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Improving the construction of RCA+ contradiction trees

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Abstract. RCA+ is a state decomposition method aimed at finding root causes of problems and describing these root causes as TRIZ contradictions. The current rules to apply the RCA+ methodology are balanced between speed of application and the quality and depth of insights. In this research alternatives methodologies of constructing the RCA+ contradiction tree are investigated and 2 templates have been developed and validated. Significant improvements were found in the width and depth of analysis as well as the level of better understanding of the problem being studied.

Keywords: RCA+, TRIZ, Root Cause.

1 Introduction

Creativity is seen as key to the fast and efficient introduction of new product variants. The human brain is designed to recognize patterns, helping to recognize objects and situations almost instantaneously. But the brain tends to stick to known patterns, and switching to new or unfamiliar patterns is difficult [1]. Creativity tools are designed to help break mental inertia and use different patterns to come to innovative solutions.

One of the tools of TRIZ is Root Conflict Analysis (RCA+) [2]. It is a tool that helps to find causes to flaws in products and links them to TRIZ by describing the identified causes as contradictions. By asking “what causes...”, aspects of the flaws of products can be defined and mapped in a tree structure. RCA+, in combination with other TRIZ tools, can be a valuable tool for product innovation. Not discovering the root causes, or defining the wrong causes may lead to the necessity to redo a cause finding analysis multiple times and thus losing important development time [3]. For this reason research was started to investigate if both the depth and quality of exploration could be improved efficiently. By improving the (methods of application of the) RCA+, the certainty of finding the right causes, and thus creating better innovative solutions, is expected to increase. To do so, research was started [6] on alternative ways to teach (students) how to analyze products and their root causes.

1.1 Problem statement

RCA+ helps with the analysis of a problem situation. The essence of a root conflict analysis is to visualize all connecting chains of causes and effects that contribute to a problem. The causes are represented as a negative effect (-). The next step is to also formulate the positive effects (+) related to already identified the negative aspect. This

is represented in a tree structure of positive and negative aspects. The relation between the branches in the RCA indicate if both causes (&) need to be present for the higher level cause to emerge or not. There are 3 reasons [2] to define the end condition that indicates to stop further development of a branch of the contradiction tree.

1. A cause is a demand or requirement that is impossible to change, for instance a policy requirement. This cause is then described as a non-changeable effect (--).
2. A cause has been reached that includes both a positive and a negative effect. This means a contradiction occurs and this is defined as a 'root conflict' (+-).
3. A cause has been reached which is not possible to control, for instance, it has to do with unpredictable changes in environment or human behavior. This cause is then described as a non-changeable effect (--).

Visualization of the problem situation (see fig. 1) is important, since it makes it easier to recognize the impact of individual contradictions on the flawed product[4].

By introducing contradictions, the product innovator can apply the results of the RCA+ analysis directly within the TRIZ contradiction matrix [5]. However, when comparing the analysis to other root cause finding tools, some fundamental differences emerged. For example, the Cause-Effect-Chain-Analysis (CECA), like RCA+, asks the question “*what causes that problem?*” to get insight into root causes. When making an RCA+, contradictions are already visualized by specifically considering both positive and negative effects. However Dobrusskin [4] states that this is not the case with CECA. Because the contradiction is a stopping condition for further developing the RCA+, the depth of the analysis results will vary when comparing both tools. Laoh [6] concluded

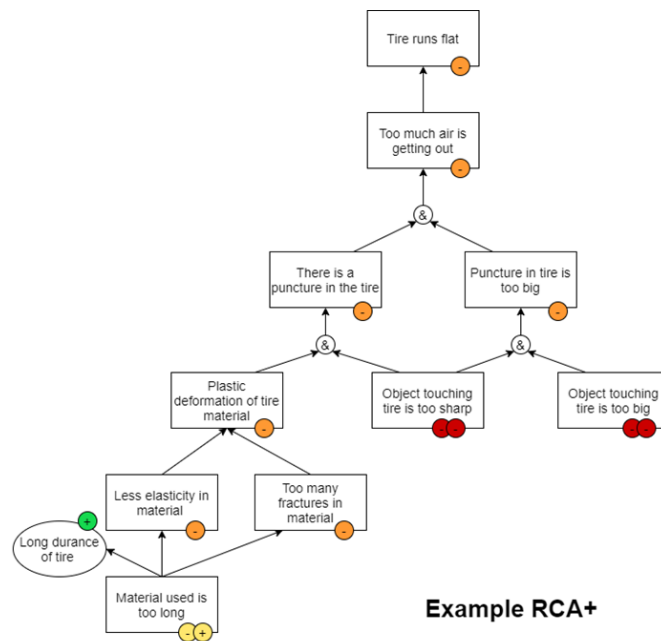


Figure 1 Example of a RCA+ diagram

that similar results were found when comparing it to other tools like 5-WHY's, Current Reality Tree and Cause and Effect Diagrams.

Assuming a well-engineered product, further development of that product towards ideality would include revisiting all the decisions made by the original engineer, discovering the contradictions he/she faced and identifying the tradeoffs chosen, together resulting in the current version of the product. However, any negative effect can be formulated as a contradiction (*"Every cloud has a silver lining"*) if all positive and negative aspects are considered valid. Defining non-optimal contradictions would lead to trying to answering the wrong question while also stopping the analysis before proper depth of analysis is reached. The reasons for defining non optimal contradictions are expected to lie in the definition of the contradiction itself, as well as in the preparation sets prior to constructing the RCA+. With that, the research question to be answered is: how can the quality of the application of the RCA+ be improved to better capture the core of the initial problem situation without increasing the complexity and effort of doing so?

1.2 Methodology

To identify possible improvement areas of the RCA+ methodology, the methodology was compared to other tools with similar functionalities. This comparison was based on literature reviews and expert survey and interviews (see section 2). This comparison led to the definition of several possible improvement areas. Based on these improvement areas, 2 concepts have been developed. Finally, these concepts have been validated in a classroom setting to identify positive and negative aspects of the concepts. Based on a statistical analysis of results obtained conclusions will be drawn on the effects on structuring the construction phase of the RCA+ more.

2 Identification of possible enhancements areas of the RCA+

To define what aspects of the RCA+ could be investigated to improve the construction process, three different information sources were used. Based on existing literature on cause finding methods the fundamental variations in the approaches for discovering causes were identified. Secondly, a panel of 7 TRIZ experts (each expert had a TRIZ level of expertise of 3 or higher) filled in a survey and were interviewed (semi-structured, with mostly open ended questions) on their preferences related to aspects of different cause-finding tools (including RCA+). Finally a group of Engineering students was interviewed on more generic aspects of tools, like their preferred way of learning new methods and their preferences on how information should be presented efficiently. From the literature research it was deduced that aspects can best be categorized in 4 groups. These groups were also used to structure the interaction with the experts (survey and interviews). The results of these analysis steps are described in the remainder of this section.

2.1 Information gathering.

Literature indicates that the quality of information, which is retrieved when applying root cause finding methods (RCA+, RCA, CRT, 5 Why's, CED and ID), mainly depend on the knowledge of the people using the cause finding method. In most cases this concerns knowledge and insights obtained during the cause finding process, not the knowledge already available at the start of using the tools. A couple of papers also mention that this knowledge gathering step should later in the process be evaluated. Finally, all information gathered should be supported by theoretical information and data [7-10].

Within the survey and interviews, multiple experts mentioned that they interview problem related experts to get more specific information on a problem or topic. Also the use of different focus area's during information gathering was suggested; engineering (how), management (why) and for example moderators with more independent insights. Finally, all experts mentioned brainstorming as an important step in this stage of the process.

2.2 Considered resources.

Literature indicates that each cause finding tool considers many different aspects of product development, although some tools are more specific about it. CED specifically mentions man, machine, material, method and measurement while CRT focusses on undesirable effects defined by the people working on the problem. RCA+ specifically mentions that, when considering the entire product development, the following categories should be considered: time, place, material, functionality, supersystem and energy & forces [7,8,9,11-13].

The breadth of an analysis is important to experts also, but they also find it hard to define (at a generic level) what resources to include. Different people can have different views on the problem, which will also lead to definition of different resources. Furthermore, it is important to recognize that each resource can have different categories itself. An example is the resource time: it can be about the time a procedure takes, a specific time an action takes place, time in between actions, total production time etc. Most interviewees did not mention specific resources to consider as they indicated that they depend on the problem, situation and personal preferences. However, it was mentioned that it could be useful to create a structured, problem depended, overview of resources.

2.3 Readability & amount of information.

From the tools investigated the ID, RCA and CED do not contain guidelines on the amount of information and level of detail that should be implemented. All others describe some rules on the when to end the exploration, although not all define a firm stop. Not having concrete and correct stopping guidelines can be a problem, as the lack of these guidelines can result into superficial or to complex overviews [2, 7, 9].

Experts express that the amount of details in the overview can have both positive and negative facets. When more details are added, the causes will be more fundamental and

include more information. But this will also result in causes that are less directly connected to the actual problem, and thus lead to more difficult and time consuming innovative step that follow. However most of the interviewees agree that more detail is often better. A majority of the interviewees have a notion on the amount of information they want in a cause-effect overview, but don't apply a predefined set of rules. Finally 3 out of 7 mention that the a root cause needs to be based on physical or mechanical constraints, while others also indicate that it cannot include ubiquitous causes and effects.

2.4 Evaluation of results

For the tools investigated most indicate that the quality of the model created can only be evaluated based on the correctness of the steps executed. Quality check procedures on the quality of overview as a whole are missing. This could be contributed to overviews of the same problem can look different, even for the same problem. This makes it hard to create and verify a preconstructed checklist [7, 8, 9, 11, 12].

Expert interviews showed that good results are highly dependent on the problem description and its analysis. By thoroughly considering the problem, results of different RCA+ should be more aligned and therefore more complete. However, it is important that the entire product lifecycle is considered. The evaluation of the correctness of the overview could be based on the "information gap" between the problem and the solution; when this gap is removed the answers have been found, and the evaluation is complete. However, among the among the experts no consensus was found on the best way to evaluate the correctness and completeness of the overview.

3 Development of RCA+ application concepts

From the previous research and interviews it became clear that the use of the RCA+ could potentially be improved if the following aspects would be considered.

1. Methods should be implemented that stimulate the engineer, during the construction of the RCA+ tree, to consider all steps of the product lifecycle, including design, manufacturing, use and end-of-life.
2. Methods should be implemented that stimulate the engineer, during the construction of the RCA+ tree, to include all resources when analyzing and describing the causes and effects. He/she should be made aware that resources maybe problem and context dependent.
3. Contradiction definition rules should be defined will results in better overview of the innovative situation. In more detail
 - A positive effect can only be accepted as a positive aspect when the effect interacts with stakeholders in a positive way.
 - A positive effect cannot be an ubiquitous effect;
 - A positive effect should always fall under one of the resource categories or be a relation between different resources.

Based on these possible improvement areas, two concepts are developed to better support the analysis steps (1 and 2). Both concepts use the modified set of contradiction definition rules (3).

3.1 Concept A

Concept 1 focusses on relating parts, stakeholders and resources, where the nature of those relations are displayed using a color coding system. The relations are identified using 6 analysis steps prior to defining the actual RCA+.

1. Determine the problem;
2. Describe the stakeholders;
3. Describe scenario's;
4. Do a functional analysis;
5. Create an overview of the relations between parts, stakeholders and resources
6. Describe the relations between parts, stakeholders and resources
7. Create the RCA+

1. Determine the problem

PRODUCT		
PROBLEM		
SUPERSYSTEMS		
SUBSYSTEMS		

4. Do a Functional Analysis

PART	RESOURCE	EFFECTED HOW?

2. Describe the stakeholder

STAKEHOLDERS	INVOLVEMENT WITH PROBLEM	IMPORTANT ASPECTS
User	Buys product and uses it	Time a certain action takes - Ergonomy - Type of action
Designer	Makes the design of the product	Aesthetics of product - Quality of product - Functions of product
Manufacturer	Creator of the physical product	Possibilities on manufacturing, material, production
Management	Makes final decisions on product related to cost	Expenses of production - Timeframe of designing and building

5. Create the relations between product, scenario and stakeholder

Part list	Time	Material	Space	Functionality	Supersystems	Energy & forces
Wheels						
Casing						
Handle						
Screws						
Hinges						
Etc...						

Stakeholders

- User
- Manufacturer
- Designer
- Etc...

3. Describe the scenario

SCENARIO	TYPE OF RESOURCE	STAKEHOLDER

Figure 2 Color coding of relations within concept 1. See Laoh [6] for details

The color coding overview is meant to be used as a help to evaluate whether or not parts of information are still missing in the analysis or within the RCA+. Besides that, the overview helps to connect different aspects that should be considered such as the connection between scenario, stakeholders and the product functionalities. Negative effect should be related to one of the colored boxes, positive effects should be related to stakeholders, and further negative effects should be related to either the

product part, the resource or a relation between different product parts. The evaluation should be continued until all branches end with a non-changeable effect or a contradiction.

3.2 Concept B

This concept has a couple of similarities with the previous concept, however, the focus of this concept is different. Where in concept 2 the focus is on creating one overview which relates all information, the focus of this concept is on functionality of the components of the product. It uses the following sequence of analysis steps:

- Step 1: Determine the problem
- Step 2: Determine the scenario
- Step 3: Determine product parts and their functions
- Step 4: Functional analysis
- Step 5: Determine the stakeholders
- Step 6: Create the RCA+

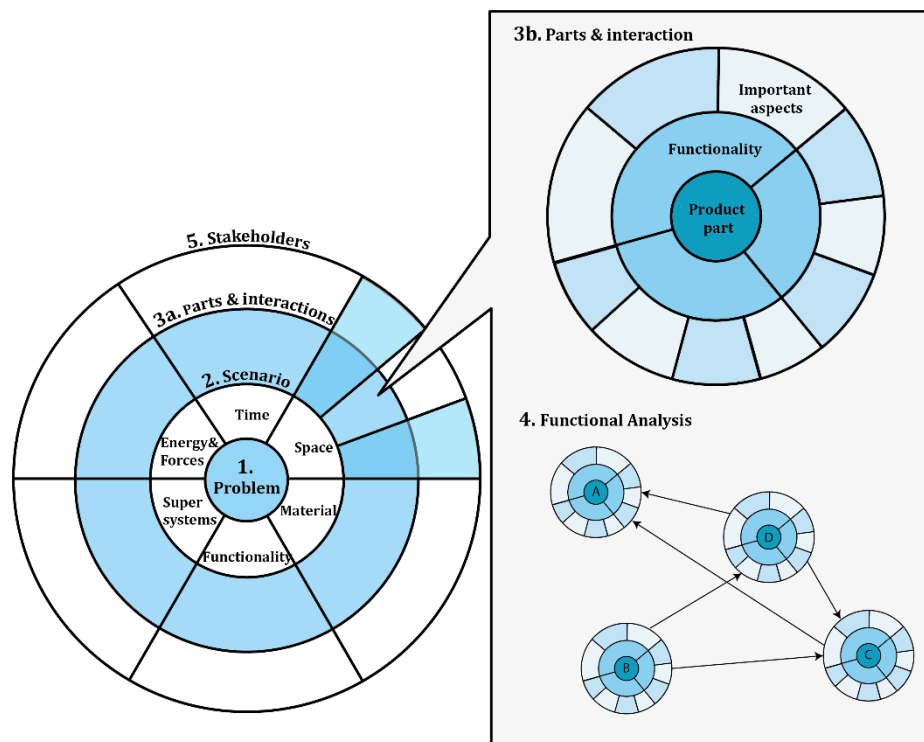


Figure 3 Graphical representation of concept 2. See Laoh[6] for details

The difference between the concepts is mainly visible in step 3. Here, information about the product should be defined. Per product component, the information that should be defined is:

- The material it is made of;
- How it is produced;
- What the function of the product component is;
- Important aspects of that component in relation to individual lifecycle stages

By adding more focus on the parts, the method attempts to make users more aware of the technical side (mechanical and physical constraints) of the product being analyzed. By decompartmentalizing the steps, more structure is added to the process of gathering information, which could make it easier to understand what aspects need to be analyzed.

4 Validation of the concepts

4.1 Setup of the validation experiments

To evaluate the effectiveness of the concepts proposed, they were tested in a classroom setting. The evaluation was part of a 10 days TRIZ course, where the students were instructed on the standard method of creating the RCA+ on day 2, while this evaluation of concepts was conducted on day 10. 31 students (Master students Mechanical Engineering and Master students Industrial Design Engineering) participated in the 3 step evaluation protocol.

In step 1 all students were asked to individually create an RCA+, using the standard rules for creating a RCA+ (see section 1.1). All students developed a RCA+ analysis for the same problem description. This is used as the dataset of the control group.

In step 2, 30 of the students were divided in groups of 3, where each group would be asked to use one of the two templates (A or B) to define a RCA+. The results of step 1 and the 2 groups of step 2 were analyzed and statistically compared on their statistical merits.

Finally, all students have been asked to fill in a questionnaire about their progress and confidence about using the RCA+ methodology.

4.2 Results of the validation experiments

For the statistical analysis two datasets were compared.

- Control group versus A+B. This to improve of the use of any template would result in improvement of the quality model created with the RCA+
- A versus B. This to identify if one of the concepts perform significantly better than the other.
- The method of gathering data in the questionnaires used a Likert scale and was based on the work presented by Belski et al. [14].

Control group versus (A+B)

The conclusion of whether or not the quality of the RCA+ improved with the use of a template was based on three categories: improvements in the details included in the analyses, the believed added value of templates for setting up an RCA+ and lastly, the improvements of the students' confidence. The results of the analysis of the details included in the RCA+ were split up. Two categories, breadth and level of details, showed significant positive results. However, two other categories (resources used and amount of causes per resource) did not show significant results at any level of analysis. Apart from the comparison of the retrieved data, the amount of participants who showed improvements, were compared as well. These comparisons showed a significant improvement for all categories. To conclude on whether the total amount of details improved by using a template, all tests were taken into account. Evaluated in this way, it became clear that using a template did help improve the level of detail incorporated in the analysis.

The second category, the perceived added value of the templates, also shows a significant result, meaning that the use of a template did indeed help create structure to setting up an RCA+. Participants who did not think the templates added value, mostly mentioned that using the templates costs too much time when weighed against the new information retrieved from the templates.

The last category was based on the confidence of students. Most results show a positive improvement, however, not a statistically significant one. The amount of improvements in the confidence levels also did not show statistically significant results. This means that it cannot be proven that the use of the templates improves the confidence levels of the students.

Group A versus Group B.

To conclude which of the two templates resulted in higher quality RCA+, comparisons were executed based on three categories: improvements of the details included in the analyses, the added value of templates for setting up an RCA+ and, lastly, the improvements in the students' confidence.

The results for the details included in the RCA+ show an insignificant difference between the use of template A and template B. The results of the tests between subcategories are also divided. The categories resources used and level of detail suggest that template A is better, however, based on the breadth of the analyses, template B is better. The last category, the amount of causes, indicates no real difference can be identified.

The next category focused on whether or not the templates gave students structure for gathering information and setting up an RCA+. The resulting differences were not significant. However, the majority of the students thought that using a template or parts of a template helped them improve their RCA+ and made it easier to make a RCA+. Also for this category, there is no real difference in preference for using template A or B. Both templates had around the same number of participants who mentioned that the templates helped improve their RCA+.

The last category tested the confidence level of students. Most results suggested that participants using template B were more positive of the used template than participants

using template A. However, this could not be statistically proven. This means that there was no real difference in confidence levels measured between group A and group B.

Observing all three categories, none of them showed significant differences between the use of template A or template B. Therefore it was not possible to determine whether the use of one template was better than the other.

5 Conclusion and discussion

Based on the idea that the process of creating a RCA+ diagram could be improved, research was conducted on possible areas of the process to improve. Based on this, two concepts were created that could support users in the process of defining that analysis step. It was found that using a template was helpful in increasing the level of detail as well as the perceived value of the structure of the process when setting up a RCA+. However, no significant increase in confidence level was found among the students. When comparing concepts A and B, no significantly better concept could be selected, although at detail level significant differences were found.

The results obtained were measure during in classroom setting during 10 day course that was, due to covid restrictions, run online. Furthermore, it was impossible to create the exact same test conditions for all tests (prior knowledge, number of participants, group size, problem evaluated). Finally, two other aspects require more attention. The depth and width of the analysis increased, although it can be discussed if this is always an improvement. Ultimately, the RCA+ is a method that should support efficient innovation. The best methodology should probably take the effort spent on the whole cycle into account; so both the definition of the RCA+ as well as the efficiency and quality of the innovation process. This brings forward the second point; in the current setup of the experiments it was not possible to measure if the (improved) RCA+ results also led to improved levels of innovative solutions.

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