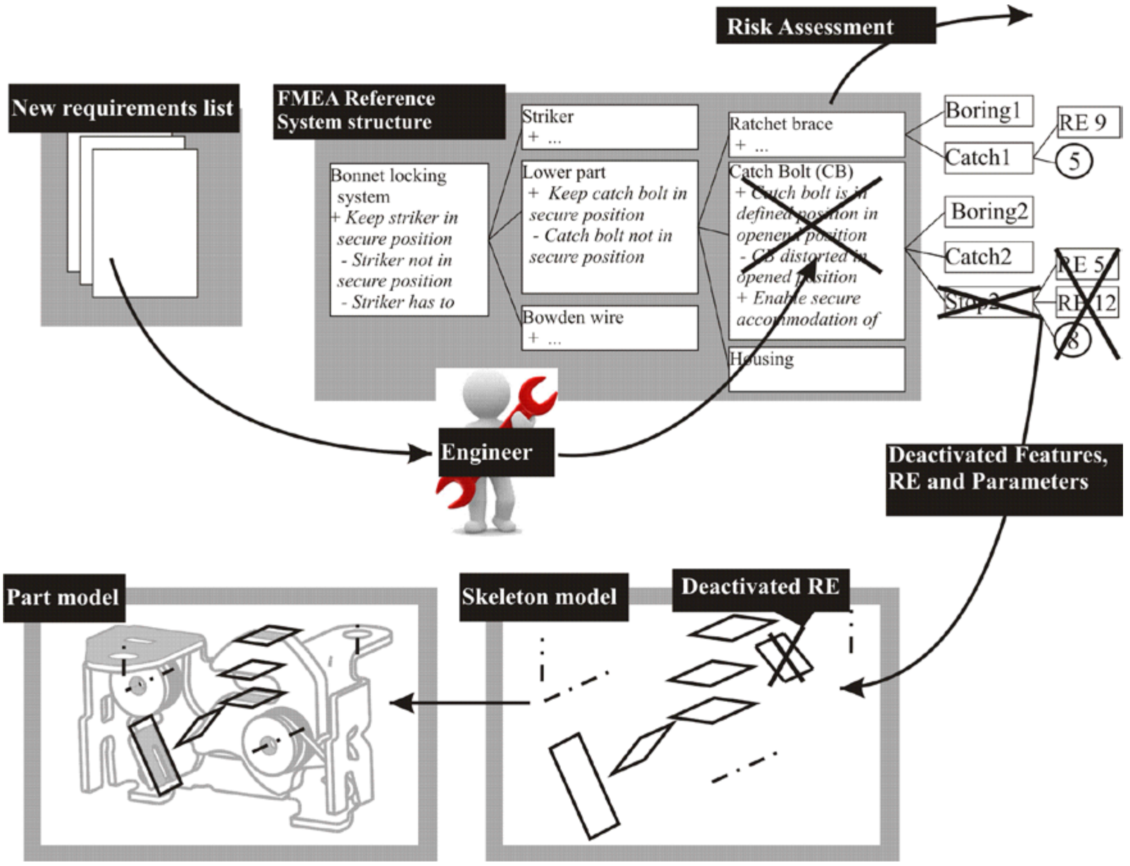

Figure 10. Application of the approach

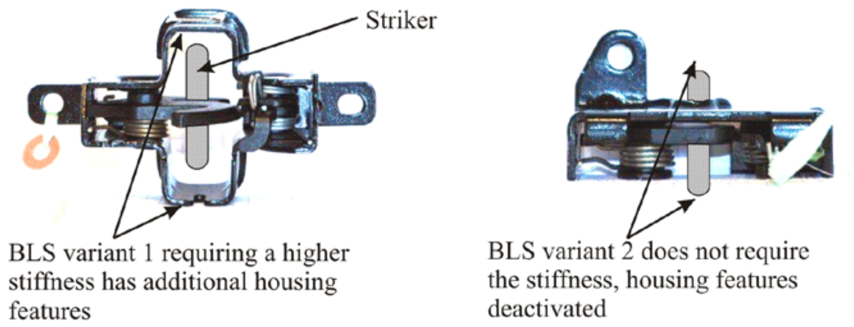

Figure 11. Bonnet locking system variants with different requirements

The set of functions is exported into an MS Excel-file. The data base contains the same system element as the FMEA software. All not required functions are deselected, setting the related parameters and REs as “deactivated”. (Figure 12) Thus the initializing parameters for the skeleton model are provided, the start of the part modeling is enabled. The Excel-file directly controls the skeleton model. CATIA provides an interface for Excel-files.

System Element	Function	Subordinated SE	Features	Parameter	Geometric Element	Activated?
Bonnet locking system		Striker; Lower part; bowden wire …				true
	Keep striker in secure position					true
…	…					
Striker						true
…	…					
Lower part		Ratchet Brace, Catch bolt, housing, …				true
	Keep catch bolt in secure position	Catch bolt				
	…		…			
Catch bolt						
	Catch bolt is pivotable		Boring2	12		true
				13		true
				14		true
…	…		…			
	CB is defined position in the opened state		Stop2		5	false
					12	false
				8		false
				15		false
				16		false
…	…		…			

Figure 12. Excerpt of the data base

In the embodiment design phase in CATIA, the engineer creates a new set of files including an assembly file, a skeleton model, and the required part files. All parameters of the active geometric elements can be set in the skeleton model. Having set these main boundary conditions, the part design can be started.

In CATIA, geometric elements and parameters are transferred to the part-files in three steps: publishing, copying, and pasting. The publishing enables the elements to be copied from the skeleton model and to be pasted into the part-files. (Figure 13)

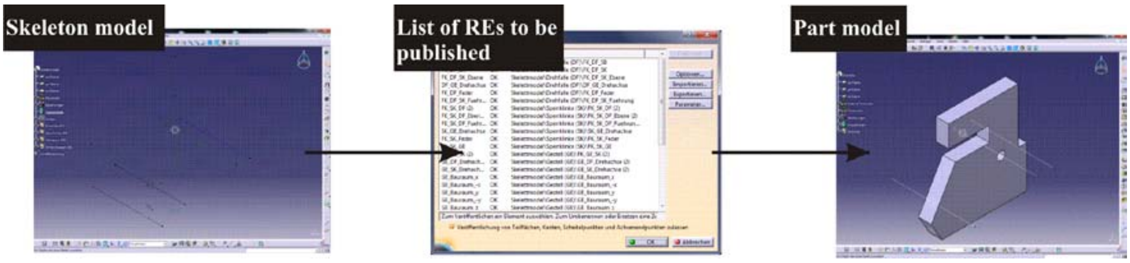

Figure 13. Publishing Reference Elements to enable part design

The advantage of this procedure is the remaining linkage between the geometric elements in the skeleton model and the part-files. Adaptations that have an impact on the assembly are made in the skeleton model. All part-files related to this change are updated, giving the CAD model an unambiguous state.

As a result, the model just contains the features being needed. Complex models arising by reason of using the same CAD model over generations of product variants are avoided. The time needed for adapting the whole model is significantly reduced.

5 SUMMARY AND OUTLOOK

In this paper, an approach is presented how the design process for products designed by variant design can be improved. Data elaborated by executing the FMEA is reused in the embodiment design phase, in order to reduce time need. Further, the costs are reduced and the quality of the product is improved.

In the Automotive industry the execution of an FMEA is mandatory for all companies developing and manufacturing products. Today in supply industry the FMEA is completely redone, even though most of the products remain similar in functions and physical effects, changing only the geometrical dimensions. In order to reduce the effort spend for the FMEA, standardized elements are elaborated for the system items, which are reused. Doing this, three of five steps during the execution of the FMEA are avoided.

As a part of the FMEA, a function structure and the geometric parameters of the parts are determined. Both are reused in the embodiment design phase. The function structure is used to select features of the product to be developed. Doing this selection a skeleton model, used as a starting model, is adjusted. Only those required geometric elements are provided which are necessary to develop the

required features of this model. The mentioned geometric elements are manipulated using the geometrical parameters. The use of the geometric elements supports the engineer, because they provide the main constraints for the embodiment design. Necessary changes having an impact on more than one part are done by adjustment of parameters in the skeleton model. The part models are adjusted automatically. Applying this approach, the time needed for the development of a new variant is significantly reduced without reducing the quality of the product. Due to this the costs are reduced.
This approach is applicable for mechanical parts like the shown bonnet locking system. It has to be checked whether this approach is also appropriate for systems having electrical components. Further, the use of two separate software systems, one for the FMEA, one for the control of the skeleton model has to be improved, either by using just one system or by the establishment of a standardized interface between the software systems.

REFERENCES

[1] Maggioni, S., Thiele, R., Rivard, S. and Turner, H. *Leadership in the Automotive Industry*, 2006 (Spencer Stuart, http://content.spencerstuart.com/sswebsite/pdf/lib/Automotive_Study_March_06.pdf)

[2] Bernhardt, W., Dressler, N. and Tóth, A. *Mastering Engineering Service Outsourcing in the automotive industry*, 2010 (Roland Berger Consultants, Munich)

[3] Wallentowitz H., Freialdenhoven, A. and Olschewski, I. *Strategien in der Automobilindustrie*, 2009 (Vieweg + Teubner, Wiesbaden)

[4] Franke, H.-J. *Variantenmanagement in der Einzel- und Kleinserienfertigung*, 2002 (Hanser, Munich)

[5] Tietjen, T., Müller, D. *FMEA-Praxis*, 2003 (Hanser, Munich)

[6] VDA. *Sicherung der Qualität vor Serieneinsatz, Vol. 2*, 1996 (Henrich GmbH, Frankfurt)

[7] Bertsche, B. *Reliability in Automotive and Mechanical Engineering*, 2008 (Springer, Berlin)

[8] Pahl, G., Beitz, W., Feldhusen, J., Grote, K.-H., Wallace, K. and Blessing, L. T. *Engineering design – A systematic approach*, 2007 (Springer, London)

[9] Ulrich, K. T. and Eppinger, S. D. *Product design and development*, 2008 (McGraw-Hill/Irwin, Boston)

[10] Nurcahya, E. *Configuration instead of New Design using Reference Product structures, CIRP Design Conference*, Berlin, March 2007, pp. 1-10 (Springer, Berlin)

[11] Feldhusen, J., Nagarajah, A. and Schubert, S. *A Data Mining Method for selecting the suitable existing product variant as a development base for a new order, DESIGN 2010,* Vol.2, Dubrovnik, May 2010, pp.895-903 (Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia)

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