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FURTHER DEVELOPMENT OF TRIZ FUNCTION ANALYSIS BASED ON APPLICATIONS IN PROJECTS

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1. Introduction

This paper aims to support the analysis of technical systems with the help of TRIZ *Function Analysis* for products. Function modelling in engineering design is used for different purposes, e.g. analysis, understanding and depiction of systems, creation of ideas, transfer of knowledge, and depiction of structures of system [Ulrich and Eppinger 1995], [Pahl et al. 2006].
Different methods for system modelling exist. Each of them pursues different goals. Some modelling methods are used to understand the exchange and transfer of material, signal, or energy, e.g. flow oriented function modelling [Lindemann 2009], [Ehrlenspiel and Meerkamm 2013]. Others are used to depict the interaction between the user and the product, e.g. user-oriented function modelling [Rumbaugh et al. 1992], [Lindemann 2009]. Equally system models are used to subdivide complex systems in manageable small systems [Ulrich and Eppinger 1995].
A comprehensive function modelling toolbox is provided by the TRIZ methodology from G. S. Altshuller [Herb et al. 2000], [Klein 2007], [Orloff 2006]. This function modelling approach targets different fields of function modelling. First it is a tool to depict structures of systems. Second the tool can be used for analysis, improvements or adaptions of systems. The tool is well-proven and is a standard tool of TRIZ training [Adunka 2012].
This paper provides insights in the application of TRIZ *Function Analysis*. It describes the application of the approach in students projects and shows the advantages and obstacles that the users of TRIZ *Function Analysis* face. In order to overcome one of the obstacles, i.e., obtaining an interpretable system model, an adaption of the TRIZ approach is introduced.
The following paper is subdivided into the following sections: introduction of the TRIZ methodology (**Section 2**) and a detailed description of the TRIZ function modelling tool (**Section 3**). **Section 4** describes the application of TRIZ *Function Analysis* and the problem statement of the arrangement of the elements of TRIZ function models. In **Section 5** the adaption of the TRIZ function model is introduced. Examples of the application of the new approach from student projects are depicted in **Section 6**. Finally in **Section** 7, an overall conclusion is drawn about the application of TRIZ function modelling and its adaption as well as a summary and an outlook are given.

2. TRIZ methodology

The TRIZ methodology was developed by the Russian engineer and scientist Genrich Saulowitsch Altshuller (1926 – 1998) [Altshuller et al. 1997]. TRIZ is the acronym for „теория решения изобретательских задач“, which translates into English as "Theory of Inventive Problem Solving".
Altshuller derived three laws for the evolution of technical systems from a study of more than 40.000 patents [Lindemann 2012]:

1. The development of technical systems follows specific patterns.
2. It is necessary to overcome contradictions during processes of inventing.
3. A small amount of solution principles underlies a great amount of inventions.

TRIZ separates the process of innovation into three phases: *analysis of tasks*, *solving of challenges*, and *selection of solution concepts* [Adunka 2013]. For each of the three phases, Altshuller developed specific tools to support them. The three phases and their relative tools are shown in Figure 1.

Analysis of tasks	Solving of challenges	Selection of solution concepts
• Innovation Situation Questionnaire • Resources-Checklist (RC) • Ideality (IFR) • Theory of Technical Systems • Technology Evolution • Trends of Engineering System Evolution (TESE) • Multi-Screen Diagram / 9 Windows • Functional Benchmarking ABC Analysis • Flow Analysis Component and Structural Analysis • Function Analysis • Incremental Improvement • Radical Trimming • Value Analysis • Function Stealing • Patent analysis and adaption • Trimming (Ideal Functional Modeling) • Cause-effect Analysis. Formulation of key problems • Alternative System Merging (Feature Transfer)	• Effects Data Base • Function-Oriented Search • Clone Problems • Open Innovation • Engineering Contradiction • 40 Inventive Principles for Resolving Contradictions • Physical Contradiction • 4 Separation Principals • Substance-Field Analysis • 76 Inventive Standards • Multi-Screen Approach / 9 Windows • Operator Size/Time/Cost • Modeling with Miniature Dwarfs • Galfmorbus • ARIZ Algorithm	• Scientific Database • Prioritize solutions • Concretize solutions • Solving of Secondary Problems • Anticipatory Failure Determination (AFD) • Super-Effect Analysis • Validation • Inverse Function-Oriented Search

Figure 1. TRIZ process of innovation with its assigned methods

3. TRIZ Function Analysis Basis

One of the basic tools used in the phase of "*analysis of tasks*" is *Function Analysis* (FA). FA is an analytical tool which helps to determine the components of a technical system and the functional relationship between the components. In design methodologies this tool can assist in the tasks of *problem understanding*, *structuring*, *goal clarification* as well as in *generating solution ideas* [Ehrlenspiel and Meerkamm 2013], [Lindemann 2009], [Pahl 2007]. In the Munich Procedure Model, FA is a supportive tool for the steps of "*goal analysis*", "*problem structuring*", and "*development of solution ideas*" [Lindemann 2009].

FA is divided into five tools: *incremental improvement*, *value analysis*, *trimming*, *patent circumvention*, and *stealing from super systems*. The different tools determine the focus of the analysis [Adunka 2012]. All these tools are based on FA basis, which is introduced in the following sections [Adunka 2012]. FA basis is the starting point of FA and describes an independent TRIZ tool. The result of FA basis is a graphical (function model) or tabular representation of a technical system, its components and functions of components. FA basis is divided into three steps, as depicted in Figure 2.

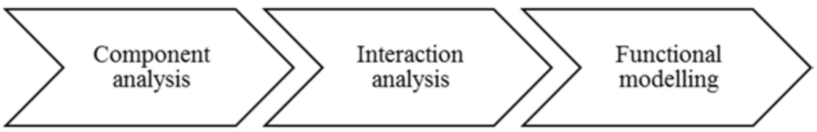

Figure 2. Steps of the TRIZ Function Analysis basis

Two definitions are important for this work with FA and the establishment of the function model. First, interaction is defined as an interaction between two components. The interactions is undirected. Although an interaction is a necessary and sufficient condition for functions. Second, function is defined as action between of a functionary (Figure 5: Hair dryer) and object of the function (Figure 5: Water). Both have to fulfill the conditions of a component (see 3.1). Additionally the action from the functionary has to maintain or change a parameter of the object of the function.

3.1 Component Analysis

The goal of the *Component Analysis* (CA) is to determine all relevant components and super system components, for the analysis. In order to do this, five steps have to be undertaken, as shown in Fig. 3.

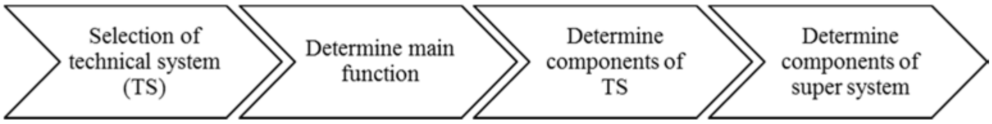

Figure 3. Steps of Component Analysis

First the level of abstraction has to be determined, because it is important to find the right level of abstraction. To exemplify the different levels of abstraction, the different levels of a hair dryer system are shown in Figure 4. The selection of the specific level of abstraction determines the level of details. With the choice of the right level of abstraction, effort and effectivness considerations of the CA and its following steps are involved. If the level is too abstract, then it is not possible to gather useful information out of the model. If the level is too detailed, then elements which are not important for the problem will be analyzed in all the following steps of FA. This leads to an increase in the processing effort.

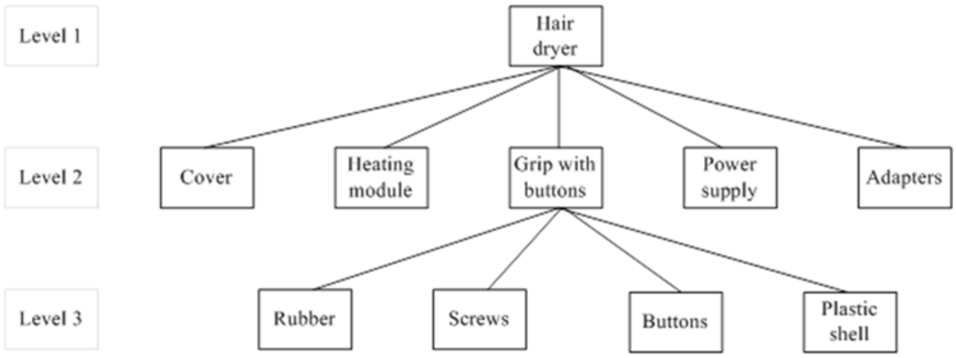

Figure 4. Levels of abstraction of a hair dryer system

After determining the level of abstraction of the system the main function, the relevant elements, and finally the super system compenents are determined. In FA components are defined as elements which, either have a specific mass or fields that allow an interaction between the components. These fields are **M**echanical, **A**coustic, **T**hermal, **Ch**emical, **E**lectric, **M**agnetic, **I**ntermolecular, and **B**iological fields which can be abbreviated as MATChEMIB [Nakagawa 2006].
The main function comprises the technical system, an action, and the target component. The main function describes the main purpose of the system. In the case of the hair dryer system, the main function "remove water" can be depicted as followes in Figure 5.

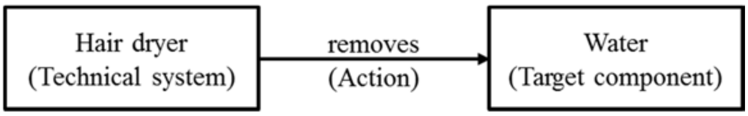

Figure 5. Depiction of the main function of a hair dryer

An excerpt of the final result of the CA (main function, super system, and technical system) of the hair dryer example is shown in Figure 6.

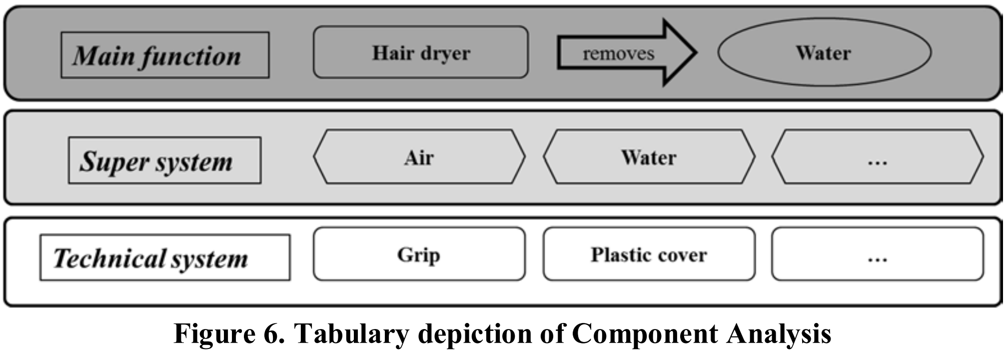

Figure 6. Tabulary depiction of Component Analysis

3.2 Interaction Analysis

With the help of the *Interaction Analysis* (IA) the mutual interference of the components is examined. The IA is subdivided into three steps depicted in Figure 7.

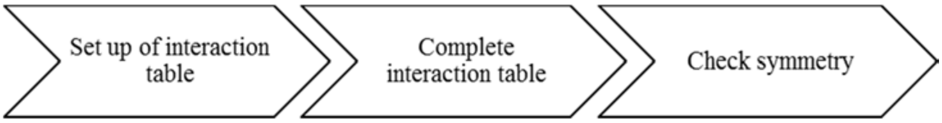

Figure 7. Steps of the Interaction Analysis

To do this an interaction table is established and filled out. The interaction table contains all elements determined in the CA. An exemplary interaction table is shown in Figure 8.

Interaction table		Cover	Heating module	Adapter	Grip	Water	Air	User
Technical system	Cover	-	+	+	+		+	+
	Heating module	+	-				+	
	Adapter	+		-			+	
	Grip	+			-			+
Target component	Water					-	+	+
Super-system	Air	+	+	+		+	-	+
	User	+			+	+	+	-

Figure 8. Exemplary interaction table

An interaction between two components is marked with a "+" in the specific row and column. An interaction is not clearly defined in TRIZ. It can be a contact between two components or an active impact of one component on another.

The interaction table has to be a symmetric matrix since the direction of the interaction is not determined in the IA. This is done in the *Function Modelling* step by developing directed actions between the components.

3.3 Function Modelling

The last step of FA basis is the *Function Modelling* (FM). The goal of the modelling is the definition of understanding and the depiction of functional coherences. In order to do this, the determined interaction of the components have to be transformed into actions between components. An action is defined as specific modification of the state of a component, such as the interaction of the air (super system component) and the heating module (component) which leads to the action "to heat". It is important to note that not every interaction from the IA leads to an action.

The final outcome of the FM is a graphical model of the systems. The model depicts the technical system, its relevant components and super system components and the actions between them (see Figure 9).

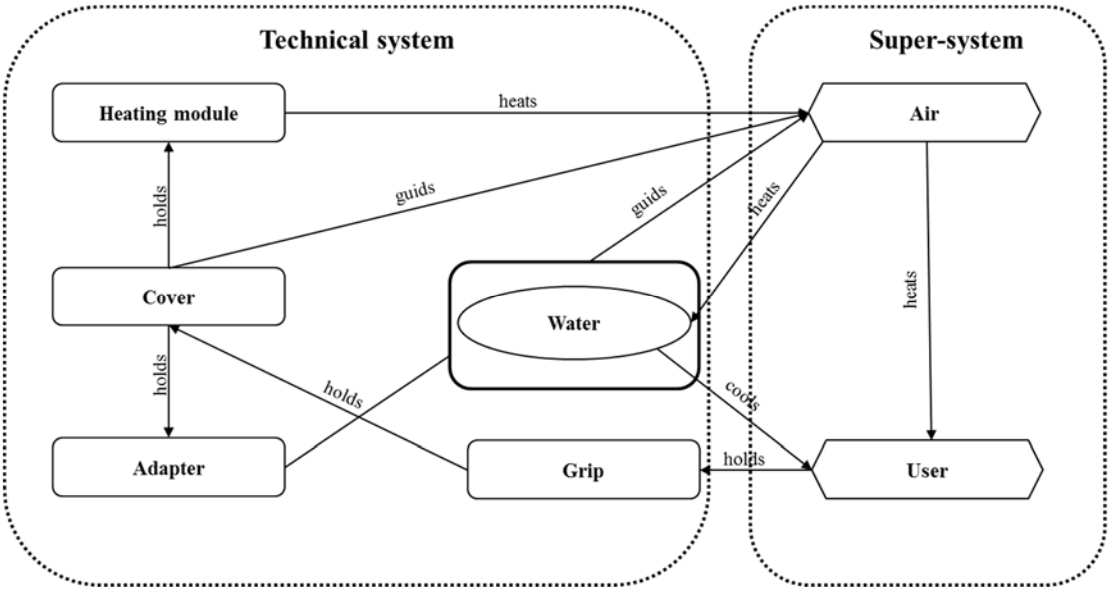

Figure 9. Exemplary TRIZ function model

4. Evaluation of Function Models and Statement of Problem

As seen in Figure 9 the relations (actions) cross over and a clear interpretation of the interaction between the different components is not given. In systems with small numbers of components and relations this does not create a problem of visualisation. However, most technical systems have more than 10 components especially when super system components are also incorporated. With the increase of the components and their relations an interpretable arrangement of the system elements becomes more difficult. The following abstract describes the use cases of FA, obtained insights, and the statement of problem which arose from the application of FA.

FA was applied in three student projects (academia and industry). The students had different educational backgrounds. The first student was a Bachelor student in mechanical engineering in the sixth semester. The student had passed TRIZ Level 1 in a one-week TRIZ training. The application of FA was in the scope of a Bachelor's thesis project. For the Bachelor's thesis 300 man-hours are planned. Since this thesis was written in an industrial setting the student needed time to generate an understanding in the special field of water purification. For the TRIZ application the student had in total 150 man-hours. TRIZ was used in this thesis for establishing a system understanding and system analysis. Subsequently TRIZ was used to identify technical problems and develop a solution for them. Therefore the TRIZ tools *incremental improvement* and *value analysis* were applied. The second student was also a mechanical engineering student with TRIZ Level 1 certificate. TRIZ was applied in the scope of a Diploma project and had the goal to improve a plastic extruder. The student had 800 man-hours in a six month project. TRIZ was applied in all phases of the development process. Main focus of the thesis was system analysis and improvement. The third student project was in couse of a Diploma project in mechanical engineering. The TRIZ application in this project was only a minor part of the thesis. The thesis took place in the field of fun ride system development. The student had no TRIZ background. FA was taught in a one-day workshop. FA was used for system improvement. To do this, the TRIZ *trimming* tool was applied after there the application of FA basis.

The application of TRIZ in the student projects led to following insights and problems. The first two steps of FA basis led to a deeper understanding, since the students had to discuss which level of abstraction they want to choose. To make this decision they needed to generate a hierarchical model of the system components and then to determine the right level. Another factor for a deeper system understanding was selection of the appropriate system components and super system components. The students had to decide which components were relevant to their system and which not. This led to healthy discussion with the advisor and responsible engineers. Further, the application of IA increased the understanding of the system. The analysis of each component and its interactions led to surprising

insights since components which did not seem to have interactions had very important interaction and vice versa. This is shown with the help of two examples.
An example can be given from the development of the extruder. The extruder screw was mounted on two angular contact bearings. To fix the screw on the bearings, an auger sleeve was introduced between the bearings and the extruder screw. With the help of FA basis and the *trimming* tool the angular contact bearings were replaced by a friction bearing which was fulfilled by the auger sleeve. This example shows that functions of important components can be transferred to other components.
The second examples stems from the analysis of the water purification system. Two systems were compared. The comparison showed that one of the system interacted very strongly with possible foam. The second system had no significant interactions with the foam. This consideration became only visible for the student with the help of FA basis.
With these insights gained, it seems obvious that the function model of the system from FA basis increases the understanding of the system. But when it comes to the visualisation, with this the documentation of the insights, interpretabilty problems occur. The main requirements in a function model (graph) are to create an output that should be readable, easy to understand, easy to remember, and illuminate rather than obscure the user of the application [Eades et al. 2010]. These requirements are not fulfilled, since the students had more or less only a bundle of crossing lines connected to text boxes with information about the components and the relations. This interpretation problem also occur in models which cover different functional modelling perspectives, e.g. functional models of product-services systems [Eisenbart et al. 2013]. To overcome this problem computational alogrithms for planarization, i.e. a graph with no crossing edges, or the automatic graph layout have been developed [Kamada and Kawai 1989], [Eades et al. 2010]. However, the generated graph layouts, e.g. for Microsoft PowerPoint or Visio, are quite unsatisfactory [Dwyer et al. 2009]. These problems led to reflections on how the system could be arranged such that adequate interpretability in manual written models or models designed in text processing programs, e.g. Microsoft PowerPoint or Visio, is guaranteed.

5. Adaptation and Application

As described in the previous chapter interpretability problems arise during the elaboration of the TRIZ function model. To overcome this problem a graphical adaptation of FA is introduced. This approach leads to more interpretable functions, since it facilitates the allocation of the system components. This first sub-section of this chapter describes the adaption of the TRIZ function model with the aid of the earlier introduced hair dryer system. The second part of this abstract describes two applications of FA basis in student projects. In these projects the adaptation of the function modelling was applied.

5.1 Approach to overcome interpretability problems of the function model

Interpretable depiction of system models is important for a detailed system and function analysis [Eades et al. 2010]. With interpretable models, the communication between the developers increases, as well as outsiders without detailed system experience can understand the technical system with less effort. To do this, we propose a further development to TRIZ FA approach by introducing a graphical approach. The general perimeter of FA stays unmodified. The proposed approach is a combination of a system graphic, e.g. a CAD model, photograph, or freehand sketch, with the TRIZ function model.
At this, the system graphic represents the complete system or only considered details. The degree of detail of the system graphic should be adapted to the needs of the system model. The proposed adaptation begins after the statement of the CA and IA. The approach follows three steps (see Figure 10):

Step 1: **Build** TRIZ function model, i. e. fulfill CA, IA, FM
Step 2: **Select** appropriate system graphic (complete system or detail view)
Step 3: **Arrange** components corresponding to the system graphic

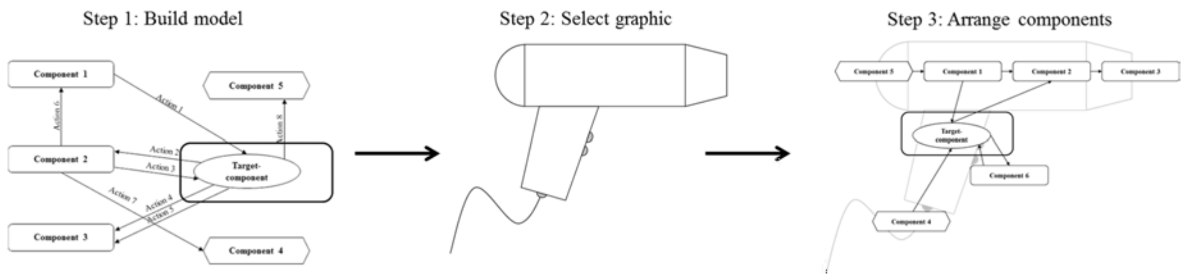

Figure 10. Approach for graphical adaptation of TRIZ Function Analysis

The first step is the set up of the function model as described in Chapter 3.3. Then a graphical representation is selected. In this step it is important to make sure that the right detail of the system is depicted with the representation. The representation is put on top of the function model. In the third step the components of the model get rearranged according to the system graphic.
In the case of the hair dryer system the function model is set up (depicted in Figure 10, Step 1). Then a system graphic of the hair dryer is prepared (Figure 10, Step 2). Since in this case the complete hair dryer system is considered the graphic shows a side view of the hair dryer system. In the last step the system components (Figure 10, Step 3) are rearranged according to the side view of the contour of the hair dryer system.

5.2 Application

In order to give a more detailed view on FA and the introduced adaptation two application examples will be given. Both examples stem from the introduced student projects. The goal of the application is to depict the system, gain a better understanding of the system, and improve the system. The first example shows the development of an extruder to recycle plastics. The second example illustrates the system view of a fun ride seat system.

Plastic extruder

The main function of the plastic extruder is to change the aggregate state of plastics, e.g. from hacked plastic or pallets to filament. The feed section gathers hacked plastic particles. With the help of different extruder components the hacked plastic particles are processed and a plastic filament is produced. The task in the student project was to improve an extruder which was developed in a previous student project. For the improvement of system the *trimming*, *incremental improvement*, and *value analysis* tool of TRIZ were later applied.

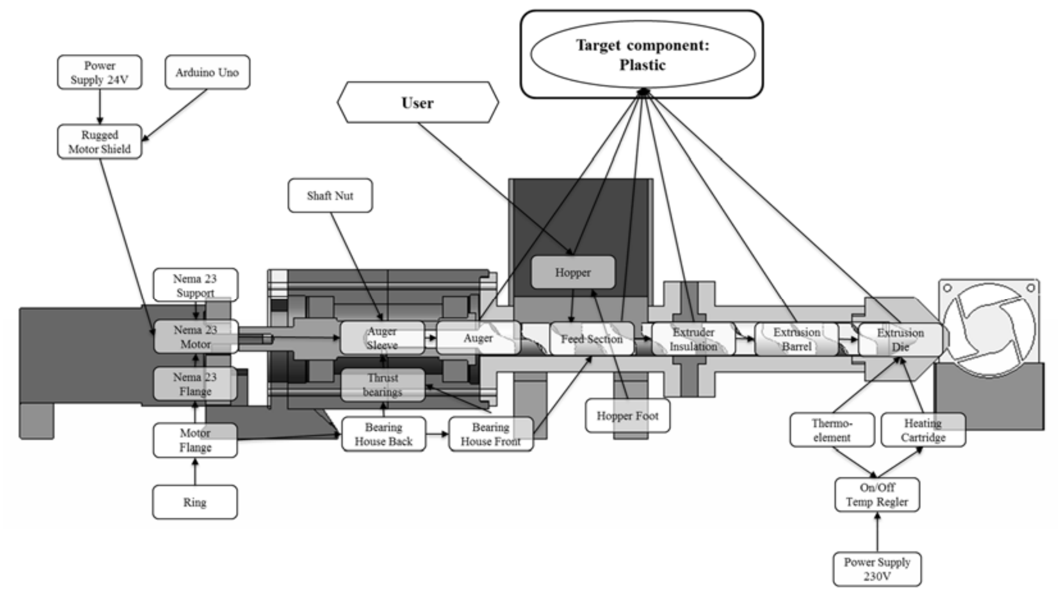

Figure 11. Function model of plastic extruder without descriptions of the relations

The system model of the extruder contains 26 components with more than 80 interactions. With the knowledge of the interaction analysis the function model and its corresponding actions were derived. The final function model had more than 30 actions which linked the components and depicted the extruder system.
Since this project was a further development of a student project a 2D section view of the extruder could be used for the arrangement of the components. The final function model together with the graphic model are shown in Figure 11.

Fun ride seat system

The second project was a student project in an industrial environment. First, FA was used to depict the system structure as a basis for discussions of the system in workshop. Second, the function model should be used as a basis for the TRIZ *trimming* tool.

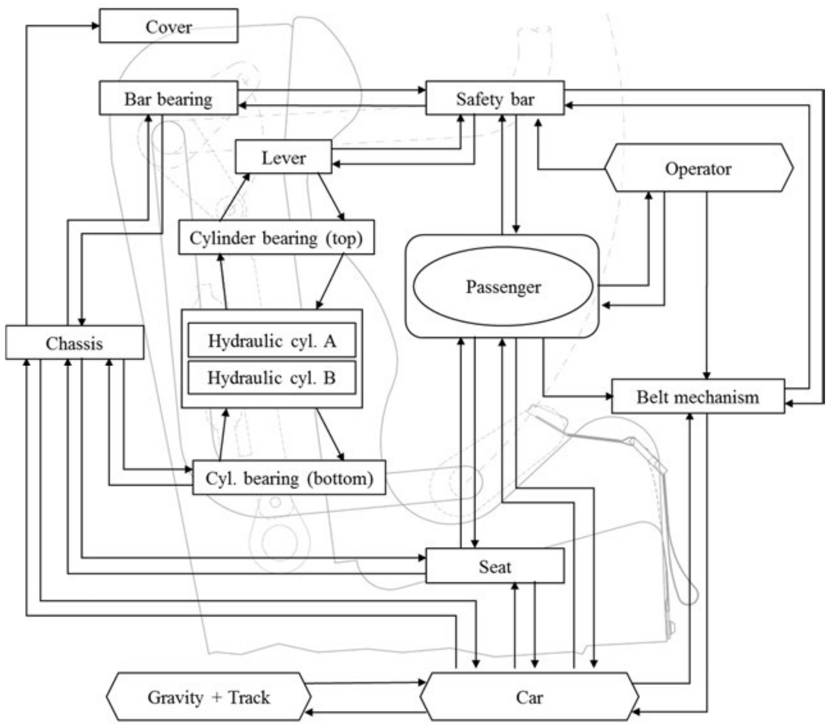

Figure 12. Function model of the fun ride seat system

The main function of the fun ride seat system is to hold the customer of the fun ride during the ride. The considered system is a subsystem of the fun ride system. It consists of 15 different components with different interactions with each other. The system is shown in Figure 12.

6. Summary, Conclusion and Outlook

This paper provides an overview of the TRIZ *Function Analysis*. The application of the approach is described in detail and shown on two specific applications in student projects. With the application of graph-based function models, like TRIZ function model, interpretability problems occur when the number of nodes and their related edges increase. In order to overcome this problem an adaption of the FA is proposed.
Beside the problem statement **Section 4** outlines the advantages of FA: increase of system understanding or system depiction. The depiction of the system is a very fertile point for discussion. Especially with the graphical adaption of FA it becomes a better platform for discussion. The interaction of components is clearly depicted and can easily be matched to the specific products. Also users who are not expierenced with function modelling can understand the system structure and its interactions. Another advantage of TRIZ function modelling is thinking about the components (CA) and the reflection of the corresponding interactions (IA). In both of these steps the students in their

project work built up detailed understanding about the core aspects of the system. In discussions with their advisors and systems engineers the students had to filter and evaluate the different information. The decision making about the importance of the components and their different interactions led to a further deeper system understanding. Finally the formulation of the actions of the components out of the interactions in the FM forced the students to think again about processes inside the technical systems. Overall it is recommended to use system or function modeling to gain deeper and sustainable system understanding.

Since TRIZ is a well-proven methodology for the development of solutions of technical problems, it can be combined with other analytical design methods. In the past, TRIZ has been successfully combined with SixSigma, QFD, or FMEA [Yamashina et al. 2002], [Barkan 2011]. At this, the adapted FA can support the linkage of TRIZ with other design methods. As seen in the student projects, the students were able to quickly understand the interaction of the different components of the systems. With this knowledge, the application of other design methods can be further improved, e.g. the analysis of the roof of the house of quality (QFD).

In future projects, the adapted FA will be applied in more students projects in order to show the benefits of FA and its adaptation. A discussion about the usefulness of the described approach for components on different levels, which can only be depicted in 3D representations has to be done. For this, the approach should be enhanced with a software-tool, e.g. soley a software platform for automated modeling tasks [Helms 2013]. In the second step investigations about the depiction of emerging systems with the help of the adapted FA can be realized. Furthermore, an attempt to give more detailed descriptions of the TRIZ tools is made, since literature about applications of TRIZ tools and methods is rare [Zaburdaeva and Zobel 2012].

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