Interdisciplinary Product Development - Virtual Reality Application in FMEA

Toni Eiselt[1], Holger Zickner[2], Juliane Schuldt[1], Sophie Gröger[1], and Dieter Weidlich[2]

[1] Institute for Production Measuring Technology and Quality Assurance
Chemnitz University of Technology, Reichenhainer Straße 70, 09126 Chemnitz

[2] Fraunhofer Institute for Machine Tools and Forming Technology Chemnitz
Reichenhainer Straße 88, 09126 Chemnitz

Corresponding author's e-mail: toni.eiselt@mb.tu-chemnitz.de

Author Note:
Toni Eiselt, Dipl.-Wi.-Ing., research associate, quality management methods, advanced quality planning
Holger Zickner, Dipl.-Inf., research associate, application of virtual reality technology
Juliane Schuldt, Dipl.-Ing., research associate, quality management methods, process-oriented quality management
Sophie Gröger, Dr.-Ing., project manager, quality management methods of the current research project
Dieter Weidlich, Prof. Dr.-Ing., project manager Virtual Reality of the current research project

Abstract: In applying quality management (QM) methods, as for instance the Failure Mode and Effects Analysis (FMEA) in the field of complex mechatronic systems, it is necessary to visually illustrate the system to be examined to all members of the interdisciplinary team. Using Virtual Reality (VR) in combination with QM methods creates conditions that help the team to improve the application of QM methods considerably. VR is particularly suitable to visualize complex mechanical systems due to its realistic three-dimensional presentation of single components, assemblies, and complete systems in combination with the interaction in all six degrees of freedom. The present article presents goals and results of a research project at Chemnitz University of Technology. One result is that all members of the interdisciplinary team easily gain insight into the stage of development when FMEA is supported by Virtual Reality.

Keywords: Virtual Reality, quality management methods, FMEA

1. Introduction and goals

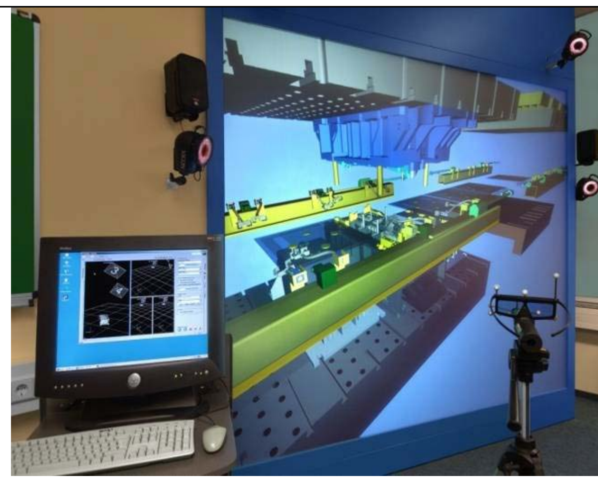
Applying different QM methods, in a structured way, as early as possible in the process of product development not only facilitates error avoidance, error detection and defect valuation, but also helps to secure results, maintain quality requirements and optimize costs and time required. In QM, about 150 methods are used during the product life cycle. This article presents a current research project on the development of Virtual Reality applications for different QM methods in interdisciplinary product development processes.

Due to current economic trends and the resulting changes of the value-added chains, interdisciplinary product development processes are a significant element of the economic environment (compare (Wildemann, 2002), (Ponn, 2008), (Gausemeier, 2006) and (Pahl, 2004)). Applying QM methods in complex mechatronic systems, such as machine tools, makes a cooperation of all disciplines involved in the product development process necessary (DGQ, 2008). The cooperation of disciplines like Mechanical Engineering, Computer Science and Electrical Engineering, the application of synergies, and the focussing on resources guarantees shorter development periods, an optimization of product innovation and, ultimately, an earlier market entry. Apart from these advantages, difficulties are to be expected. For instance, communication and cooperation between experts of the different disciplines can be complicated by different trainings, different technical terminology and different ways of description. This can be a considerable obstacle (compare (Pfeifer, 2007) and (Ponn, 2008)). Also, insufficient synchronization in interdisciplinary product development processes can cause a variety of errors and ambiguity throughout all project phases. Correction later in the process causes additional effort and often results in budget overrun and missed deadlines (compare Gausemeier, 2008). Therefore, it is necessary to apply strategies for error avoidance and teamwork methods in interdisciplinary new product development (NPD) processes to combine all that is required to guarantee a high product quality.(Eiselt, 2011). Here, visualisation is one of the most effective means to support communication, since humans perceive about 70% of all information visually. To make visual representation accessible to the entire team, new technologies like Virtual Reality (VR) are used. This makes the development of new methods necessary that connect both QM and VR. A basis for the development of new methods is the application of Virtual Reality to already approved QM methods, such as the FMEA, Design Review or DRBFM. This paper concentrates on the application of Virtual Reality to FMEA.

2. Virtual Reality

The Virtual Reality (VR) is a visualization technology. It aims at presenting digital models in an absolutely realistic way to create a lifelike experience. This is called immersion. Such immersive visualization systems are not only capable of depicting stereoscopic and true to scale 3D models, but also of interacting realistically, as for instance taking up objects. For a lifelike feeling, visualization and interaction have to be real time simulations. Examples for immersive visualization systems are Powerwalls, CAVE Systems and head mounted displays (HMDs). The abilities of a 5-sided CAVE and a Powerwall are compared below (see Table 1). Tests have shown that the CAVE System is not suitable for the support of the FMEA because of the possible amount of users and the limited space for the presentation of additional information as explained in Figure 1.

Table 1. Comparison of the VR systems CAVE and Powerwall

 5-sided CAVE	 Powerwall
• 1 tracked main user • maximum of 5 passive users • very high immersion level for main user • passive viewers experience edges of the CAVE as fractures in the 3D model • desktop workstations cannot be integrated easily	• 1 tracked main user • >10 passive users possible • high immersion level for main user • homogeneous picture for passive viewers • simultaneous use of desktop workstations is easily possible

Usually, tracking systems are used for the interaction in six degrees of freedom. These systems determine the exact position of the user and the input devices inside the room. In this way, the movement of the user's hand can be transferred one-to-one to the movement of a virtual component (virtual assembly).

VR is an ideal visualisation and communication basis to discuss questions of all disciplines, from design, technology, production planning, and maintenance to training and marketing. Its application as a “conceptual design tool” in the development process is object of current research (compare Weidlich, 2007). In industrial practice, VR is mainly used as a tool to virtually evaluate 3D design data during the design process, and in presentations for sales and marketing (Neugebauer, 2006).

VR is a popular technology in automotive industry, where immersive systems are used for visualizing and evaluating product designs, and also for planning and simulating production processes and systems. Due to its ability to realistically represent models on a 1:1 scale from all perspectives, VR is perfectly suited to evaluate ergonomic aspects. In the development of human-machine interfaces, VR helps to analyze the space within reach and the view field. Designers can use VR to demonstrate the stage of development to their team. Through selections or sectional views, they can interact with the

VR model. In this way, the inside of a machine can be displayed and explained, so it is not necessary to produce elaborate and expensive prototypes (Eiselt, 2012b).

3. Systems Approach for the Implementation of Quality Management Methods in Virtual Reality

The basis for a VR based QM meeting is the 3D CAD model of the object to be analyzed. To create the VR model, the data of the model are used. In contrast to the original CAD data set, the VR model is a polygon-based surface mesh, optimized for an interactive real-time-visualization. For generating this model, the geometric information is adopted, as well as the structure and names of components and assemblies structure. Further information on design features, surface and material parameters is not available in the VR model. Therefore, the VR model alone is not sufficient in the QM meeting, and additional information, like the original CAD model or drawings, have to be used as a back-up to evaluate assemblies or components. Hence, additional areas are required, where information is visualized next to the VR display of the product geometry. In this way, drawings, circuit diagrams, parts lists, forms, functional and requirement specifications, and suggestions for improvement can be shown to all participants at once. These areas of information can be embedded into the VR directly (pictured in Figure 1) or be projected next to the VR environment on an additional area, for example next to the Powerwall. In both cases, the information areas can be controlled from a separate PC, with changes, for instance in form sheets or programs updating in real time. (Eiselt, 2012b)

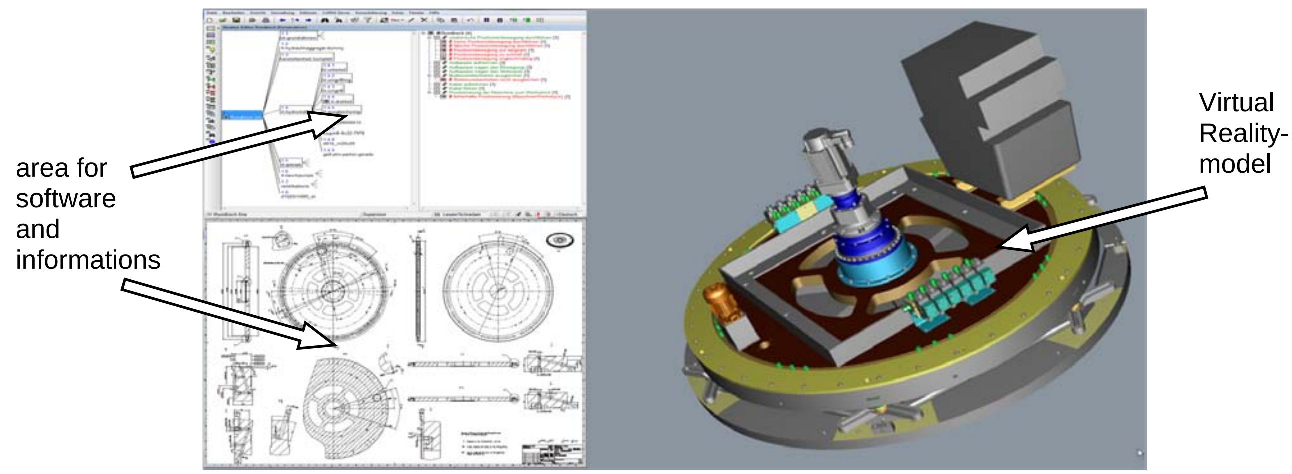


Figure 1. additional information area for the Virtual Reality model

This basic approach can also be used for other QM methods. The content of the information area can easily be changed (Eiselt, 2011).

4. Selection of suitable QM methods for the application in Virtual Reality

For the application of QM methods in connection with VR, certain selection criteria have been defined for choosing the most appropriate of all QM methods for the implementation. The QM methods were evaluated from a QM and VR perspective, according to criteria with differing importance. Thus, all criteria have been divided into QM criteria, VR criteria, and K.O. (Knock-out) criteria. K.O. criteria serve to eliminate the QM methods that have no potential to be implemented in VR. The application of Virtual Reality for a QM method is only reasonable if it is a team based method that needs CAD model visualization and supports the product development process (see K.O. criteria in Table 2).

Table 2. Knock-out criteria to evaluate the quality management methods

K.O. criterion					
team method	product development process: product development stage				CAD model
	planning	concept	design	detailing	

By means of these K.O. criteria, all but eleven QM methods were eliminated. These eleven methods have been evaluated in detail according to the QM and VR criteria. Below, some examples of those criteria are listed:

- using a form for the method,
- visualization is an advantage,
- amount of time required for using the method,
- complexity of the method,
- necessary preparations,
- presentation of the method by a moderator, ...

On the basis of these criteria, following methods are considered best suitable for the implementation in VR:

- FMEA (Failure Mode and Effects Analysis),
- Design Review,
- DFMA (Design for Manufacture and Assembly),
- DRBFM (Design Review Based on Failure Mode),
- Risk Assessment.

The emphasis of the current research project lies on interdisciplinary processes in product development. The FMEA is an ideal tool for the application in VR. Therefore, the next sections focus on the implementation and application of the FMEA and the results of the user tests.

5. Application of the Failure Mode and Effects Analysis (FMEA) in Virtual Reality

The FMEA is one of the most popular QM methods in preventive QM. It is used in risk and system analysis during the process of development. The FMEA aims for example on locating potential errors, their causes and evaluating their effects, increasing the functional and process reliability, preventing system failures, and reducing development time. Two types of FMEAs are applied to products and processes. The design FMEA (hardware FMEA) serves the analysis of assemblies and components to reveal potential faults in product design, and to decide on an adequate containment action. The process FMEA serves the analysis of processes and sub-processes. Figure 2 shows the five steps that must be followed in both FMEAs.

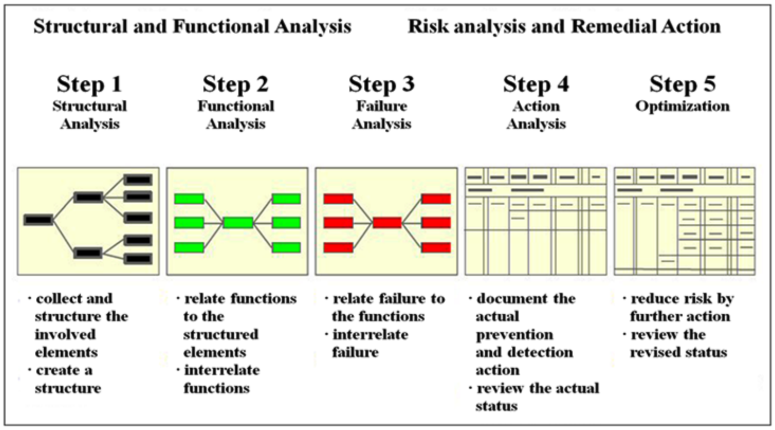


Figure 2. The five steps of the FMEA (according to VDA Vol. 4)

Steps one to three provide the basis for a structured analysis, steps four and five comprise the actual evaluation. In step one, a structure tree is created to illustrate the connections between the individual assemblies and components. Based on this, the functional and failure analysis are conducted in the next two steps. In the functional analysis, each structural element is linked to at least one function. These functions are combined into a function network to identify interrelations between them. The failure analysis consists of finding failure functions and creating a failure network. Each structural element is linked to at least one potential failure. In step four, methods to eliminate possible failures and their causes are defined. Afterwards, the effectiveness of the implemented measures is evaluated in the last step (VDA Vol. 4, 2009).

Especially for the design FMEA, visualizing the object of investigation is beneficial for a short and productive team meeting. In this way, the basis for communication concerning the stage of development is the same for all participants (compare Kunz, 2002). VR can provide the required illustration. Crucial advantages, compared to other techniques, are for instance true-to-scale representation and immersion (Eiselt, 2012b). Today, prototypes or CAD models are used to facilitate an understanding of the object of a FMEA. For economic reasons, it is impossible to produce prototypes of complex mechatronic systems such as machine tools, and also the CAD is only of limited use.

VR, as a well-approved interdisciplinary tool for visualization, interaction and communication, could solve this problem. It is particularly suitable for the use in the above mentioned field.

A first approach to the application of VR technologies in QM processes is the development of a tool for the VR-based supply of information and the effective support of visualization tasks in the context of a FMEA (Kunz, 2002). The CAD and FMEA data were shown via two separate projectors. The intention was a FMEA that accompanied the product development and supported the development process (Breiing, 2002).

Further possible applications of VR technology combined with QM methods were successfully turned into projects with partners from the field of machine tool engineering (Neugebauer, 2007). In these projects, a FMEA was conducted for four assemblies of a new machine tool. This FMEA demonstrated the major advantages of VR compared to 2D CAD. It also showed that combining established QM methods and VR is a good way to illustrate issues of design layout, and their implications for fields like mounting and service (Eiselt, 2012b). The application of VR created an interdisciplinary basis for discussion, which is a considerable improvement in the process of error prevention.

The following three steps describe how a FMEA is applied in VR.

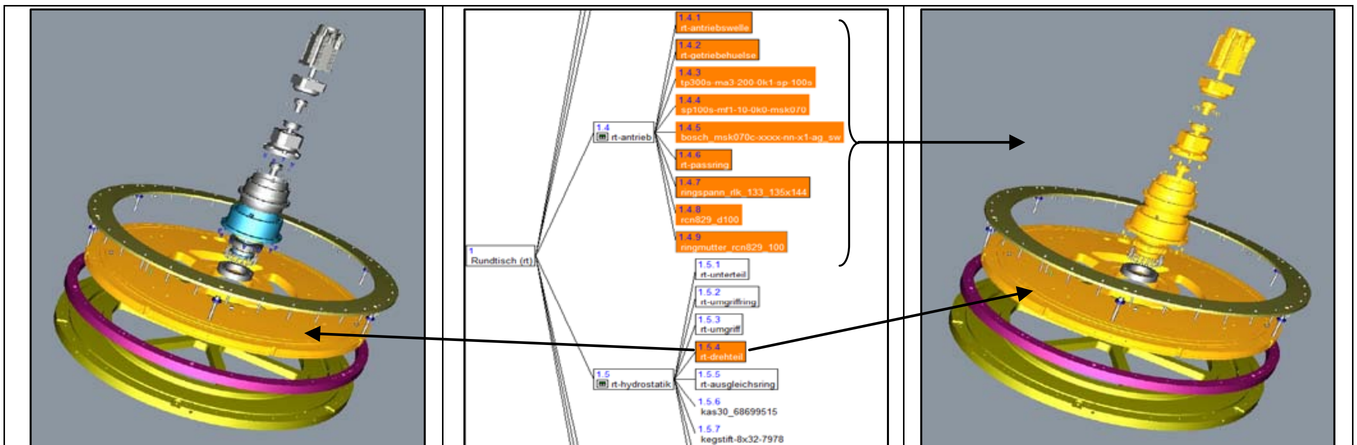
I) Preparation of the VR-FMEA meeting

The preparation of a FMEA meeting where VR is used includes familiar tasks like appointing a FMEA person in charge and a FMEA presenter, building a FMEA team, collecting information and creating a time schedule. Furthermore, the CAD model has to be transferred to VR and reprocessed. In the current version of the demonstrator, the interface between the FMEA software and the VR model has to be linked manually for each object. To support different points of view within the team, different sections of the model can be prepared. It is also important to check if all team members are aware of possible side effects of VR, for instance indisposition or a feeling of dizziness.

II) Holding of the VR-FMEA meeting

For the implementation of the FMEA in VR, conventional FMEA software can be used. The basic steps of the FMEA method (see Figure 2) are the same in the VR supported FMEA, but the user interaction with the model and the FMEA software has been improved.

The essential interaction tool in the FMEA team meeting is the structure tree created in step one. To improve the interaction between structure tree and model, the FMEA software is connected to the VR model, permitting single or multiple selections in the structure tree (see Figure 3). The single-selection highlights one element (orange object) of the model in VR, so it is easily identifiable within the complex system. In the multi-selection, additional parts (other orange objects) are highlighted to enable the analysis of their interaction. After an element has been selected, a previously chosen document shows up in the information area, for instance a drawing, a calculation or the CAD desktop.



single-selection	structure tree	multi-selection

Figure 3. Comparison single-selection and multi-selection

The above mentioned points improve interaction during the VR meeting and facilitate the coordination of FMEA software and virtual object. The automatic provision of additional information contributes to a successful meeting, since the FMEA team members can focus on locating potential faults and finding possible ways to avoid them. The following features of the VR software can further support the FMEA team:

- transparency mode for surrounding parts,
- true to scale presentation for a realistic impression of the system,
- exploded view drawing, sectional view, make transparent or hide components and elements,
- different colors (for purchase parts, standard parts, own designs, variants, adaptations),
- bookmarks on components or assemblies,
- use of screenshots for post processing,
- elements can be mounted and dismounted fast and freely,
- movement simulation.

Figure 4 shows a typical scene from a VR-FMEA meeting. Based on drawings and the virtual 3D object, certain parts are rated.

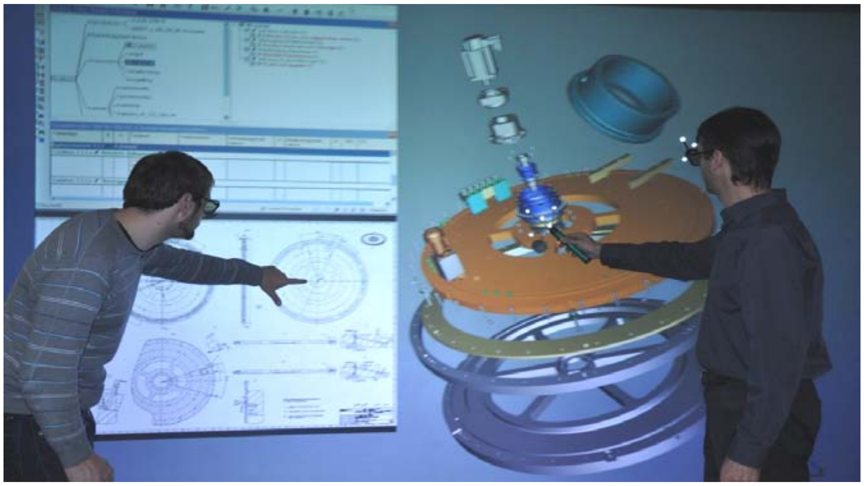


Figure 4. FMEA in Virtual Reality

The FMEA software is used to document the VR-FMEA results, so one person responsible has to be appointed previously. The tools of the VR software (screen shots or bookmarks) also help to document the results.

III) Post-processing of VR-FMEA meeting

The post-processing of the VR-FMEA is identical to a FMEA without using VR. The measures arranged in the meeting have to be distributed and their implementation and effectiveness have to be checked. The FMEA results and the successfully implemented measures have to be passed on to all attendees. The screenshots made during the meeting have to be added to the FMEA database. This facilitates the implementation of the measures. Furthermore, additional information that was added to the structure tree can be visualized.

6. Evaluation of the Implementation

During this research project, the application of Virtual Reality to FMEA was tested in a real VR environment by different users. Analyses of the ideal environment for interdisciplinary FMEA sessions were conducted. An important factor here is the VR system which is used. It has been shown that a conference room equipped with a Powerwall (see Table1), a CAD workstation and a FMEA software workstation make the perfect environment for the tasks of interdisciplinary FMEA sessions, particularly due to the necessity of interaction within the VR system and the simultaneous use of desktop based systems (Eiselt, 2012a). Furthermore, the illustration facilities of the display areas, where the true to scale representation of the product geometry is conducted, have been analyzed. One possibility is the embedding of additional levels as geometrical objects into the VR environment. On these levels, desktop contents of the CAD or FMEA workstation computer can be integrated as textures. Figure 4 represents a CAD drawing in addition to the VR visualization of an assembly. On a large Powerwall of 6m width, the space for the drawing measured about 2m. The display of details and the legibility of small fonts in this section of the wall have been evaluated as good. In the use cases, the following advantages were observed:

- centralized information platform in the Virtual Reality environment,
- due to visualization, less explanation necessary,
- short phase of familiarization for each participant,
- instant connection of information and object,
- intuitive interface,
- team can move freely, meeting in a relaxed atmosphere
- realistic, true to scale representation of objects,
- various views (complete, exempted, excised, blanked, transparent), and
- different colors.

It has also shown that the various multimedia interactions during the application of the FMEA in VR disturb the flow of the session. In the current state of development, two additional team members are therefore necessary to run the VR equipment and to do the documentation. Certain aspects of the VR system place changing demands on the user, for instance perspective distortion, delayed picture transmission during fast movement, or low resolution of the information areas.

7. Summary and Outlook

As the article showed, the application of QM methods can be supported and improved by the use of Virtual Reality. As an important preventive QM method for failure avoidance, the FMEA is particularly applicable, because here the visualization of the object of investigation is crucial for the result. Due to the realistic representation of a product in VR, all members of the interdisciplinary team easily gain insight into the stage of development. Using VR is especially advantageous for visualizing products of high complexity that cannot, or not easily, be prototyped. During the usage and validation, further possible applications were discovered, which will be the subject of following studies. A first step is to enhance the connection between the FMEA software and the VR model to automate certain sub-steps of the still manually operated software. Additionally, the applicability of other QM methods in VR is being explored.

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