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Method Integration to enhance the Quality Capability of the Product Development Process

Dipl.-Ing. Sebastian Schlund
e-mail: schlund@uni-wuppertal.de

Dipl.-Ing. Stefan Ott
e-mail: ott.stefan@vdi.de

Prof. Dr.-Ing. habil. Petra Winzer
phone: +49 (0) 202 / 439-2061
e-mail: winzer@uni-wuppertal.de

University of Wuppertal
Faculty Civil Engineering, Mechanical Engineering, Safety Engineering
Research Group "Product Safety and Quality Engineering"
Gaussstrasse 20
42119 Wuppertal
Germany

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MORE THAN THE SUM OF ITS PARTS

In order to achieve quality goals, adequate methods have to be used during all phases of the product life cycle. In particular preventive quality engineering methods play a decisive role for product quality and product costs, which are widely determined in the early stages of the product development process (cf. VDI 1994, p.5).
To enhance the quality capability of the product development process, various process models and guidelines have been developed (cf. Moehringer, 2005). They rely on a large multitude of methods and techniques and are all aiming at one common goal: preventing faults - preferably in the early stages of the development process.

Despite all these efforts the number of breakdowns and factory recalls does not seem to diminish (cf. KBA, 2006). Obviously risk potential remains, which is not or only partially addressed by the conventional, mostly isolated, application of these methods. By integrating different methods, advantages of several complementary approaches are combined in order to identify faults and their potential causes more effectively (cf. DIN, 2005, p.11). Work in this field has already been done combining methods such as QFD and FMEA (Sesma Vitrian, 2004) or FMEA and FTA (DIN, 2004, p.8). Thus the contribution to the quality capability of a product is more than the sum of the outputs of separately used techniques. To show the potential of this method integration a conjoint use of Fault Tree Analysis (FTA) and the DeCoDe method of **De**mand **Co**mpliant **De**sign will be discussed.

DEPENDABILITY ANALYSIS USING FAULT TREE ANALYSIS (FTA)

“The FTA represents an analytical method of dependability analysis. It is concerned with the identification and analysis of conditions and factors which cause or may potentially cause or contribute to the occurrence of a defined undesirable event” (DIN, 2004, p.4). Depending on the scope of the application this so-called top event is represented by an undesirable parameter value in the field of product safety, operability or cost effectiveness.
As the FTA belongs to the group of deductive (top-down) methods, the potential causes of an undesirable event are subsequently tracked down to so-called ‘basic events’. The Fault Tree itself shows graphically the relations between these elements. On the basis of this hierarchical structure a qualitative analysis can be undertaken. Moreover, in case that the probability of occurrence of the basic events is known, a quantitative analysis using Boolean logic or Markov models can be carried out. Both modes of the FTA are used in the product development process.
This paper focuses on the qualitative aspects of the FTA, leaving out any statement on failure rates and failure times. Thus the proposed procedure of an FTA (DIN, 1981) can be limited to the following highlighted steps (Zacher, 2006):

1. **System analysis**
2. **Definition of the top event and its failure criteria**
3. Definition of the respective dependability parameters
4. **Derivation of the basic failure events**
5. **Construction of the fault tree**
6. Assorting the probabilities of occurrence or other attributes to the basic events
7. Analysis of the fault tree
8. Appraisal of results

The successful conduction of a FTA requires several preconditions. Firstly, system elements have to be independently definable (Feldhusen, 2005) and secondly structures of both the product components and functions have to be available (Schneeweiss, 1999).

DEMAND COMPLIANT DESIGN USING DECODE

Following the initial idea of requirement engineering and systems engineering the objective of the DeCoDe method is an integrated, holistic and traceable management of requirements during the entire product life cycle (Ott, Lex and Winzer, 2005). Conventional methods and utilities either consider solely the elicitation of requirements (list of requirements, tender specification, and performance specification) or their structuring (pairwise comparison). Other methods like the QFD focus on the translation of the voice of the customer (VoC) into engineering specification, but do not consider other stakeholders. DeCoDe brings together these approaches in order to survey complex systems over their entire life span. For this reason the respective system is represented in four different views. The requirements of all stakeholders are elicited, grouped, compared and ranked, resulting in a requirements structure of the respective system. This structure now has to be mapped with the system's functions, processes and components (figure 1).

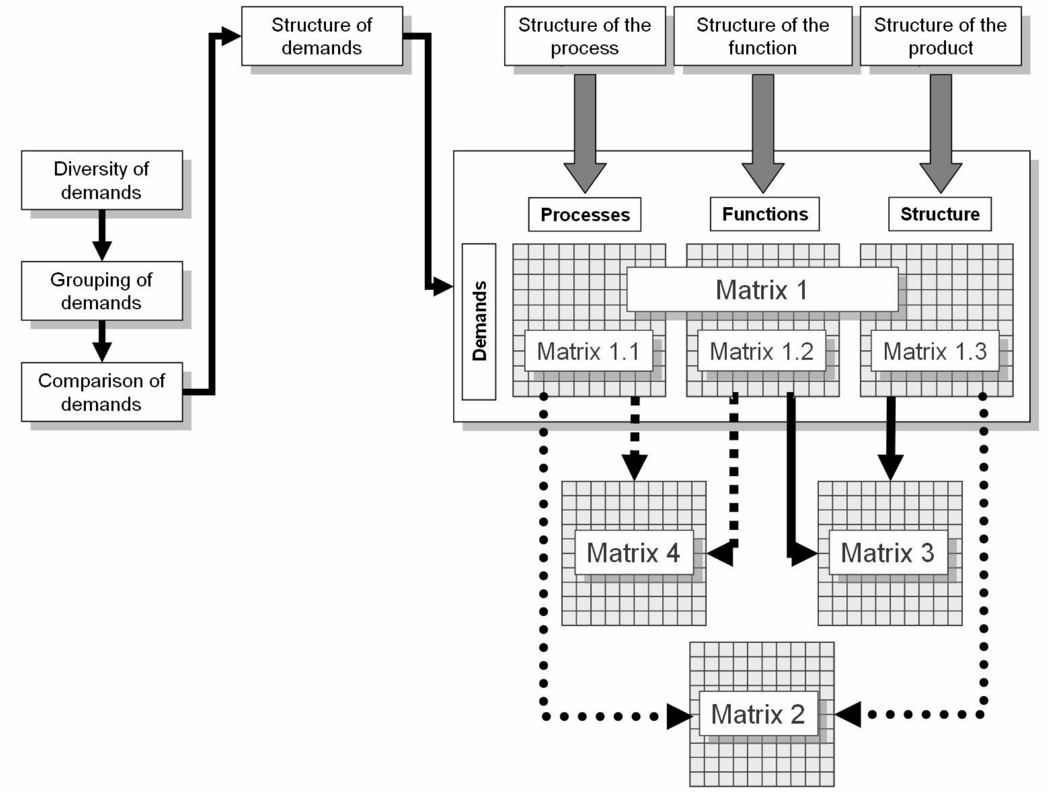

Figure 1: Schematic description of DeCoDe (Ott, Lex and Winzer, 2005)

While the clear definition of the system structure enables a deeper understanding of the respective system, the additional benefit is created by the systematic identification of the relations between the individual system elements. The analysis of these interactions pinpoints potential weak spots in systems design. Using consequently this bottom-up method allows the systematic analysis of the impact of structural changes on the entire system.

INTEGRATING BOTH METHODS

Both, FTA and DeCoDe are based on detailed knowledge of the system, its elements and its surrounding. For this reason a system analysis is conducted (DIN, 2004), (Sitte and Winzer, 2005). In case of the FTA the underlying standards and guidelines do not give precise directives of its proceedings. Conducting a top-down method like the FTA oversight and omission are considered as the major disadvantages (Barlow and Lambert, 1975) and thus the risk of construction of a faulty fault tree is of particular importance.

In this point a combination with a bottom-up approach like DeCoDe seems sensible.

By cross linking the elements of the different views of a system design, gaps can be identified. Furthermore a system representation using matrices allows a transparent and well structured analysis. Hence, both methods complement one another – the identical product and function structure can be used together, so that it has to be set up only once. Regarding the structure of functions, the FTA does not consider interrelations between function-subsystems and function-elements respectively. The functions of a given system are only derived from its components. In case the latter is overlooked, interrelated functions will be left out of the scope of the analysis. Using the DeCoDe components-functions-matrix (matrix 3 in figure 1), relations between components and functions can be examined in both directions. Additionally taking into account the process-related matrices of DeCoDe, the FTA can be even more precise. Considering the processes of a system's life cycle possible supplementary sources of defect might emerge.

APPLICATION TO A PRACTICAL EXAMPLE

Taking a gearbox of a motor drive for the backrest angle adjustment of a car seat as example, the FTA and DeCoDe have been applied. The practical implementation has been carried out by Zacher in the context of a Bachelor's Thesis (Zacher, 2006).

Following the procedure stated in the relevant guideline (DIN, 1981) in the first step of the system analysis the system function is defined (cf. figure 2).

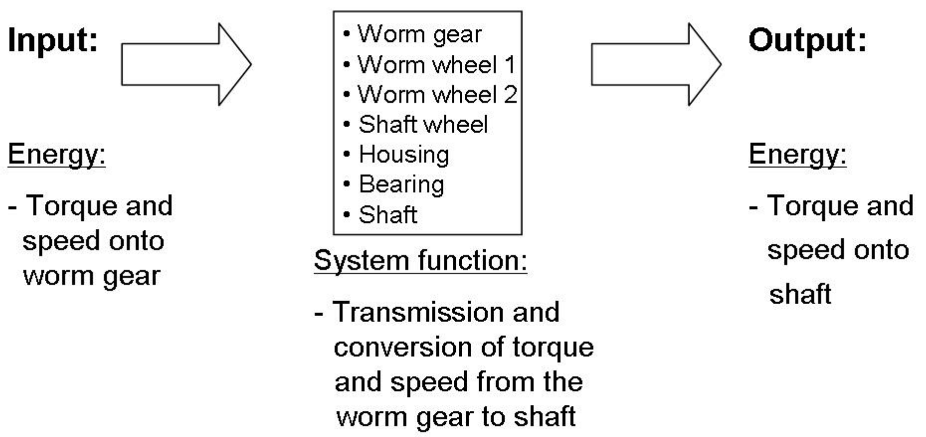

Figure 2: System Analysis following the FTA specifications (cf. Zacher, 2006)

In this case the transmission and conversion of torque as well as speed are considered as the major function. As we consider a qualitative fault tree and therefore quantitative examination is not the goal of the analysis, tolerances are not compulsory. Meeting the FTA specifications with the inspection of the surrounding conditions, resources and components as displayed in figure 2 the system analysis is completed. In the next step the undesirable event has to be defined. As the existence of a gear with different sized gearwheels already implies a conversion of torque and speed, the failure of the transmission of torque from the worm gear to the shaft is seen as the top event. Figure 3 shows the resulting fault tree for all considered basic failure events which individually or combined can contribute to the occurrence of top event.

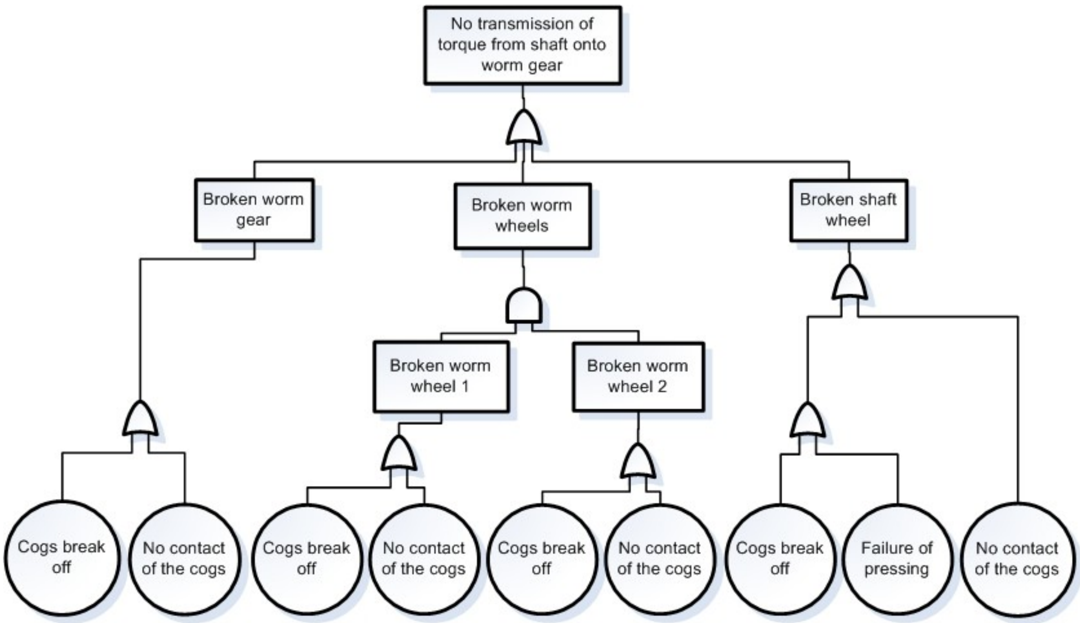

Figure 3: Fault Tree for the gearbox of a motor drive (cf. Zacher, 2006)

According to this the system fails 'at least' in case the worm gear, the two worm wheels or the shaft wheel fail.
Using DeCoDe another approach of system analysis is carried out. The identified components are matched with one another in the component-component-matrix and relations between the components are highlighted. In table I the physical contacts between components are marked. In more complex systems a hierarchical structure facilitates the comprehension of the matrix.

Component-component-matrix	Shaft wheel	Worm wheel 1	Worm wheel 2	Worm gear	Housing	Bearing	Shaft
Shaft wheel							
Worm wheel 1	x						
Worm wheel 2	x						
Worm gear		x	x				
Housing	x	x	x	x			
Bearing				x			
Shaft	x						

Table I: Component-component-matrix (cf. Zacher, 2006)

The functions of the gearbox are identified using brainstorming as a supporting method. The structure of functions is matched with itself in the function-function-matrix in table II. In case a function (column) is necessary to realise a function (row) the respective box is marked.

Function-function-matrix	Protection against outside influences	Bearing function	Transmission of torque to the shaft	Transmission to the worm wheel	Reduction in speed	Increase in torque	Fixation of the housing	Rotation	Transmission onto shaft wheel	Transmission onto worm gear
Protection against outside influences							x			
Bearing function							x			
Transmission of torque to the shaft								x	x	
Transmission to the worm wheel								x		x
Reduction in speed			x	x		x		x		
Increase in torque			x	x				x		
Fixation of the housing										
Rotation		x								
Transmission onto shaft wheel				x				x		
Transmission onto worm gear								x		

Table II: Function-function-matrix (cf. Zacher, 2006)

By means of the matrix a logical activity chain is defined, which describes the need of rotation to transmit a torque. The rotation can only be ensured by an intact bearing function, which can only be optimal in case the housing is fixed properly.
In the next step this functional interrelationship is to be related with the respective components. This is achieved by using the function-component-matrix. Therefore it is checked which component is necessary to enable a given function.
Examining the rows of the matrix in table III no components can be found that would enable the fixing of the housing. Thus the absence of mechanical elements becomes apparent (table III, highlighted row). In case of the considered system this mechanical fixation is resolved using rivets. Although they have not been defined in the system analysis until this point they have to be completed in the component structure. Consequently all arising relations have to be added. As this example only considers the structures of functions and components, with the implementation of a new component two matrices (table I and table III) have to be modified. Using the complete DeCoDe-method implications for the relations with the requirement and the process structure would become relevant and therefore would have to be modified as well.

Function-component-matrix	Shaft wheel	Worm wheel 1	Worm wheel 2	Worm gear	Housing	Bearing	Shaft
Protection against outside influences					x		
Bearing function					x	X	
Transmission of torque to the shaft	x						
Transmission to the worm wheel				x			
Transmission onto shaft wheel		x	x				
Reduction in speed	x	x	x	x			
Increase in torque	x	x	x	x			
Fixation of the housing							
Rotation	x	x	x	x			x

Table III: Function-component-matrix (cf. Zacher, 2006)

Using DeCoDe and examining interrelations by the help of matrices it becomes evident that the system analysis within the FTA has not been carried out completely. Both, the importance of the rivets and the functional relations, have been pointed out by the systematic analysis using a clearly defined product and function structure.
Besides this finding it now becomes evident that the redundancy of the worm wheels does not exist. In fact a breaking up one wheel infects the rotation function of the other worm wheel.
Therefore it can be stated that in the modified fault tree none of the “OR gates” exist no more. In fact all basic events are now combined with “AND gates”. Taking into account the importance of the rivets as a mechanical fixation of the housing, their failure is added as a basic event. The modified fault tree is displayed in figure 4.

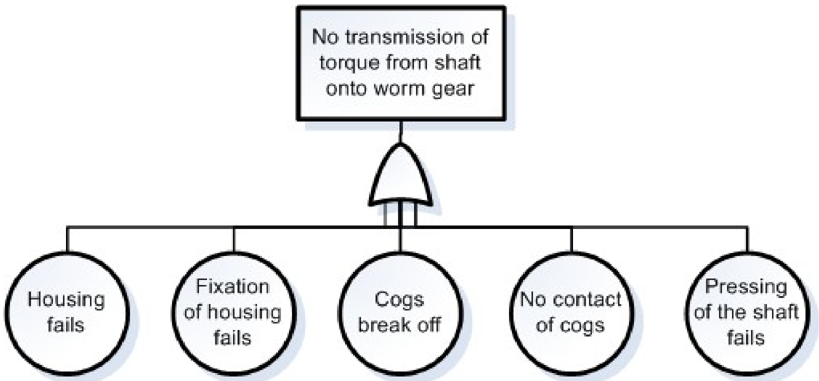

Figure 4: Modified fault tree (cf. Zacher, 2006)

CONCLUSION

Taking a gearbox of a motor drive for the backrest angle adjustment of a car seat, we achieved a more systematic FTA by carrying out the system analysis using the DeCoDe method. A more precise system analysis as a starting point for the definition of the undesired effects in the FTA was therefore accomplished. The theoretical fundament has been laid out by the clearly defined characteristics of the system elements as well as by its functional description. By appointing distinctly the system elements and their interactions, a system analysis and thus the entire FTA both now become traceable and more comprehensible. Integrating different methods multiplies the chances to identify failure causes compared to the conventional FTA.

This new approach brings together two different methods of product development. It is shown how the DeCoDe method can contribute to conduct a precise system analysis as the first step of a FTA. Method integration can therefore play a vital role to enhance the quality capability of the entire product development process.

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Short biography of the author(s)

Name: **Prof. Dr.-Ing. habil. Petra Winzer**

Contact: **phone: +49 (0) 202 / 439-2061**
e-mail: winzer@uni-wuppertal.de

Since 1999	University-Professorship for Product Safety and Quality Management, University of Wuppertal
1996	Professorship, TU Berlin, faculty Mechanical Engineering
1995	Auditor for environmental affairs of DGS
1994	Subject auditor for quality of DGQ
1985	External doctorate, TU Dresden, section Work Science
1977	Qualified engineer/ Diploma in Electrical Engineering and Work Organization, TU Dresden

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Name: **Dipl.-Ing. Sebastian Schlund**

Contact: **phone: +49 (0) 202 / 439-3183**
e-mail: schlund@uni-wuppertal.de

Since 2006	Assistant and doctoral student at the research group "Product Safety and Quality Engineering", University of Wuppertal
2006	Diploma in Transport Engineering, Technical University of Berlin

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Name: **Dipl. Ing. Stefan Ott**

Contact: **e-mail: ott.stefan@vdi.de**

Since 2006	Doctoral student, research group "Product Safety and Quality Engineering", University of Wuppertal
Since 2006	Quality Engineer, 3M Germany GmbH
2006	Diploma in Safety Engineering, University of Wuppertal
2005	Participant in the European Masters Program in Total Quality Management (University of Linköping)