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Crisis Situations in Engineering Product Development: A TRIZ based approach

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Abstract

Crisis situations are special situations during the development process. They are characterized by time and handling pressure. Therefore, it is necessary to identify and apply a methodical problem solving approach to overcome these situations. Due to their prescriptive character, problem solving approaches reduce the problem identification time and increase the efficiency of crisis management. The goal of this research is to identify methods which are able to support the crisis management process successfully. Therefore, a literature-based analysis of developing methods, especially TRIZ is conducted. Regarding the main steps of problem solving, evaluation criteria are identified and considered. This bases on standardized method descriptions and is evaluated by criteria regarding training effort, usability, time, quality of solutions, required resources, and effort for application by 12 TRIZ users and experts. Result of this research is a situation specific approach for crises. The evaluated methods are clustered considering the main steps of problem solving. Results indicate that TRIZ methods support especially the idea generation process with structured and detailed approaches.

Peer-review under responsibility of Scientific committee of Triz Future Conference

Keywords: Crisis Management, Theory of inventive problem solving (TRIZ, TIPS), Design Support

1. Introduction

The presented research is part of an overall research about crisis situations in product development. This research has two main goals: (1) Building of an overall understanding about crisis situations and (2) development of a support for effective crisis management. The main research question of this paper is: **Which TRIZ methods are suitable for effective crisis management?**

Crisis situations are special situations during the development process. If these situations are not solved, they have a high impact on cost, resources of a company and customers. Additionally, further setbacks during crisis situations need to be prevented [1].

Therefore, it is necessary to identify and apply a methodical problem solving approach to manage crisis situations. Due to their prescriptive character, problem solving approaches reduce the problem identification time and increase the efficiency of crisis management. Furthermore, Bear et al. assumed that ´systematic problem formulation will result in better quality decisions as well as in decisions that are likely to be more acceptable to upper management and thus more likely to be implemented successfully and expeditiously´ [2].

To answer the research question a literature-based analysis of developing methods especially TRIZ is conducted [3]. Regarding the main steps of problem solving, evaluation criteria are identified and considered. The assessment is evaluated by criteria regarding training effort, usability, time, quality of solutions, required resources, and effort for application.

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2. Crisis situation in engineering product development

Crisis situations in engineering product development are special situations. When these situations occur they need to be solved immediately because their causes influence the success of projects and companies. A crisis situation is defined as a situation which is triggered by undesired and unexpected events. These events are connected with high time and result pressure [1]. Important aspects of crisis situations are [1]:

- Achieving the solution quickly while keeping risk low is crucial – not the degree of innovation.
- As there are time constraints no detailed planning is possible.
- Further setbacks during crisis situations need to be prevented.

Since literature about crisis management in engineering product development is limited, crisis situations are described based on the knowledge of crisis management in economics, business science, and project management [4].

Crisis situations can be represented in cause-effect-chains. There are external and internal causes for crisis situations. External causes stem from changes in the environment of a company. They can be legal, technological, or sociopolitical changes. Further influences like scarcity of resources or even wars and natural disasters may impact crisis situations [5].

Internal causes arise from the inside of a company. The company has direct impact on them. They can be clustered into three categories: organizational problems (e.g. miscalculation, missing know-how), task-related problems (unclear defined tasks), or lack of action (wrong consultancies, loss of important employee) [6].

Effects of a crisis situation turn out variously. They pose a danger to human life and environment and may lead to company damage. They reach from unemployment, overtime, stress, reduction of social services to obstruct personal development. Moreover, equity providers may lose their investments or personal assets.

A general crisis process is depicted in Figure 1. In this representation a crisis situation is the deviation from the target state over time. Possible indicators for the deviation from the target state are exceeded project milestones, budgets, or the ready state of the product.

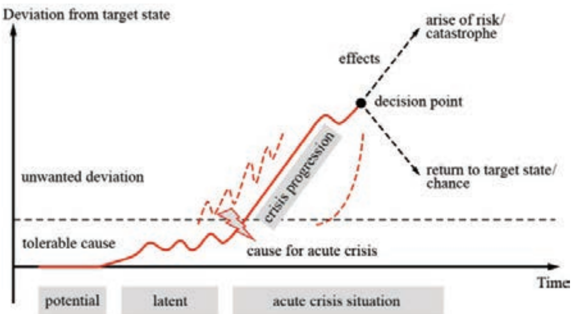

Figure 1. Depiction of a crisis process based on [1, 7]

The crisis process can be divided into three phases: potential, latent, and acute crisis [8]. A potential crisis implies deviation from the target state but causes are tolerable since they can be countered with preventive crisis management. In a latent crisis situation the crisis already erupted but is not yet noticeable to the participants. The acute crisis situation describes all events occurring after the outbreak of the crisis.

The progression of an acute crisis situation can have different characteristics. Töpfer distinguishes three different processes: eruptive, periodic, and abrupt (see Figure 1) [9].

At a specific event the situation turns into a risk or chance (decision point). The most extreme form of a risk is called catastrophe, e.g. bankruptcy of a company. On the other side the participants can turn the crisis situation and return to target state, e.g. normal work process. In addition participants can even benefit from the crisis, e.g. through a competitive advantage due to an innovative product.

3. Introduction of TRIZ

The Theory of Inventive Problem Solving (TRIZ, TIPS) is a problem solving toolkit which is based on logic and data [10, 11].

The founder, Genrich S. Altschuller, realized that technological systems follow an expectable way that overlaps with all fields of science [12]. Thereby, he specified that all ways of problem solving are repeatable and predictable [12]. Contemporary descriptions of TRIZ indicate that it extends, beyond being merely a theory or a set of principles, as its name suggests. TRIZ is a knowledge-based systematic methodology of inventive problem solving [13]. Fey and Rivin described TRIZ as a methodology for the effective development of new (technical) systems in addition to being a set of principles that defines how technologies and systems evolve [14]. It provides a systematic approach for finding solutions to technical problems and innovating technical systems [15].

Livotov described that the accurate integration of TRIZ into innovation management enables companies to benefit from the full potential of TRIZ in the following fields [16]. Thereby, TRIZ:

- Supports conceptual development of new products, processes and business strategies.
- Enables forecasting of evolution of technological systems, products, processes.
- Improves inventive and technical problem solving.
- Supports comprehensive search for solutions and protection of company expertise (so called patent fences).
- Supports the evaluation of the hidden wants and needs of the customer; customer-driven market segmentation.
- Enables anticipatory failure identification and troubleshooting of new and existing products.
- Illustrates advanced solutions for idea and knowledge management.

A survey with 40 participants listed more than 100 benefits derived from TRIZ and pointed out the benefits concerning the following categories [15]:

- Approach to problems: TRIZ provides a structured approach to problem solving. This prevents erratic brainstorming and search for solutions. The methodology helps to identify and to clarify problems and offers good solution hints.
- Idea generation: TRIZ provides useful and usually novel solutions. Apart from the quality of ideas, TRIZ helps to generate more innovative ideas than will be generated otherwise.
- Innovation and new solutions: It provides breakthrough innovation and solutions and new concepts for development.
- Speed: The resolution of problems and arriving at innovation solutions is achieved in shorter times because it becomes possible to identify the problems and focus on them
- Looking into the future: With the help of TRIZ it is possible to predict next products/services/markets.
- Teamwork: TRIZ offers a common language among the participants, this supports the teamwork.

The TRIZ tool and its' advantage to companies, especially in fields of improving inventive and technical problem solving, supporting comprehensive search for solutions and protection of company expertise, the anticipatory failure identification, troubleshooting of new and existing products, and the advanced solutions for idea and knowledge management, support the special needs in a crisis [16].

The benefits of TRIZ related to crisis management are structured approaches to problem solving, useful and usually novel solutions, the possibility to generate breakthrough innovation, solutions and new concepts for development, and the increase of speed and supporting teamwork with a common language [15].

Referring to Ilevbare and Möhrle, the following tools are most often applied in companies [15, 10]:

- 40 Inventive Principles
- Ideality/IFR
- Contradiction Matrix
- Patterns of Technical Evolution
- Function Analysis
- Substance-Field Analysis

Derived from this and supported by a further literature research the classification of TRIZ tools according to the application field and the experience of the authors the methods Function Analysis (FA), Contradictions, Substance-Field (Su-Field) Analysis, and Problem-oriented 9 Screen Approach are selected and described in the following. No attempt will be made to explain them in detail in this article. However, there is a need of a short overview.

- 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, and goal clarification as well as in generating ideas for possible solutions [1, 17, 18]. FA is divided into five main tools: incremental improvement, value analysis, trimming, patent circumvention, and stealing from super systems. The different tools determine the focus of the analysis [19, 20].
- Contradictions are indicative of inventive problems arising from the obvious incompatibility of chosen features within a system [15]. Using the contradictions in combination with the 40 Inventive Principles or Separation Principles will solve the problems. There are two major types of contradictions: Engineering Contradictions and Physical Contradictions [15].
- Su-Field Analysis is a TRIZ analytical tool for modelling problems related to existing technological systems. Su-Field is a model of a minimal, functioning and controllable technical system [21]. Every system is created to perform some functions. The desired function is the output of an object or substance (i.e. S1) caused by another object (i.e. S2) with the help of fields (types of energy).
- The Problem-oriented 9 Screen Approach is used to change the perspective toward a problem. It leads from a profound analysis of the system and its surroundings to the questions how to use the resources [19]. The arising questions lead to a new way of thinking and thus to new solutions [19].

4. Design support

This section introduced the boundary conditions and requirements for the Design Support. Based on them the Design Support for crisis situations is proposed.

4.1. Boundary conditions and requirements for the design support

Different approaches for the systematic development process are existing [1, 3, 17, 18, 22]. These approaches describe the development process in a generic way. On the one hand these approaches propose specific instructions or provide methods to perform the design process. On the other hand they can be used for overall project planning and provide a beaten track which engineers can follow during the product development process. Depending on the situation these approaches have to be adapted. They have in common that the problem solving process is divided into three steps: (1) goal or target analysis, (2) development of ideas, and (3) decision making [1].

Based on these findings a situation specific problem solution approach for crisis situations in engineering product development was developed. Therefore, crisis situation specific boundary conditions based on literature and tool specific requirements have been identified during the research [4].

Situation specific boundary conditions influence the engineers during the problem solving process in a crisis situation. Tool specific necessities are requirements for systematic tools or methods which should be considered to increase the performance of the tool/method application.

Four situation specific boundary conditions have been identified [4]: time, resources, solution quality, and human behavior. First, time pressure is one of the main features of a crisis situation. Engineers do not have the time for holistic situation or system analysis [1]. All problem solving tasks need to be performed with maximum effectiveness and efficiency to develop a solution in time and reduce the damage of the crisis situation. Secondly, resources can be limited during crisis situations due to unpredictability of the situation. Resources can implicate manpower, competences, machines, or money [23]. Thirdly, Lindemann argues that the quality of solution is important [1]. Not the degree of innovation is important but the practicability of the solution in order to reduce the risk of further setbacks and with this a decline of the crisis situation. Fourthly, human behavior in crisis situations differs from behavior in non-crisis situations. Time pressure can lead to stress and fears which can influence engineers. On the one hand stress can increase performance for a short time. On the other hand it hinders the performance of individuals or teams, i.e. concerning the overlook of mistakes, wrong decision making, or limitation of communication.

To react to the situation the following tool specific requirements have been formulated: Identify process steps, externalize knowledge, and highlight methods.

First, the approach should highlight the status of problem solving process to the engineers. Often problem solvers already performed first tasks, e.g. problem analysis, or specific results are given, e.g. solution possibilities are known. Here the approach should support the engineers in easily and fast identifying their relevant step. In order to increase efficiency engineers should identify the right step as quickly as possible.

Secondly, product and problem knowledge of each team member should be externalized to increase the effectiveness of communication. If engineers are not able to communicate their ideas and understandings each team member works on different goals and the team does not cooperate.

Thirdly, situation relevant methods should be highlighted. Depending on the given resources, e.g. possibilities of simulation or machine tools, team size, time pressure, competences of team members, or local conditions, different methods are favored or eliminated.

4.2. Design support for crisis situations

In this section a Design Support to overcome crisis situations is proposed. Regarding to Blessing and Chakrabarti a Design Support can implicate beside knowledge, guidelines, or checklists, a sequence of activities to be followed in order to improve particular stages of the design process [24].

As shown in section 4.1. Lindemann identified three main steps which standardized procedure models for technical problem solving have in common [1]. Based on this finding a crisis situation problem solving process is proposed. Hence, the Design Support consists of the following four steps (see Figure 2): (1) identification, (2) analysis, (3) generation, and (4) evaluation. The crisis situation solving process should always start with the identification of the situation relevant problem solving step: goal or target analysis (analyze), development of ideas (generate), or decision making (evaluate). Therefore, the engineer is guided by the help of questions he has to answer. [25].

After the identification step the problem solving process starts. Within the analysis step, the problem solver performs goal planning and analysis as well as task structuring actions and methods. Within the (idea) generation step, solution ideas for the given problem are developed. In the evaluation step property assessment, decision making, and ensuring of goal achievement are performed.

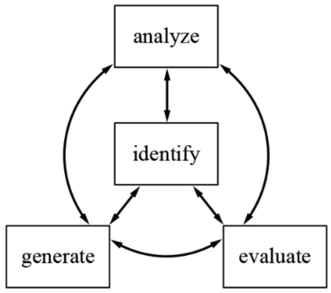

Figure 2. Design Support for problem solving in crisis situations

4.3. Integration of TRIZ into design support

Based on the considerations about crisis situations and the identified boundary conditions the TRIZ methods are evaluated regarding their suitability for the proposed Design Support. Therefore, the methods are assessed by the following criteria:

- Team size: How many users are needed to apply the method?
- Required prior knowledge: Which level of prior knowledge is needed to apply the method successfully?
- Training effort: Which level of training effort needs to be invested to apply the method successfully?
- Application time: How much time is needed to achieve good quality results?
- Externalization of knowledge: How suitable is the method to document the individual knowledge of the user?
- Quality of solution: In which way the results of the method application are documented?
- Required resources: Which resources are needed to apply the method successfully?

The criteria *training effort*, *application time*, and *externalization of knowledge* are rated on a 1/3/5-scale. 1 represents low level of effort, time or quality of the externalization. Accordingly, 3 represents a medium and 5 a high level of the criteria mentioned.

5. Results and implications

In the following paragraph the results of the literature research and the evaluation of the methods regarding suitability for crisis situations in engineering product development are presented and discussed. The results of a questionnaire study with 12 TRIZ users and experts (MATRIZ certification – 3x level 2, 6x level 3, 1x level 4, 2x level 5) is illustrated.

As shown in section 4.3 the first three aspects were asked to rate on a 1/3/5-scale. The last aspects were answered with short text descriptions.

Table 1. Evaluation of training effort

Rank	Method	Training Effort
1	9 Screens (problem-oriented)	1
2	Engineering Contradiction	3
3	Physical Contradiction	3
4	Su-Field Analysis	3
5	Function Analysis	5

Table 1 shows that the experts rate the *training efforts* for 9 Screens (problem-oriented) as low. With this the method is best suitable for the application in crisis situations. Engineering and Physical Contradiction as well as Su-Field Analysis are rated with medium training effort. So these methods could also be applied in crisis situations.

Function Analysis is rated with high *training effort* and with this not suitable for crisis situations.

Table 2. Evaluation of application time

Rank	Method	Application Time
1	Engineering Contradiction	3
1	Physical Contradiction	3
1	Su-Field Analysis	3
1	9 Screens (problem-oriented)	3
5	Function Analysis	5

Table 2 summarizes the results of the evaluation regarding method *application time*. The evaluation shows that Engineering and Physical Contradiction, Su-Field Analysis, and 9 Screens (problem-oriented) are rated with medium *application time*. Based on this these methods are on the one hand suitable for crisis situations. But on the other hand it shows that none of the five methods is rated with low *application time*. From this point it should be discussed how suitable TRIZ methods are for users who are not trained in TRIZ.

Furthermore, the evaluations show that Function Analysis is rated with high *application time*. With this Function Analysis is not suitable for the application in crisis situations.

Table 3. Evaluation of externalization of knowledge

Rank	Method	Externalization
1	Function Analysis	5
2	9 Screens (problem-oriented)	3
2	Engineering Contradiction	3
2	Physical Contradiction	3
2	Su-Field Analysis	3

Table 3 summarizes the results regarding the aspect e*xternalization of knowledge*. It shows that Function Analysis has very high potential to externalize knowledge of the applicants. 9 Screens (problem-oriented), Engineering and Physical Contradiction, and Su-Field Analysis are rated by the experts with medium potential.

In addition the experts commented the methods regarding *team size*, *quality of output*, and *required resources*. The results are that all experts classify the methods as team methods. The number of applicants is set between 2 to 10 persons. Engineering and Physical Contradiction as well as Su-Field Analysis are stated with 5 persons in average. Function Analysis and 9 Screens (problem-oriented) are stated up to 10 applicants.

Regarding the *quality of output* all experts rate the quality as good or even very good. Due to the fact that *quality of output* was not further detailed this aspect should be evaluated carefully. It is necessary to say that TRIZ experts rely on these methods but they can be biased due to their high experience in TRIZ. This aspect needs further and more elaborated research.

The evaluation of the *required resources* for the method application shows that 9 Screens (problem-oriented) needs only few (template) or no extra resources. For the other methods the experts suggest to add (system/process/product) experts and further training materials, e.g. software, templates, or presentation material, for a successful method application.

Table 4. Average overall ranking of the evaluated methods

Method	Training Effort	Application Time	Externalization	Average Rank
9 Screens (problem-oriented)	1	1	2	1
Engineering Contradiction	2	1	2	2
Physical Contradiction	2	1	2	2
Su-Field Analysis	2	1	2	2
Function Analysis	5	5	1	4

The expert interviews show that not all of the methods are suitable for the application during crisis situations (see Table 4). Best rated was 9 Screens (problem-oriented). It scores rank 1 in all of the aspects considered. Furthermore, nearly no material is needed for the method application. Engineering and Physical Contradiction are ranked on position 2. Concerning evaluation, these methods lack the externalization of knowledge but have an overall potential for the application in crisis situations. Su-Field Analysis is ranked on position 3. These methods require a high *training effort*. In addition, the *externalization of knowledge* is only rated medium.

Function Analysis is not suitable for the application in crisis situations. Even if the *externalization of knowledge* is rated high, the *training effort* and *application time* are rated high. Additionally, extra resources are need for the application.

A further implication of the questionnaire study is that the TRIZ methods fit best in Step 3 (idea generation) of the proposed Design Support for crisis situations. TRIZ provides methods for problem analysis and idea generation.

6. Limitation and scope

The TRIZ framework provides a huge variety of methods. However, four selected TRIZ methods (i.e. Function Analysis, Contradictions, Substance-Field Analysis and Problem-oriented 9 Screen) have been analyzed and evaluated in this research. Further work should focus on the whole framework, especially of ARIZ. In addition, Design Support for problem solving in crisis situations should be matched with the classification of TRIZ tools according to the application field in order to get more information about synergies.

The criteria selection is based on literature research. The survey represents a qualitative approach with 12 participants. Concerning further work, an empirical selection of criteria and an increasing number of participants should be considered.

Furthermore, there is only a limited amount of established research and literature for crisis management in engineering product development. So far, crisis situations are described based on the knowledge of crisis management in economics, business science, and project management.

7. Conclusion

The goal of this paper was to identify TRIZ methods for effective crisis management. In order to achieve this goal TRIZ methods were identified and evaluated.

Regarding the literature research and conducted survey the selected methods fit to the requirements and necessities a crisis causes very well. TRIZ methods especially support the idea generation process with structured and detailed approaches. Apart from this, Contradictions and Su-field Analysis use elaborated standard solutions (i.e. 40 Inventive and 76 standard solutions). These methods lead involved people very straight to new ideas for their problem. The TRIZ user interviews show that not all of the methods are suitable for the application during crisis situations (see Table 4). Best rated was 9 Screens (problem-oriented) which scores rank 1 in the average ranking.

Overall most TRIZ tools need a significant amount of training time. For experienced TRIZ users TRIZ provides useful tools (more than the evaluated) for efficient crisis management.

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