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Development of a Data Model for an Innovative Analysis Method for Mechatronic Systems in the Field of Automotive Engineering

Patrick Dallinger[1], Markus Ernst[1], and Jürgen Fabian[1]

[1]Graz University of Technology, Institute of Automotive Engineering,
Inffeldgasse 11/II, 8010 Graz, Austria

***Abstract*:** *This paper deals with the application of classical analytical methods in the field of automotive engineering and subsequently the overview of its most important functions in a data model. The state of the art analysis methods are currently the Failure Mode and Effects Analysis (FMEA) and the Fault Tree Analysis (FTA). These methods were developed in part based on conventional approaches and are suitable for the analysis of mechanical products. However, the rules of safety and quality standards can only be met by combining different types of analyses which thereon results in significant redundancies and poor efficiency. Due to the increasing electrification of powertrains in the automotive industry, alternative drive mechanisms are needed for the realization of modern vehicle concepts. The development of a new type of analysis methodology is essential to meet the challenges regarding upcoming mechatronic systems and their technical specifications, complex relations regarding security and quality, the demand of OEMs and their suppliers, increasing component reliability, and the necessary failure risk reduction of subsystems. For the realization of such new and innovative analysis software, the data model of the conventional technology is developed and the incoming demand on storage resources evaluated both qualitatively and quantitatively.*

Keywords: *Failure Mode and Effects Analysis FMEA, Fault Tree Analysis FTA, Data Model, Entity Relationship Model ERM, Analysis Software, Automotive Engineering, Mechatronic Systems, Quality and Safety Standards, Failure Risk, Reliability of Components, ISO 26262.*

1. Introduction

The increasing electrification of powertrains in vehicles such as hybrid or electrical engines renders a new method for the analysis of the system and its subsystems necessary. In the same time the increasing quality and reliability standards are a major challenge for the automotive manufacturer and their suppliers. The requirements regarding the reduction of the contingency risk are getting higher than they used to be. Especially the safety-critical aspects must be thought of. The plurality of technical features and complex relationships of mechatronic systems in modern vehicles require innovative analysis and evaluation methods during the development process. State of the art are classic analysis methods, such as Failure Mode and Effects Analysis (FMEA) or Fault Tree Analysis (FTA), [1], [2], [3].

These methods were developed based on traditional approaches and are for mechanical products well suited. However, the requirements of safety standards can only be performed by combining different analytical techniques. Therefore, these conventional methods do not provide satisfactory solutions for complex systems. A modern development process for mechatronic components requires new, innovative analysis tools to optimize the behaviour and malfunctions of the system. The proposed new analysis method recognizes hazardous situations, assesses their impact and defines remedial measures so that the whole development process can be improved, [4], [5].

2. Concept of the innovative analysis method

The approach to an innovative systems engineering is based on the targeted combination of existing analytical and modelling methods. For an overall analysis of the structure, functions and failures of a system, the best already known methods, such as FMEA, FTA, and block diagrams, are used in a new way of interaction. With this combination the complex functionality and error behaviour of a mechatronic system can be represented. Instead of the classic network of functions represented in modern FMEA, structural and functional block diagrams (for example the block diagram of SysML) are shown on several levels, see Fig. 1. Level 1 of this sample shows the entire system with the environmental influences or inputs and outputs, as for instance CAN, chassis, and battery. Section 2 of the example system is divided into an ECU, an actuator, and the cabling. The last level is detailing the subsystems further. The ECU itself is divided in hardware and software, the actuator is divided in sensor, mechanics, and motor. The arrowheads are representing the paths of signals or the connectivity of the several parts. This structure in modules and levels allows variable itemization per stage. By increasing the level, more details of the system are shown. The compounds in Fig. 1 can be used to represent error, signal, data and communication paths, so that a more precise analysis is possible, [4], [5].

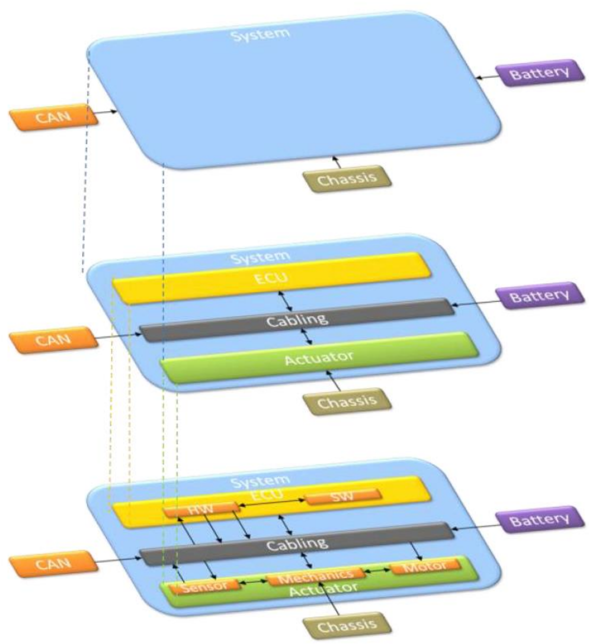

Fig. 1: Structural block diagram on several levels, [4]

An optimized display of error propagation allows the analysis of complex faults and reproductive mechanisms. In addition to traditional multiple faults, there is the possibility to detect error gaps which are related to the diagnostic principle, latent errors and the propagation of errors can be analyzed and evaluated through functional and signal paths. The iterative development process in the automotive industry will be supported by a much clearer view of various optimization measures. This procedure improves the traceability of complex design optimization measures, such as the introduction of redundant sensor systems, adding new security mechanisms or the use of less error-prone technologies. In addition, the modular structure methodology promotes the communication between technology and quality management, because the technical understanding of the system can be displayed better in this way than with conventional analysis methods, [6], [7].

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3. Practical implementation of the concept in the automotive industry

The automotive industry is forced due to the desire for new drive concepts and the increased safety regulations to analyze the behaviour of developed systems in case of faults even more thoroughly. The standard analysis tools enjoy wide acceptance and dissemination in the development of automotive components. The boundaries of these tools and the significant overlap of common analysis shows, however, that the development of analytical methods, especially in terms of safety between man and machine, has become indispensable. The implementation of such innovative concepts always represents a certain break in the industrial flow processes.

The expansion and combination of existing analysis methods has a significant impact on the tools. Therefore, the focus of the innovative analysis method has been placed on the feasibility in terms of tool creation. The base for the practical application is a data model that represents the programmability on the one side and the low difference to the data model of conventional analysis tools on the other side. Nevertheless, this new data model causes a large potential of advanced features and another point of view, [4], [5], [8].

3.1. Data modelling as programming base

Within this paper, the selected method to create a data model is ERM (Entity-Relationship-Modelling or ER-Modelling). Using this technique, the main elements (entities) are connected to each other with links (relationships) and are described by attributes. The resulting ER-diagrams are the base to program a tool which implements the innovative analysis method. The basic elements of this data modelling language are shown in Fig. 2, [9].

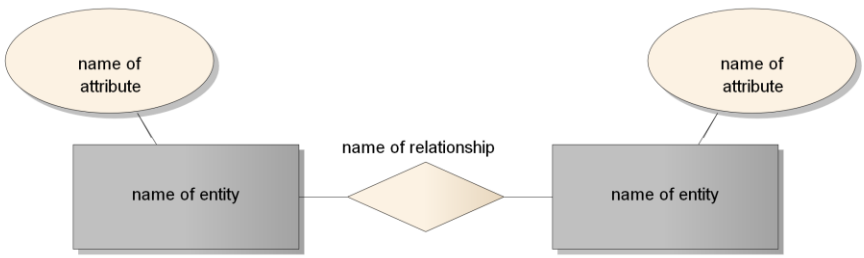

Fig. 2: Basic elements of Entity-Relationship-Modelling

3.2. Data Models of standard applications

To ensure comparability of the new analytical method with the conventional method, the innovative analysis method is using a multi-stage expansion to create an application step by step. As a comparison, the data models of a standard Failure Mode and Effects Analysis FMEA and the Fault Tree Analysis FTA are shown in Fig. 3 and Fig. 4. These ER-diagrams are representing the basic functions of these two analysis method, although there are more functions realized in some applications.

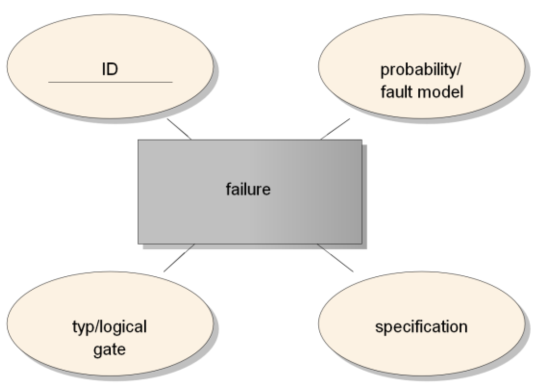

Fig. 3: Example for a standard FTA ER-Model, cf. [4], [8]

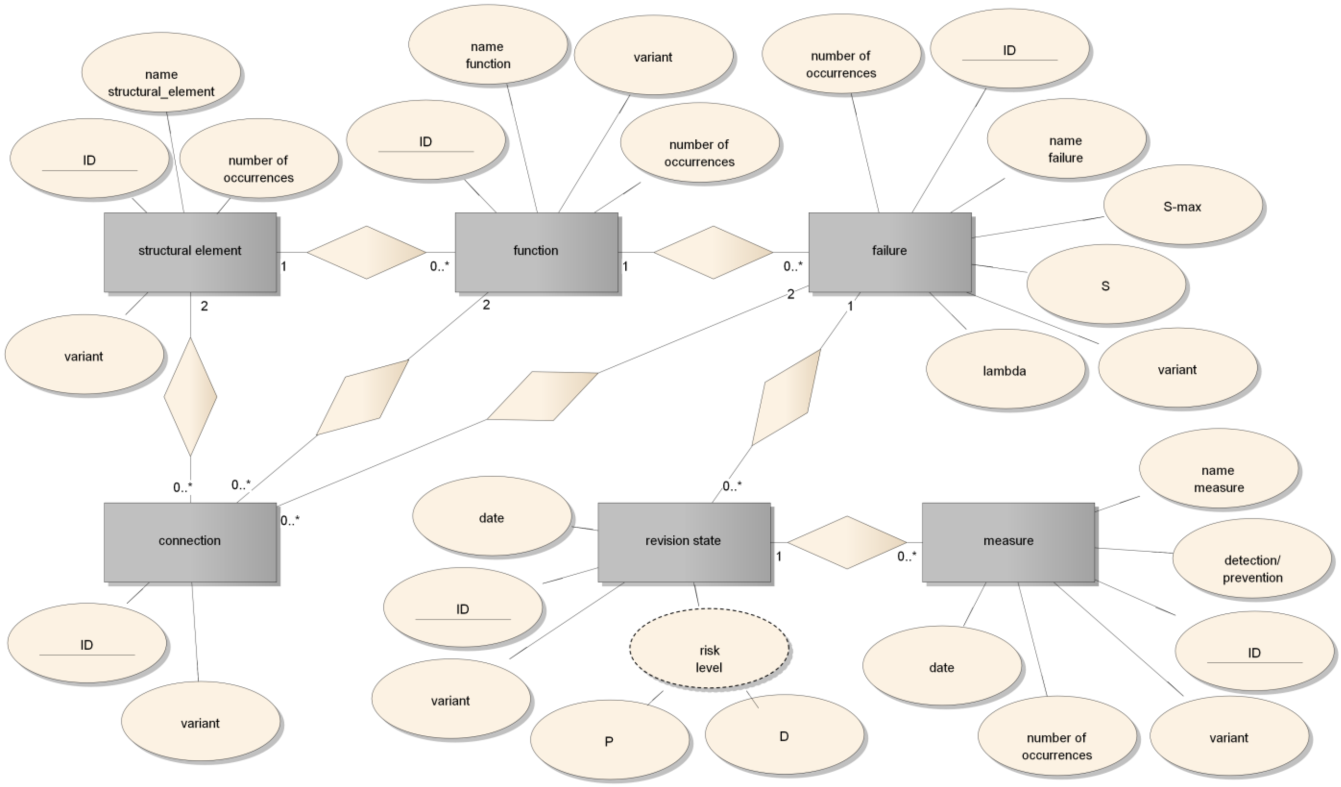

Fig. 4: Example for a standard FMEA ER-Model, cf. [4], [8]

The data model of a standard FMEA (Fig. 4) is the base for the individual stages of the innovative analysis tool. For better understanding, the attributes of the conventional FMEA ER-diagram are hidden subsequently, [4], [5], [8].

3.3. 1st stage of expansion

The first stage shows the data model of the structural and functional analysis of a standard FMEA with the features such as presentation and linking possibility of the innovative method in the form of modular construction in levels. The major elements in this ER-diagram are the connections as an own entity and the ports which serve as an interface between the different structural and function elements, [4], [5], [8].

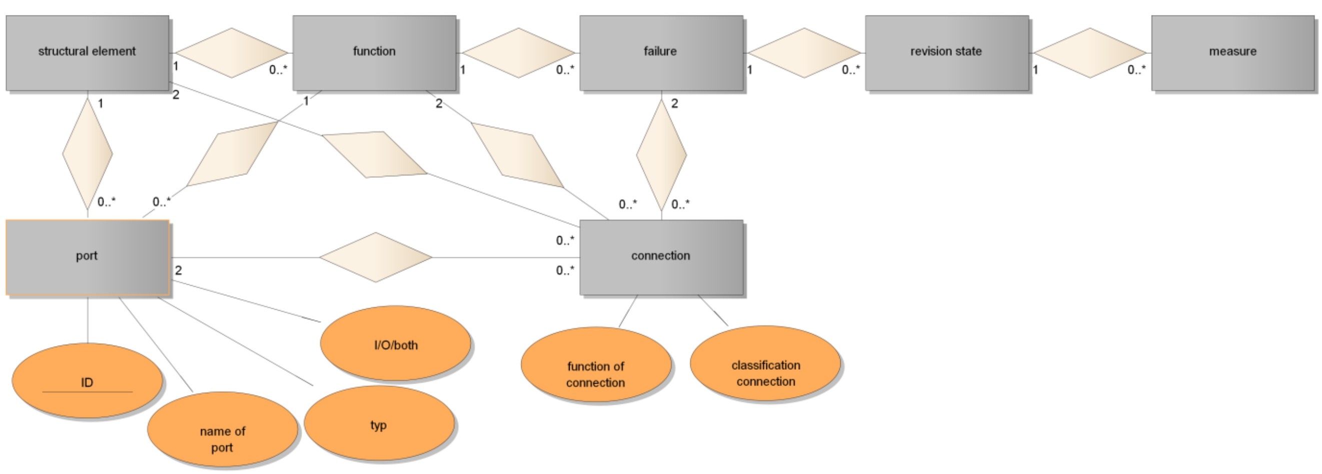

Fig. 5: Entity-Relationship-Model for the first stage of expansion, cf. [4], [8]

3.4. 2nd stage of expansion

The next expansion step includes error propagation using functions, linking the malfunction by logical gates and the distinction of latent and not latent failures. These features are implemented in the ERM, as shown in Fig. 7. A detailed analysis of error propagation paths requires the imaging of multiple branches in the form of logical gates and the display of error propagation on the function and signal paths of the product. The innovative analysis method combines the advantages of FMEA (function and fault networks) and those of FTA (fault tree) by using logical operations. The consideration of latent errors is very important for an exact analysis of a system. Although these errors do not lead directly to a failure of a component, it may come to a critical system failure due to the interactions of these latent defects or their indirect error reproductions. Therefore, the consideration of all possible errors and their differentiation according to latency are necessary for a representative system analysis. An error also does not have to directly cause another one. It could also be transmitted through several functions to another error, as illustrated in Fig. 6, [4], [5], [8].

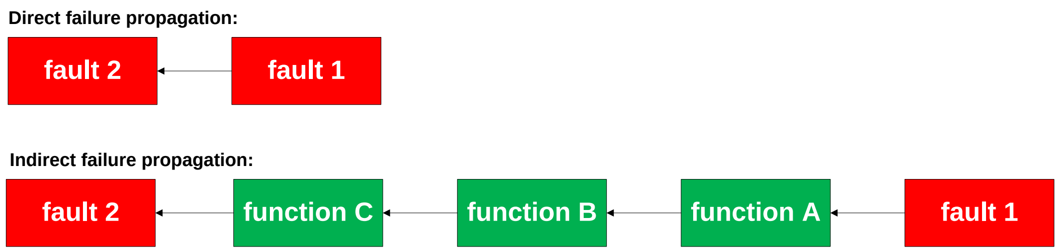

Fig. 6: Direct and indirect failure propagation, cf. [4], [8]

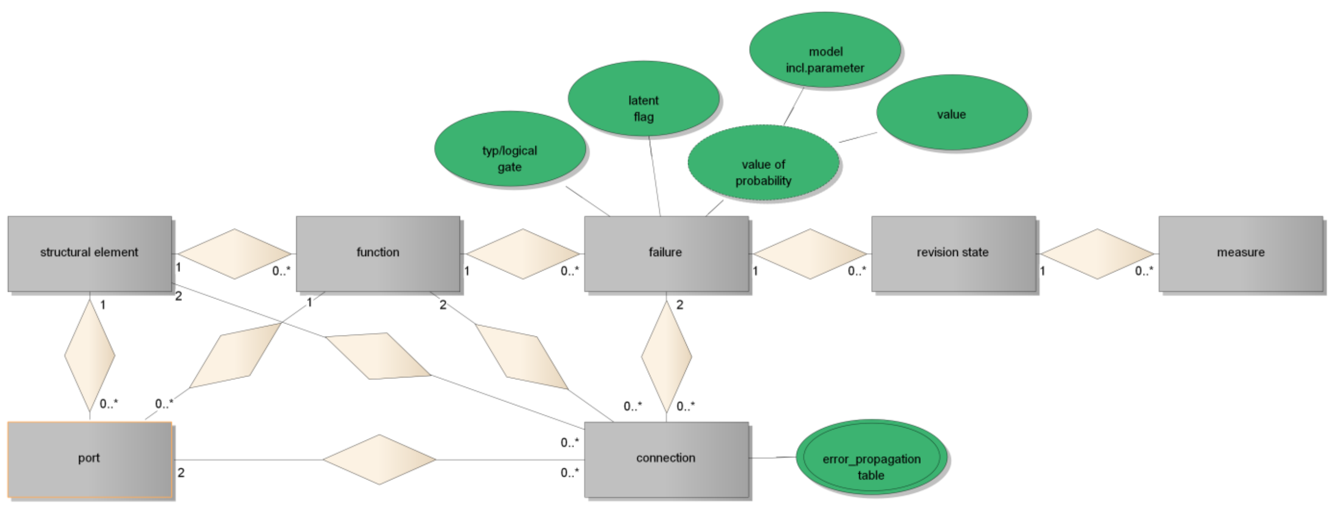

Fig. 7: Entity-Relationship-Model for the second stage of expansion, cf. [4], [8]

3.5. 3rd stage of expansion

An important aspect in the analysis of systems is the diagnostic coverage (DC) of security systems. This value shows how high the percentage of discovered hazardous mistakes is. With the use of multiple security mechanisms, the resulting total diagnostic coverage may not be determined when summing the individual DC-values. The reason is that it is not possible to exactly define which areas are covered by the respective security system.

The modular design of the analytical method and the achieved possibility of linking the components allow a variety of new display options. In contrast to a conventional FMEA, the fault network can be displayed by viewing the security features and their possible errors including the DC value. In addition, this stage provides a combined view of an error path, representing the malfunctions of the security mechanisms and their consequences, [4], [5], [8].

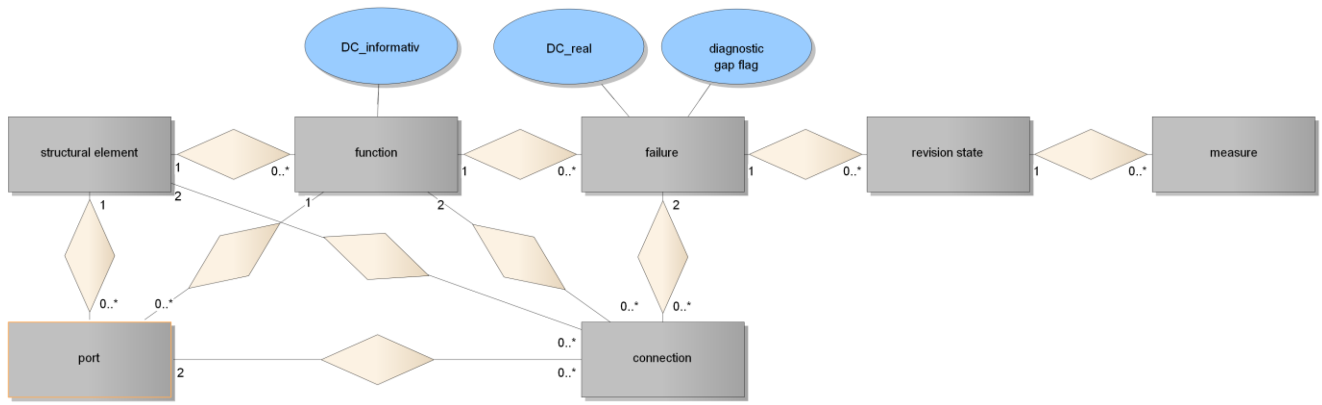

Fig. 8: Entity-Relationship-Model for the third stage of expansion, cf. [4], [8]

3.6. 4th stage of expansion

During the development process, there are some system changes or extensions, hence the analysis is confronted with permanent changes. The innovative analysis method also includes the possibility of integrating subsequent changes in the existing system. The inserted extensions can be structural elements, links, functions, errors, etc. In addition, this functionality provides the advantage that – in contrary to standard FMEA applications – the design optimizations no longer have to be represented as a measure, but as a new structural element, new function, etc., [4], [5], [8].

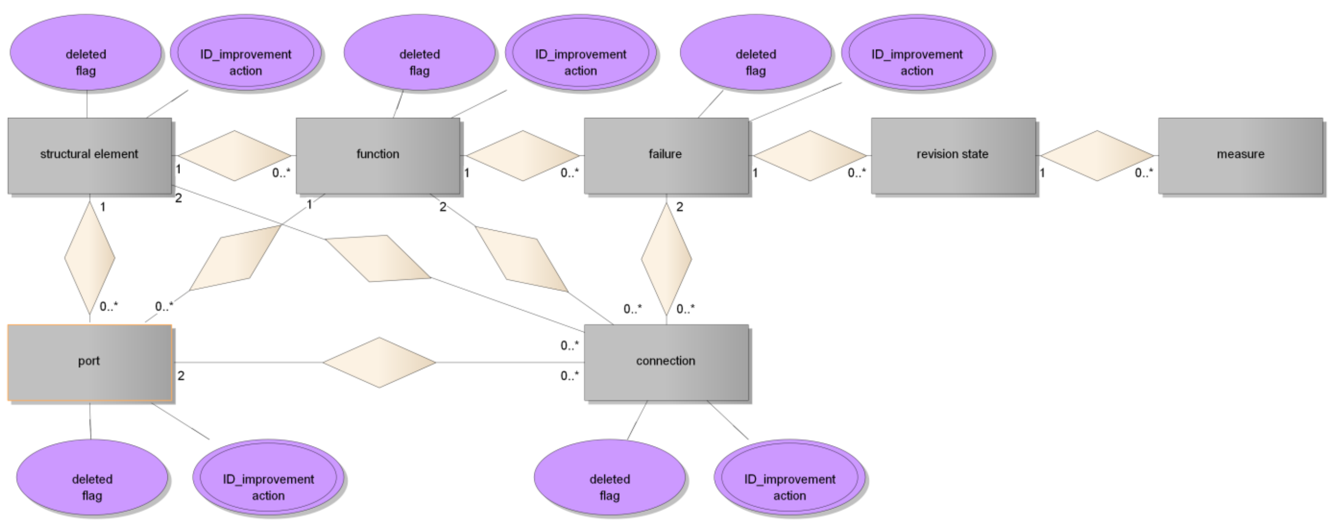

Fig. 9: Entity-Relationship-Model for the fourth stage of expansion, cf. [4], [8]

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