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Using MBSE for conflict managing TRIZ on a systems engineering level

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Abstract. The objective of the presented research is to find a method to identify and resolve high level conflicts with TRIZ applications in systems engineering on a parameter level. These conflicts are caused by several competing TRIZ problem solving patterns (innovative principles) on lower system levels. Here, interference parameters result from the physical adoption of the general innovative basic principles in a specific application context (e.g. vibration, heat, additional energy consumption). To manage these conflicts on a parameter level, the system engineering point of view is matched with the physical parameter level in the engineering design of a product. Within an experimental research approach, an exemplary MBSE system model of a technical device is used to resolve parameter conflicts on a higher system level. The conflicts only arise on a higher system level consideration, which makes computer-aided conflict identification essential to design engineers. The presented method does help system engineers to foresee conflict potentials of innovative principles on a system level and to control them accordingly using a MBSE system model approach.

Keywords: MBSE, Systems Engineering, Systematic Innovation, Methodology, Engineering Design.

1 Introduction

1.1 Motivation

A holistic and creative problem analysis in combination with innovative solution finding are crucial for the development of marketable and innovative products in a strongly changed business environment [1]. For this purpose, companies use different methods and tools from TRIZ [2, 3]. TRIZ contains a comprehensive collection of methods and tools for innovative problem solving. However, the problems are only considered partially and not in the overall system context. A holistic view of the system is provided by Systems Engineering (SE). Existing approaches dealing with the combination of SE and TRIZ only consider the interaction between functions and components [4]. But if

contradictions are investigated on the system level, individual parameters on the component level must be taken into account. This leads to the necessity of combining TRIZ with a parameter based approach of model based systems engineering (MBSE).

1.2 Problem statement

Technical contradictions result from uneven development of subsystems [5]. This phenomenon can be observed when attempting to identify the technical contradictions of a system. Contradictions can be identified at the system level. Usually, their cause can only be determined by considering the subsystem level. This becomes relevant in the case of interdisciplinary product development according to SE. Different disciplines work independently on subsystems while also using TRIZ tools to solve their individual problems. This leads to the chance that interactions between the solutions and their effects on the system level are not taken into account (see Fig. 1).

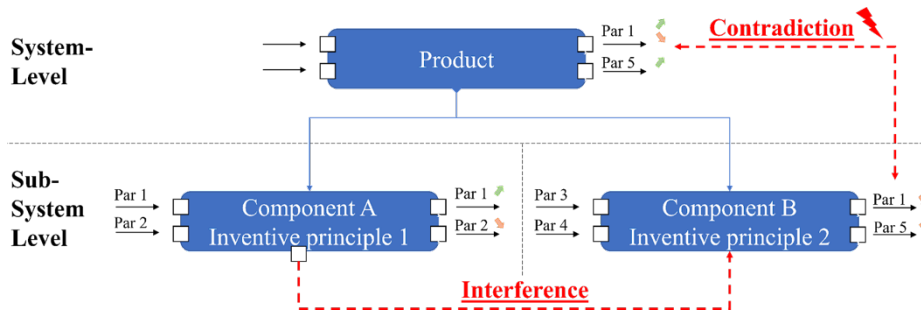


Fig. 1. Interferences between TRIZ IPs and resulting contradiction on the system level

E.g. components A and B are developed independently and different inventive principles are applied. The overall product has two target values which are characterized by the parameters (Par) 1 and 5, which are influenced by the output of component A and B. A is responsible for an increase of Par 1 while B causes Par 1 to decrease as well as Par 5. The result is a contradiction at the system level. The inventive principle (IP) 1 has a negative interference on the IP 2 which causes the decrease of the parameters. In this context, the following challenges (CH) can be derived.

CH 1. A comprehensive understanding of the system at the top level does not exist across disciplines. E.g. electrical engineers have no deep knowledge in the field of mechanical engineering which could lead to negative effects among different discipline dependent subsystems.

CH 2. Contradictions are only visible at the system level. But they arise at the parameter level. Developers of the subsystems are not aware of the impact of their solutions on the system level which could lead to contradictions.

CH 3. The ancillary variables of IPs negatively affect other IPs and the target variables of the system. E.g. dynamization according to IP 15 may be accompanied by heating or vibration, which can have a negative influence on other parameters.

These challenges lead to the research questions: Can technical contradictions in product systems be regulated down to the parameter level? Which IGPs contradict each other and cannot be used in combination? How can TRIZ and MBSE be combined at the parameter level?

2 State of the art

Models are simplified representations of reality. In mechanical engineering, different models of a product can be generated, each providing a different view on the same product (e. g. product requirements, product structure, physical description, etc.). Model-based systems engineering (MBSE) aims at a formalized product description. The aim of this modeling is to support the product data management throughout the entire product life cycle [6]. MBSE does focus on a parametric system model of the product including all different stakeholder perspectives in one data model [7].

Bielfeld et al. showed the principle connection of the TRIZ method with an MBSE model [8]. With the help of the Demand Compliant Design (DeCoDe) MBSE approach, which combines the system views requirements, functions, processes and components, a product model was developed respecting the requirements of generic systems engineering. Here, technical contradiction problems according to TRIZ could be considered on a functional level, including the structure of the entire product system. The interferences of components and their effects on a system level were then investigated and quantified using real product application examples [9]. The quantification was performed in detail by weighting critical components, without proceeding from the functional system level to the detailed parameter level. Consequently, the combination of the DeCoDe approach with TRIZ is only suitable for complexity management with respect to high-level systems structures and functional hierarchies within the system [10].

However, a quantitative evaluation of the effects of interferences of individual IGPs to the total system requires a consideration of the specific parameter level in the systems engineering model (see 1.2).

3 Methodology and approach

To identify inconsistencies between IPs, a system is modeled at the parameter level. The potential IP contradictions are analyzed in advance with a matrix in pairwise comparison of IPs. The assessment of the impact of each parameter on a system-level contradiction is then performed using an MBSE+DOE approach.

3.1 Contradiction Matrix of the inventive principles

IPs implemented at the component level have the potential to conflict at a higher system level, as explained in chapter 1.2. In a pre-study, the common known 40 IPs of TRIZ have been compared pairwise according to their main working principles. For example, a combination of IP 1 “fragmentation, segmentation” and IP 5 “combining, merging”

within a product system can lead to conflicts due to their opposite characteristics. The found potential contradictions with other IPs are documented in **Fig. 2**.

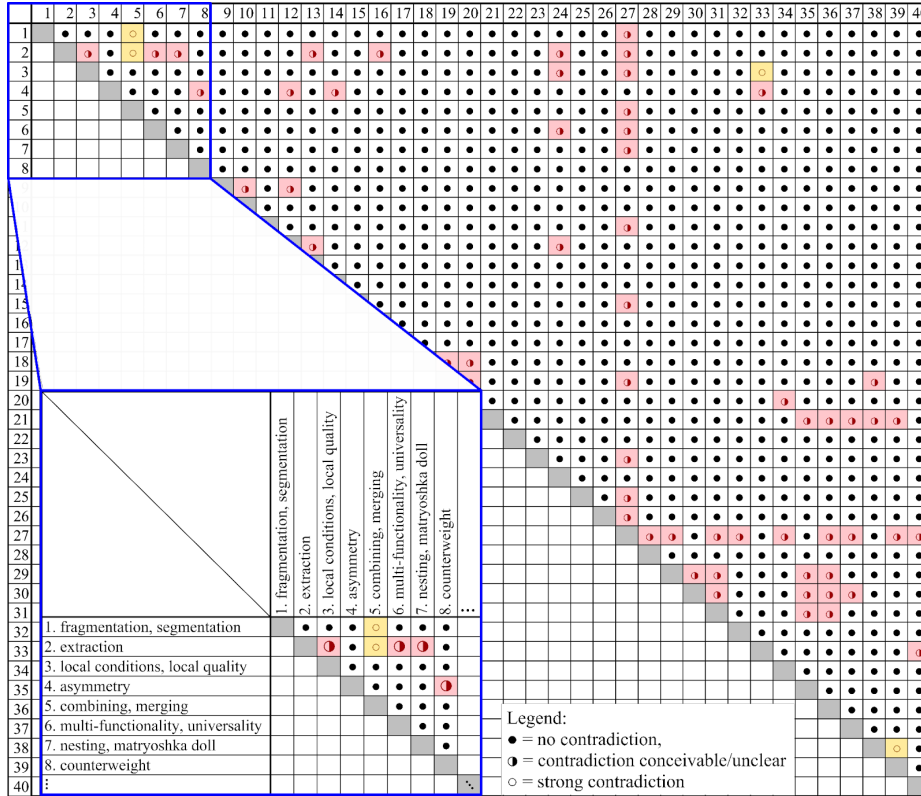


Fig. 2. Potential contradictions of TRIZ IPs in a pairwise comparison

In the presented matrix, the three attributes "no contradiction", "contradiction conceivable/unclear" and "strong contradiction" have been used to qualitatively assess the contradiction potential. If IPs are used in a system that contradict each other according to this table, it can be assumed that there will be target conflicts at the parameter level.

The pre-study shows that potential contradictions (126) are not very numerous throughout the total number of possible combinations of IP pairs (1600). However, their occurrence is spread throughout the total field of the combination matrix. Therefore, the potential risk of contradictions on a superior system level could not be located to a specific cluster of IPs. Consequently, a general system engineering approach has to be found to deal with the problem of IP contradiction throughout the whole product system.

3.2 Implementation of a model-based systems engineering approach

In addition to the fundamental conflict potential of the operating principles of individual IPs, disturbance variables or secondary variables also occur in technical implementations. This is due to the fact that the specific boundary conditions of the product and its environment must also be taken into account for the physical implementation of an IP. For example, the application of IP 29 "pneumo / hydro designs" always requires the safeguarding of a certain sealing capability or the potential disturbance variable leakage.

Since the specific disturbance variables result from the specific application in the product context, the classic TRIZ application requires the expertise of the product designer. Unfortunately, this expertise is no longer part of the knowledge of a system engineer for more complex, domain-distributed products. In order to enable a conflict resolution on system level for early phases of the development process, a SysML based MBSE database of innovative principles was created. In this database, known disturbance variables from documented use cases are stored for the IPs. With the help of this MBSE database, disturbance variables and conflicting goals can be identified in the early stages of product development on a system level.

Besides the knowledge database about potential disturbance variables, the application of the MBSE principle in the context of TRIZ offers the further advantage that the design of the system can be systematically accompanied down to the physical parameter level and the intensity of the disturbance influences can be numerically evaluated.

Based on the system engineering with the SysML-based MBSE approach, the product structure is now refined with the involvement of all domain-specific experts and stakeholders.

3.3 Trade study on parameter level

Since all input and output variables as well as disturbance variables are always recorded in a defined context, the methodical MBSE approach can then be used in later phases of the product development process to evaluate the parameter influences. Here, the first step is to formulate the physical relationships in the specific product context (expert knowledge) and then to perform a computer-aided system-wide evaluation by means of a sensitivity analysis of the parameter relationships. With the help of established computer-aided tools, this last step can be performed directly from the MBSE model according to the Design of Experiments approach.

4 Explorative study

The method presented in chapter 3 is now demonstrated in the context of an experimental study on a real product model. For this purpose, the technical system is represented as an MBSE model using the SysML language within the software tool Cameo Systems Modeler (CSM) from Dassault Systems Inc. Based on a real life parameter conflict, the application of the IGP database during the concept phase of the product development process is first demonstrated. Then, the final parametric system model is

subjected to a sensitivity analysis using the ModelCenter software from the company Phoenix Integration.

4.1 Technical system description

The example product used in this paper is a fanless laptop for compact and lightweight mobile use (ultrabook). The main requirements of this product can be stated as low weight, high battery runtime and quiet operation. In real-life operation, however, the so-called coil whine occurs in such devices from time to time, which can be attributed to the high-frequency oscillation of inductive coils in circuits on the mainboard or graphics card [Cgdirector 2022]. Depending on the user's hearing, this coil whining is annoying and contradicts the requirement of low-noise operation. At the same time, the cause of coil whining is located at the level of a specific subcomponent of an electronic circuit, which consequently represents a complex system engineering problem.

While modeling the product example in a SysML MBSE model, some simplifications have been made. The laptop is not described in its complete product structure, but reduced to the relevant components. This reduces the modeling effort and makes it easier to understand the application example. The following figure shows the top level product structure (fig. 3).

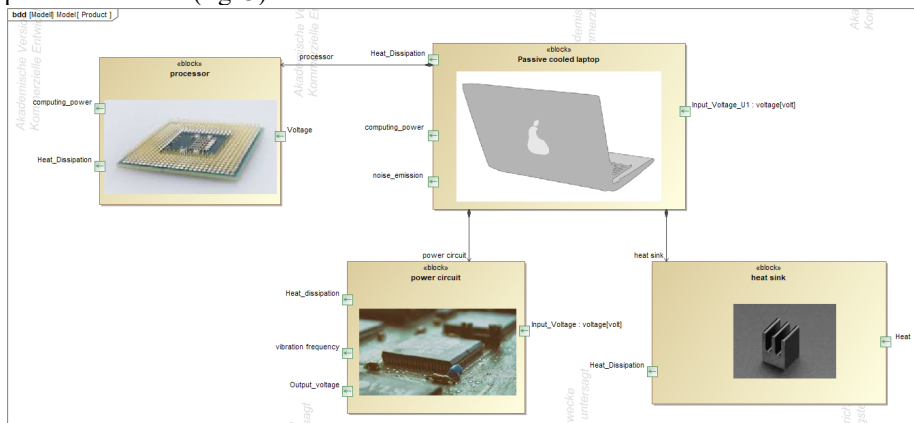


Fig. 3. Product structure of the MBSE model

Furthermore, the parameter relationships are reduced to simple mathematical formulas. The real acoustic correlations can in principle also be mapped mathematically correctly in the system, but they increase the degree of complexity many times over without contributing significantly to the understanding of the method. Finally, only the actually relevant IGPs are mapped in the database in the following. For this purpose, the relevant parameter conflict was defined according to the TRIZ methodology as follows [Mann 2009]:

Parameter to be improved: Adaptability / versatility. This is based on the consideration that the individual components (e.g. processor) have a versatile voltage requirement over the service life, while the power supply is provided via a constant voltage.

Deteriorating parameter: Time loss. A component-dependent adjustment of the voltage at the external power supply of the laptop requires a time-discrete adjustment of the respective states, which means that other components cannot be supplied simultaneously with their individual demand.

Using the updated TRIZ contradiction matrix of Mann, the following innovative principles have been identified as potential solutions, see Table 1.

Table 1. Suitable Innovative Basic Principles from TRIZ Matrix 2010 [Quelle].

IP Nr.	Name
15	Dynamisation
28	Replacement of mechanical principles
29	Pneumo / hydro designs
35	Parameter changes

In the next section, the methodical use of the MBSE model in product development at an early stage (preliminary design) and then at a later stage (design refinement) is discussed.

4.2 MBSE concept modeling

According to the methodological approach from chapter 3.2, a database in the form of a SysML package was created in the MBSE system model, which contains named IPs. Each IP was created with a solution-neutral input or output as well as specific potential disturbance variables. Here, the disturbance variables were identified based on a literature search of validated IP solutions. For example, implementation examples for the IP "Dynamization" can be found in the literature, where the disturbance variables "Increased component variance", "Vibrations", "Volume change" and "Waste heat" were identified [11].

This form of database is solution-neutral and can be imported or exported across projects. The problem to be solved is created within the system model as a black box in the form of a block element in the internal block diagram (ibd) of the product. Here, the actual inputs and outputs, as far as known, are concretized. In a way, this step represents the preliminary work of the engineer.

In order to now use individual suitable IPs as solutions of the black box, the IP blocks can be used (corresponds to type change). Here, a comparison of the two element information takes place, whereby the developer is confronted with the potential disturbance variables of the specific IP documented in the database (fig. 4).

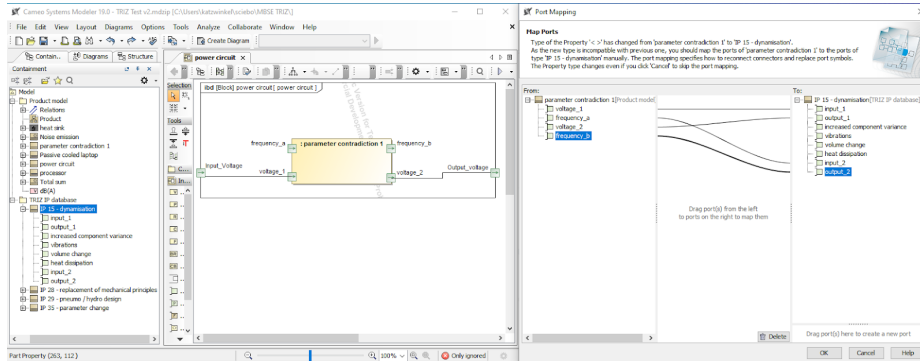


Fig. 4. IP database (left) and type change revealing potential interferences (right)

In this step, the engineer is provided with specific database knowledge, on the basis of which previously unknown potential disturbance variables are visualized and now need to be evaluated in the system context. This process is redundant for different IPs, so an iterative evaluation of different solution approaches for the parameter conflict is also possible.

4.3 MBSE parameter study

In the further elaboration (design refinement) of the product concept, solution-specific physical relationships between the respective parameter flows within the overall product architecture must now be worked out. With the help of expert knowledge, concrete formula constraints are determined and entered in the system model (parametric diagram). Figure 5 shows an example of the modeling of heat dissipation and noise emission for the given product example.

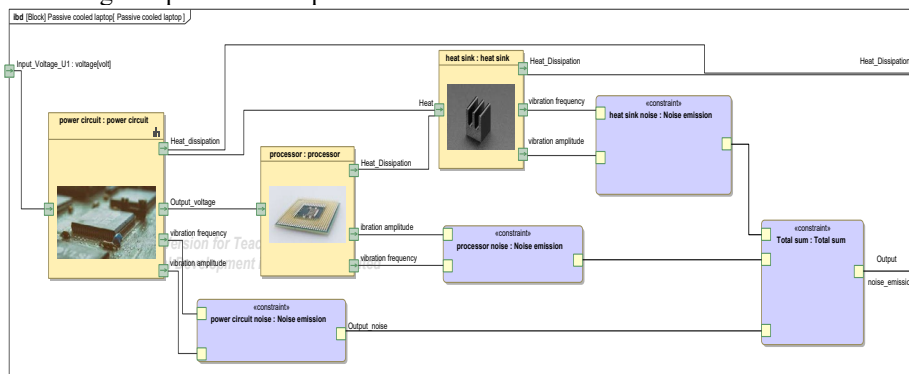


Fig. 5. Example of heat dissipation and noise emission parameter constraints within the MBSE model

Due to the complexity of the parameter interrelationships, it is not yet possible for the system engineer to objectively assess at this point which parameters influence the

final target variables and in what quality. In addition to the complexity, this is also due to the domain-specific expertise of the individual constraints, which are created by experts in the system model shared throughout the company (e.g., electrical engineering, mechanics, IT). A sensitivity analysis (Fig. 6) is now carried out to counter this circumstance.

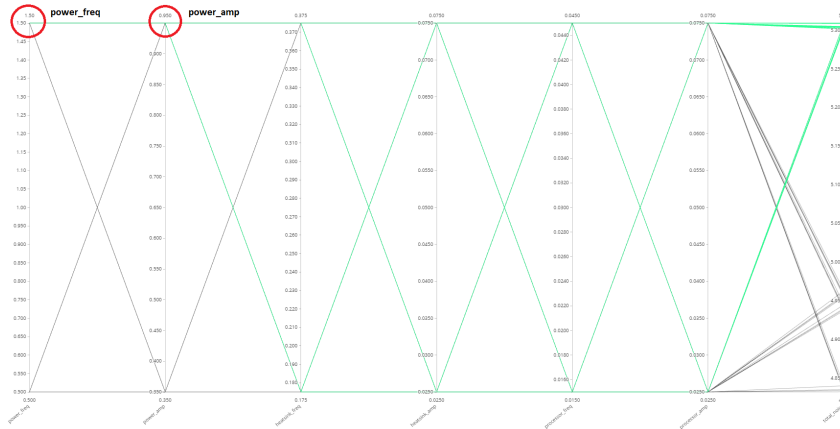


Fig. 6. Sensitivity analysis carried out with ModelCenter using the DOE approach

For this purpose the program extension ModelCenter of the company Phoenix Integration is used. By coupling the SysML parameter relationships and constraints, a numerical sensitivity analysis can now be performed according to the DOE approach. For this purpose, the problem of noise generation is modeled in a mathematically simplified way. The DOE tool of ModelCenter can now vary all input parameters in given ranges and interval steps. With each variation, the calculation is performed automatically. Finally, a graphical comparison shows the relevant influencing variables for the specific loudness values (fig. 6), showing that the power circuit vibrations variables (frequency and amplitude) have the biggest influence for the maximum noise emission in the mathematical model.

It becomes apparent that the disturbance variable "vibrations" of IP 15 "dynamization" has a significant influence on the target variable "noise emission" by influence of the component "power circuit". Consequently, this influence must be minimized in the subsequent design (e.g. by damping, changing the material or changing the IP).

5 Discussion

The presented method enables a computer-aided integration of expert knowledge about the IP into the product development process. The disturbance variables stored in the database are important indicators for design decisions of the system engineer. The IP database makes the system engineer more independent of his TRIZ expertise and also provides him with domain-specific disturbance information.

In contrast, the initial effort for MBSE system modeling in general and the specific effort for creating the IP database can be classified as high to very high. This problem is inherent to the SysML-based MBSE approach and is amplified by the required parameter-based level of detail of the model.

Moreover, both the SysML-based system design and the IP database maintenance require the collaboration of domain-specific experts.

Therefore, the presented approach is particularly suitable for products of medium to high complexity in those companies that implement an IT infrastructure for collaborative system model maintenance across domains.

Finally, the actual disturbance variables of each IP depend on the concrete implementation of the generic solution approaches, so that in early concept phases no generally valid statement about the relevant disturbance variables can be made at first. Rather, the database contains a collection of all previously known possible disturbance variables in the context of the respective IP. Therefore, the product developer must make a context-sensitive adaptation to the specific use case and company context here. On the other hand, the IP database can be easily transferred to further development projects or other product types due to its generic content, enabling knowledge-based engineering.

While for the IP database is particularly suitable for early concept phases in product development, the presented method for sensitivity analysis of the disturbance variables first requires a complete capture of the parameter interrelationships in the form of calculation rules. While this approach seems particularly attractive for adaptation and variant designs, the initial modeling effort could be a significant hurdle for innovative new developments.

6 Conclusion and outlook

In this paper we have discussed the research questions: Can technical contradictions in product systems be regulated down to the parameter level? A method for a systematic and data-based identification of potential contradictions on a parameter level has been presented using a SysML-based MBSE approach in combination with a DOE sensitivity analysis strategy. The method has been demonstrated using a technical product example with a commonly known contradiction problem.

Within the experimental approach, the presented method seems feasible for products of mid-range complexity. However, the approach requires a solid IT-infrastructure and a MBSE oriented development process for industrial application feasibility. In Addition, the database approach needs a continuous enhancement and refinement in the future.

The research of TRIZ contradiction problems in systems engineering and the refinement of a application oriented MBSE methodology is topic of future projects at the chair for product safety and quality engineering at the university of wuppertal.

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