xtriz.com

xTRIZ

TRIZ & SYSTEMATIC INNOVATION

A Guide to Root Conflict Analysis (RCA+)

Valeri V. Souchkov

CONTENTS

Guide to Building Root Conflict Analysis (RCA+) Diagrams and Recommendations for Contradiction Selection[1]

Version 1.5

Root Conflict Analysis (RCA+) is a relatively new addition to the set of TRIZ tools and techniques which is aimed at helping to manage complexity of inventive problems by identifying the contradictions which compose a problem and the relations between these contradictions. The Root Conflict Analysis modeling is performed within the scope of three tasks:

1. To solve a specific problem related to a certain specific product, service or a process (e.g. to increase sales of a specific service produced by a specific company, to eliminate failure of a specific product).
2. To solve a broad problem related to a whole class of products, processes or services (e.g. to prevent all ships from sinking, eliminate a possibility of an error made by a pilot during flights, eliminate errors by a call center, etc.)
3. To predict and eliminate possible and potential failures within systems and processes (e.g. to identify possible causes of project failure).

Root-Conflict Analysis was developed on the basis of three methodologies:

- Cause-Effects chains, which were a part of classical Root-Cause Analysis, first invented for exploring the roots of accidents.
- Theory of Constraints, founded by E. Goldrat to identify bottlenecks in business challenges.
- TRIZ definitions of administrative, technical, and physical contradictions for inventive problems solving as suggested by G. Altshuller.

This document consists of four parts:

A. Algorithm of RCA+ Modelling and Building RCA+ Diagrams.
B. Recommendations on Selecting Contradictions from RCA+ Diagrams.
C. A case study.
D. Glossary.

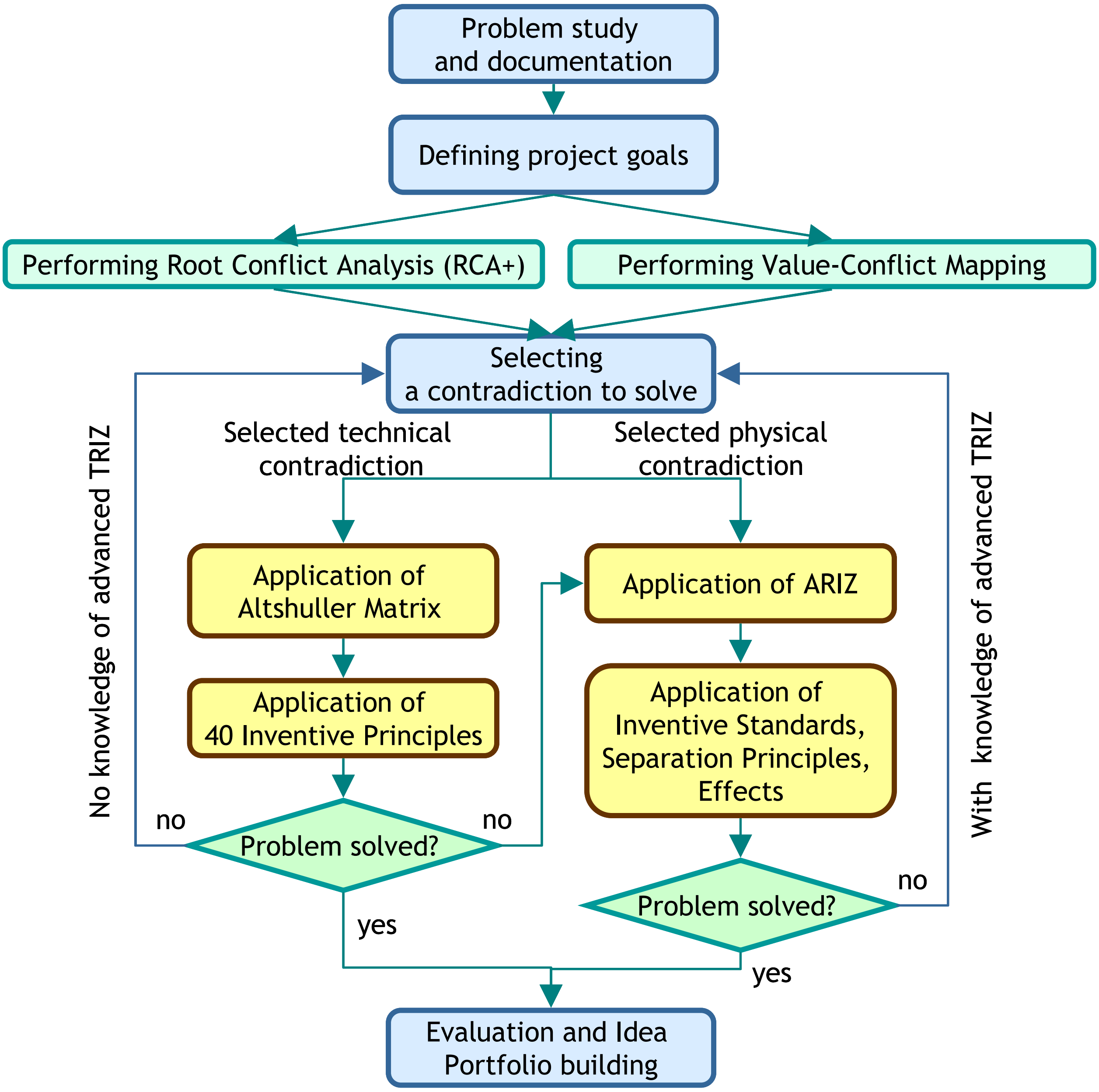
This text explains how to analyze and model problems with RCA+ and assumes that the reader is familiar with the TRIZ fundamentals.

This document exposes application of RCA+ in the areas of technology and engineering. Nevertheless, RCA+ can be applied to any area where conflits can take place: business, management, social systems, legal systems, planning, arts, and so forth.

[1] This chapter is written together with Karel Bolckmans, Koppert b.v., The Netherlands

TRIZ Process with RCA+

The overall process of problem solving based on using RCA+ in TRIZ (during the use for technology and engineering) for defining and selecting contradictions is presented below. The process uses RCA+ to identify and select contradictions, and then splits into two flows: a flow based on the application of basic TRIZ tools (Altshuller Matrix and 40 Inventive Principles) and a flow based on the use of advanced TRIZ tools, such as ARIZ, Inventive Standards, and so forth. The selection of a flow depends on the degree of TRIZ expertise of the problem solver.

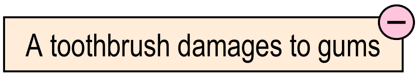


However, although RCA+ was developed as a technique to support an analysis phase of TRIZ process, today many find it useful to analyze, understand and visualize complex problems as an independent tool as well.

PART A: ALGORITHM OF RCA+ FOR MODELING AND BUILDING RCA+ DIAGRAMS

STEP 1 State the general negative effect of concern and start drawing the RCA+ diagram in a top-down manner.

Example: A toothbrush with strong and hard bristles cleans the teeth well but might damage to gums during brushing. A negative effect is therefore presented as "*A toothbrush damages to gums*".



STEP 2 Ask the question "***What causes this effect to occur?***" to find all the causes of the negative effect.

a. A cause should be stated as either:

i. A subject or "tool" (noun) + a function or an action (verb) + an object or a "product" upon which the action is directed (can be an object or field) (noun). Sometimes conditions can be refined with extra words:
Example: *water moves; a wire conducts electric current; electromagnetic field attracts ferromagnetic powder; a knife slices bread; etc.*

ii. A property (parameter) of an object or a field and its relative value with respect to the desired situation (it is highly advised to use the word "too"):
Example: *temperature is too high; speed is too low; friction is too high, etc.*

iii. Change of a property (state) of a field or an object and its relative value with respect to the desired situation: e.g. maintain (is), change, increase, decrease + a property or field or an object + its relative value:
Example: *Decrease of temperature is too fast; increase of voltage is too large; water freezes too slow.*

iv. Radical change of the state of an object or of a field:
Example: *ice melts, magnetic field disappears, etc.*

v. Absence of a needed condition:
Example: *luck of support, absence of liquid*

b. Add a new cause to the diagram by using a line with an arrow towards the negative effect. It is important to use arrows to indicate the direction between a cause and effect in RCA+ diagrams.

Note 1: Always avoid the question "Why?"

The question "why?" in classical Root Cause Analysis (e.g. why are you going to the supermarket?) can be interpreted in 2 different ways: (1) what for? (e.g. to buy bread) or (2) what causes? (e.g. because I'm hungry). Therefore when constructing an RCA+ diagram we prefer to ask the question "What causes …?" When answering the question "What causes …?" we have to identify exactly:

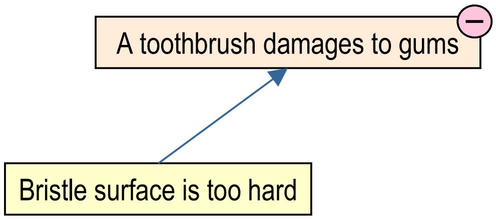
a. Which object and which feature of this object causes the negative effect.;
b. Which physical parameter associated with an object or a field, like "temperature" and its relative value causes the negative effect;
c. Which action (or its lack) causes the negative effect.

We must identify a specific feature or a condition which contributes to producing the negative effect.

Note 2: Factual and Assumptive causes

There might be two types of causes which are presented at RCA+ diagrams: *Factual* and *Assumptive*. Factual causes are based on verified information while assumptive causes are based on hypothetical information which remains unverified during a process of building RCA+ diagram and still has to be confirmed. For instance, during analysis of a problem "*Rate of receiving information from a supplier is low*" two causes might be identified: 1) "*Information overload in our office is too high*" and 2) "*The supplier does not prepare information for us in time*". While the first cause can be factual since we know exactly that we experience information overload and can not process information faster, the latter cause is assumptive: we might not be sure of it until we check it with the supplier. After a cause is confirmed, it can be either converted to factual, or if not it should be eliminated from the RCA+ diagram. Assumptive causes are usually shown by a dashed box.

Example: We added the cause "*Bristles are too hard*" by answering the question: *What causes the effect "A toothbrush damages to gums?"*:

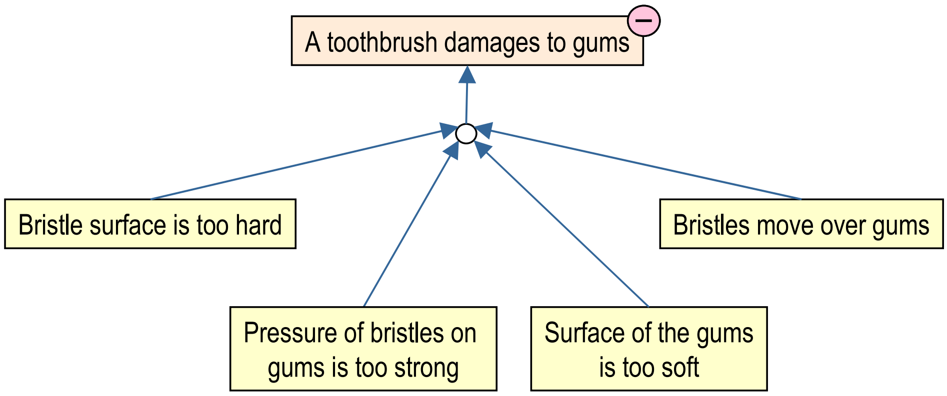


STEP 3 After identification of a cause in Step 2, check if this cause is **the only condition** which is enough to produce the negative effect. In many situations, a single cause is not enough because two or more causes acting together are needed to produce the negative effect.

There are two types of relationships between causes which can contribute to the same negative effect: AND and OR relationships.

1. In case of the analysis of a *specific problem* different causes of the same negative effect are usually interrelated (AND) and cannot produce a negative effect independently of each other.
2. In case of analysis of *all potential causes which may possibly lead to a failure or a negative effect*, the causes can be either interrelated (AND) or independent (OR).

Example: It is obvious that just having too hard bristles is not enough to damage gums. Other factors are also needed to produce damage. We need to add these other conditions (causes) to the diagram:

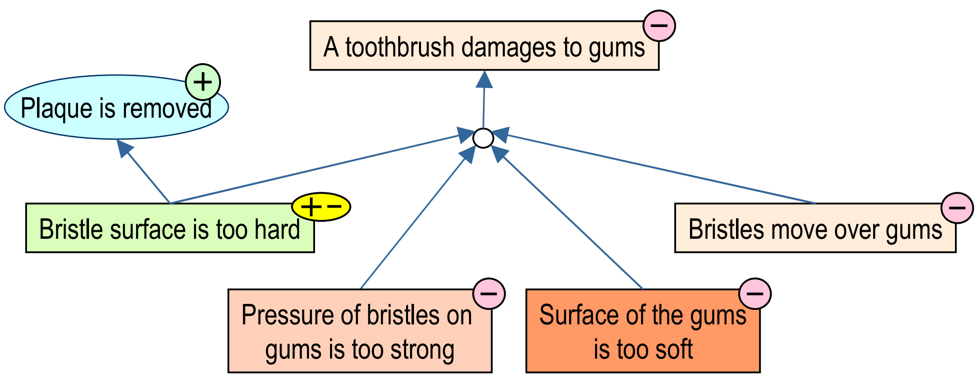


Note, all these conditions are interrelated ("AND" relationship: shown as a circle), because if we remove just any one cause, the negative effect will completely disappear.

STEP 4 Ask for each cause if it also produces a positive effect. A cause which produces both a positive and negative effect identifies a contradiction. We can have four types of causes/effects in an RCA+ diagram:

a. *Negative* (-): the cause/effect is totally negative and we would like to fully eliminate it.
b. *Positive* (+): the effect is positive, there is no need to change. Usually positive causes can not exist alone inside of the chain, otherwise there would not be negative effects resulting from them.
c. *Combined Negative and Positive* (+/-): the same cause results in both positive and negative effects.
d. *Non-Changeable* (--): the cause contributes negatively but can not be eliminated, changed, or modified since it is beyond our control within a given problem scope. Usually such causes are produced by supersystem components.

Example: We need bristles to be hard to remove plaque effectively. Therefore the cause "*Bristle surface is too hard*" becomes a cause of a contradiction between positive effect "*Plaque is removed*" and negative effect "*A toothbrush damages to gums*". Other three causes are presented as negative effects.



Note that we used different colours in the RCA+ diagram to distinguish between different types of causes:

a) tagged with "+-": a source of a contradiction
b) tagged with "-": a negative effect/cause

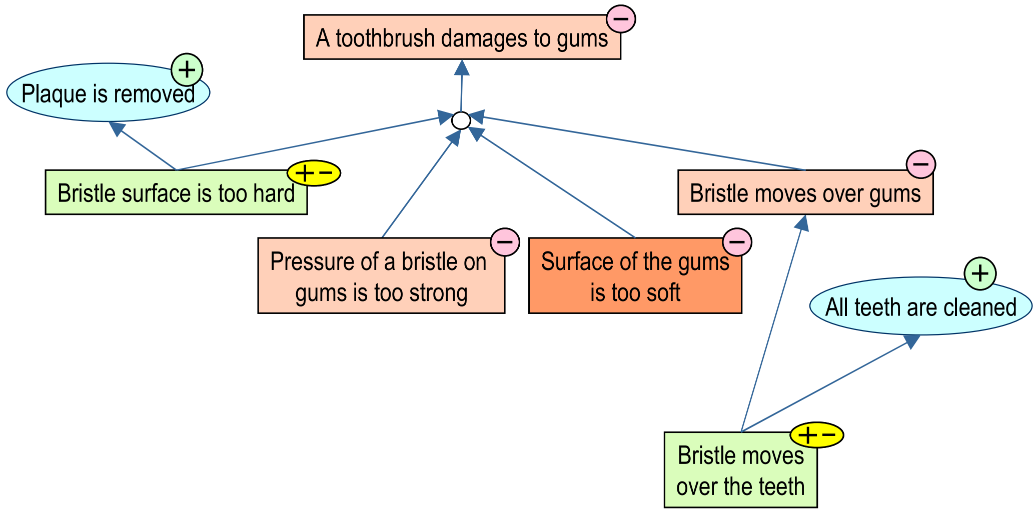
c) tagged with "--": a negative non-changeable cause.
d) tagged with "+": a positive effect

STEP 5 For each negative cause already present in the diagram continue to ask the question "*What causes this effect to occur?*". Build a top-down tree-like Cause-and-Effect Diagram. However, for those causes which are beyond our control (non-changeable negative effects) and for contradictions we do not continue analysis.

Stop a chain when either:

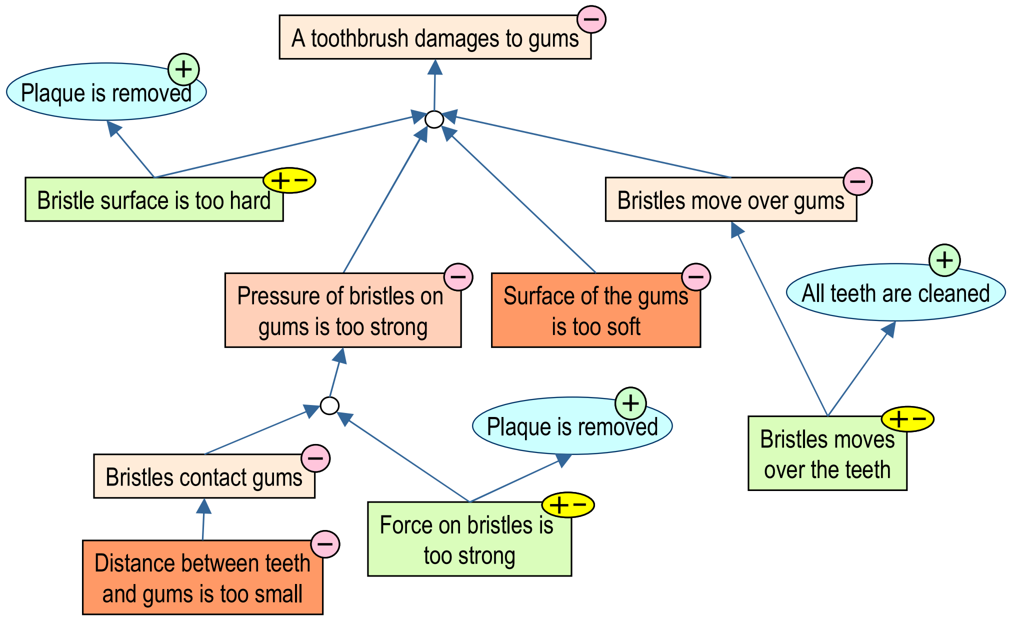
- You reach a cause which is a *demand or requirement that is impossible to change*, for instance, it is a *policy requirement* or it is a "must" part of *technical specifications*, or,
- You reach a *cause which contributes to both positive and negative effects*. This is what we call "a root conflict" or "root contradiction". However, in certain situations it might be useful to continue deeper analysis to investigate the underlying causes of the conflict as well, or,
- You reach a *cause that we can not influence in any way*, for instance, when it has to do with unpredictable changes in *environment* or *human behaviour*.

Example: We decided to further analyse two causes: "*Pressure of bristles on gums is too strong*" and "*Bristles move over gums*". We will not analyse further "*Surface of the gums is too soft*" since it is beyond our control for the given problem.



STEP 6 For each newly described cause, which is indicated as an underlying negative effect, check again if it is the only cause which creates the negative effect or if there are also other, additional causes interrelated with an "AND" relationship.

Example: We added a new cause "*Bristles contact gums*" as a cause of "*Pressure of bristles on gums is too strong*". However, just to have the contact is not enough to create strong pressure; therefore another cause should be added: "*Force on bristles is too strong*", which becomes a contradiction. We also stopped analysis after the negative effect "*Distance between teeth and gums is too small*" since it is a non-changeable cause.



Note that "Distance between teeth and gums is too small" is decided to be a non-changeable cause, thus we do not analyze it further.

Sometimes problems might include underlying causes which do not lead to contradictions. In such cases, these causes have to be first candidates to check if their elimination can directly solve a problem.

STEP 7 Create a table of the revealed causes. The table has 4 columns: Cause, Type of Cause Positive effect from the cause, Negative effect from the cause.

There are 4 types of causes in RCA+: N: negative causes; N+P: causes which have a negative and a positive effect; NC: non-changeable causes; P: positive effects, which are not listed in the table.

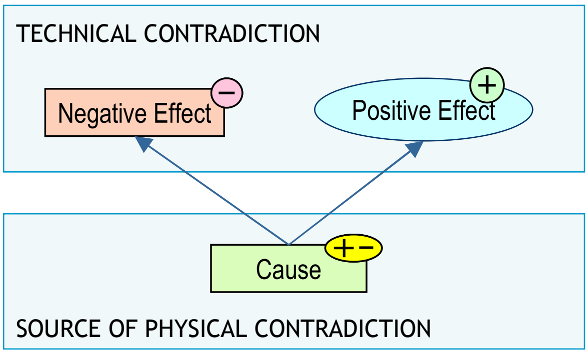
Example:

Cause	**Type of cause**	**Positive Effect**	**Negative Effect**
Bristle surface is too hard	N+P	Plaque is removed	A toothbrush damages to gums
Pressure of bristles on gums is too strong	N	-	A toothbrush damages to gums
Surface of the gums is too soft	NC	-	A toothbrush damages to gums
Bristles move over gums	N	-	A toothbrush damages to gums
Bristles contact gums	N	-	Pressure of a bristle on gums is too strong
Force on bristles is too strong	N+P	Plaque is removed	Pressure of a bristle on gums is too strong
Distance between teeth and gums is too small	NC		Bristle contacts gums
Bristles move over the teeth	N+P	All teeth are cleaned	Bristle moves over gums

STEP 8 Select your problem. Two scenarios are possible:

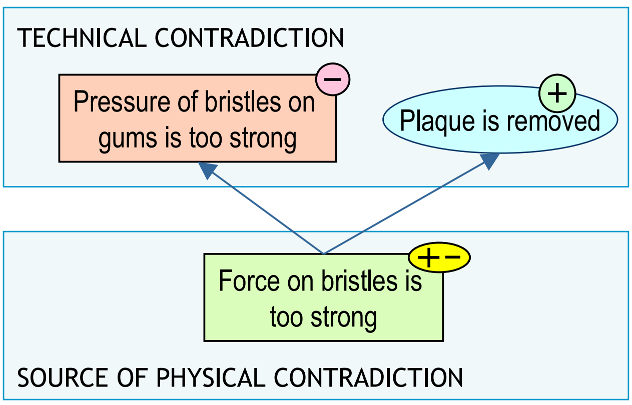
1. If the RCA+ diagram contains a negative cause which is possible to change and without an underlying contradiction, solve the problem by eliminating the cause. In most innovative and complex problems, however, negative effects have underlying contradictions; and therefore they may not be directly eliminated.
2. Select a contradiction to solve by following the "*Recommendations for Selecting Contradictions from RCA+ diagrams"* which can be found in the second part of this document:
    a. In case of "AND" causes selecting and solving one of the root contradictions will solve the entire problem;
    b. In case of "OR" causes all of them need to be solved to solve the problem and prevent it from occurring again.

STEP 9 Use TRIZ techniques for contradiction elimination to solve a selected problem(s). In every contradiction, we can separate between two types of the contradictions: technical and physical.



- A technical contradiction is formed by a couple "Negative Effect" vs. "Positive Effect". These two effects can be directly matched against positive and negative parameters in the Contradiction Matrix.
- A physical contradiction is defined as two opposite states of a cause which is a source of the physical contradiction: one state of the cause should provide a positive effect whereas its state should be opposite at the same time to avoid appearance of a negative effect. Such contradictions can be solved either with Principles for Physical Conflict Separation or ARIZ.

Example:



- Technical Contradiction: "*Pressure of bristles on gums is too strong*" (Negative) vs. "*Plaque is removed*" (Positive)
- Physical contradiction: "*The force on bristles should be strong to remove plaque and should not be strong to avoid creating strong pressure on gums*".

PART B: RECOMMENDATIONS ON SELECTING CONTRADICTIONS FROM RCA+ DIAGRAMS

An RCA+ diagram usually contains a number of contradictions which contribute to a general negative effect. These contradictions are related to each other in one way or another. We distinguish between five different types of relations between contradiction causes (further in the text we will call a contradiction cause which is tagged with a "+-" sign a "contradiction):

1. Independent contradiction causes (linked by ä logical "OR" relationship): contradictions which independently contribute to producing a negative effect.
2. Dependent contradiction causes (linked by a logical "AND" relationship): contradictions which "co-exist" at the same level and cannot produce a negative effect independently of each other.
3. Causally related contradiction causes: one contradiction is the cause of another one.
4. Complexly related contradiction causes: a combination of causally-related and dependent contradiction causes.
5. Root contradiction causes: two or more contradiction causes share the same cause (which is a contradiction cause too due to inheritance within a contradiction tree).

For these situations the following recommendations apply:

Situation	What to select
Independent contradictions	Comparative ranking
Interrelated contradictions	Ideality-based criteria
Chained contradictions	Ideality-based criteria
Contradictions with the same cause	A "root" contradiction
Complex interrelated contradictions	Ideality-based criteria

Below we will explore each situation separately with specific recommendations and examples. Note that the diagrams shown in the examples below are only fragments of actual, more complex RCA+ diagrams. They are presented to illustrate the selection process.

B1. SELECTION CRITERIA

NAME	WHERE APPLICABLE	DESCRIPTION
Comparative ranking	independent contradiction causes	In case of independent contradiction causes all contradictions should be eliminated independently to solve a problem, unless they cannot be eliminated because they are beyond the control of the problem solver. The contradiction that contributes most to the general problem can be identified by subsequently comparing the degree of contribution to the general problem by each contradiction and selecting the best candidate.
Ideality-based criteria	a) dependent, b) causally related c) complexly related	This is the most complex situation since it involves a number of related contradiction causes. Choosing a contradiction is difficult due to the fact that it is not possible to predict in advance what contradiction will provide the best solution. However, there are a number of heuristic criteria which we can identify as "ideality-based" criteria. Such criteria help to select the best candidate by estimating the expected degree of ideality of each potential solution: to solve a problem, only minimal changes should be made to a system while we achieve the maximum effect. This definition implies that we have to focus on a narrow conflict zone within a system or at the place of interaction between the system and its supersystem which is responsible for producing the contradiction, and which involves those elements which we are allowed to change or modify. We therefore use a set of rules to identify such a contradiction: • **Involving a minimal number of elements:** In case if a contradiction is caused by interaction by many elements, we should choose such a contradiction where the number of involved components is minimal. • **Focusing on system elements:** A contradiction which does not involve (or involves the least number of) components of the supersystem, should be chosen first. In case when there are no contradictions which only involve system elements, the contradiction which involves elements of the supersystem which we are allowed to change or influence (modify, replace, access, interact with, etc) should be selected. • **Easy to change:** It is logical to choose a contradiction which is formed by elements that are the most easy to change or possible to influence: modify, replace, access, protect, interact with, etc. However, there are a limited number of situations when it is easier to change the supersystem rather than the system itself (for instance, by combining several systems into a supersystem). Therefore the choice of a preferred candidate should be made by analyzing what system or supersystem elements are involved in each contradiction and selecting the

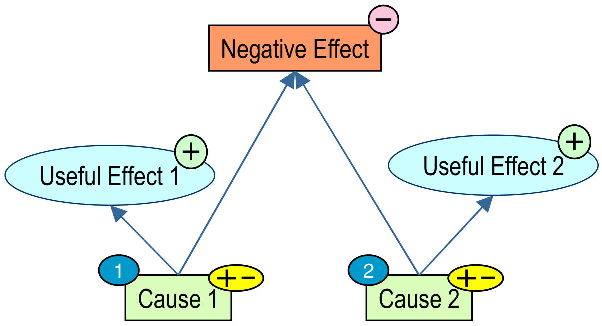
<table>
<tr><td></td><td></td><td>contradiction which contains the elements that are the most easy to change or influence.
Alignment with the overall strategy of the problem owner: Finally, in case when there are several equal candidates, the contradiction which fits the best with the long-term strategy of the problem owner should be chosen. Usually, selecting a contradiction from the upper part of the RCA+ diagram solves a problem in a more specific way than selecting a contradiction from the lower part.
To help defining what contradiction to choose in cases when there are more than two contradictions involved, we complete a table for each contradiction which includes the following elements:
The cause of the contradiction.
The positive effect produced by the contradiction.
The negative effect produced by the contradiction.
Main system and supersystem parts which are responsible for causing the contradiction. It is recommended to specify exactly what parts of the system (or its supersystem) components are involved in the contradiction (e.g. surface, etc.). The physical space between components can be considered as well.
The property (or parameter) which is responsible for causing the contradiction. This can be any physical or non-physical parameter or a property of a system or a supersystem component which is responsible for producing contradicting effects.
The time when a contradiction (conflict) occurs.
After the table is complete, we analyze what contradiction matches the criteria presented above best of all.</td></tr>
<tr><td>“Root” Criteria</td><td>Chained contradictions</td><td>In case of a single contradiction cause which contributes to two or more upper-level contradictions, this “bottom” (root) contradiction should be selected since its elimination will automatically eliminate all contradictions above it (unless they are also caused by some other independently related factors) and, therefore, the negative effect. However, in some cases the root contradiction can not be eliminated due to certain constraints such as, for instance, government policy or because it is caused by a supersystem component that we are not allowed to change. In such situations, other contradictions should be chosen for elimination.
In cases when there are two or more root contradictions, their selection is defined by ideality-based criteria</td></tr>
</table>

For all situations: when a selected contradiction does not produce a desired solution, the next best candidate should be chosen according to the same selection criteria and recommendations for each specific situation.

B2. FIVE SITUATIONS OF CAUSAL RELATIONSHIPS

SITUATION 1: INDEPENDENT CONTRADICTIONS

Situation: These contradiction causes are independent of each other ("OR" relationship). In this situation, both (or more, in case when more than two contradictions independently contribute to the same effect) contradictions should be eliminated to prevent the negative effect from occurring, since both contradiction causes contribute independently from each other to the same negative effect.

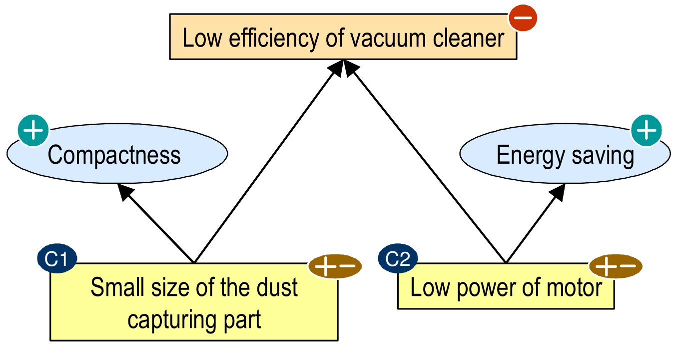


Selection Criteria: To decide which contradiction to resolve first, we estimate the degree of contribution of each contradiction to the negative effect, and select the most contributing contradiction. After that, if we want to completely eliminate all potential causes of the negative effect, we should eliminate the other contradictions too. Sometimes when resolving a selected contradiction we change a system in such a way that other contradictions are eliminated as well. However to predict what contradiction will lead to such changes is very difficult at this stage.

Since we build an RCA+ diagram within the context of a specific problem and focus on the causal relationships, the diagram only defines those contradictions which are relevant within this specific context. However, system components might have deeper connections, outside the presented problem, at a functional level. This situation addresses to general failure prevention or problems of quality/performance decrease. An example: let's suppose that we have two contradictions related by a single "OR" connection. For instance, a car might not brake properly because either 1) the braking pad is worn off (has to be soft to enable better friction and hard to avoid wearing off), or b) the car is too heavy (it has to be lightweight for easy braking and fuel consumption and heavyweight to withstand the cargo load). These two contradiction causes are not related: the brake distance is still too long even if the pad is perfect in the second case. If we resolve the contradiction "lightweight-heavyweight" by completely redesigning the car to make it stop faster, we might come up with a solution that does not require the braking pad at all: for instance, braking might be performed by a field, or instead of pressing the pad against a disk we somehow use the road for braking. In this case the problem with the braking pad will cease to exist since we will not have the braking pad in the new design of the car.

Although the contradictions were causally independent within the context of this problem, we can see that solving one contradiction might completely eliminate the existence of the other contradiction.

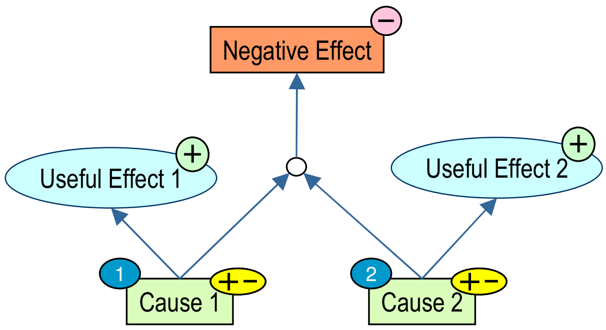
Example 1: Low efficiency of a vacuum cleaner:



In this example we can see that both contradiction causes (contradictions C1 and C2) act independently of each other. By judging what contradiction is more important to us (assuming that we are a vacuum cleaner manufacturer), we decided that the size of the dust collector is more important within the context of the given problem than increasing the power of the motor and thus selected "*Small size of the dust capturing part*" to solve.

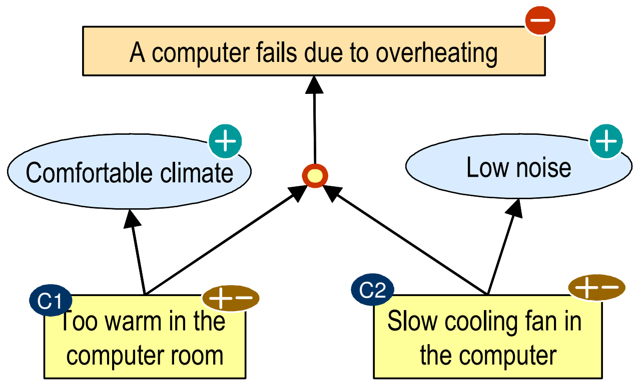
SITUATION 2: DPENDENT CONTRADICTIONS

Situation: These contradictions are interrelated with each other by an "AND" relationship and therefore contribute to the same effect. In this situation, no matter how many contradictions are interrelated via the same "AND" relationship, it is enough to eliminate just one contradiction, and the negative effect will be completely eliminated.



Selection Criteria: For such situations, we should select Ideality-based criteria which are defined in section 4.2, and thus select a contradiction which a) involves the least number of (supersystem) components, b) involves components we can change easily, and c) fits the best with our strategy.

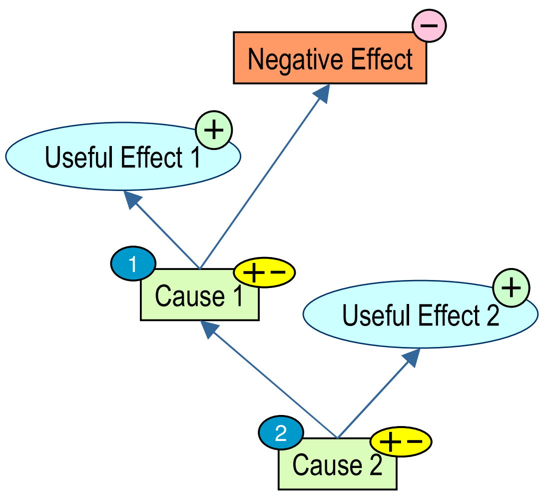
Example 2. Computer overheating:



In this example (assuming that we are a computer manufacturer) we can not influence the temperature in the office where the computer is supposed to run, but we can change the design of the cooling fan. Therefore the cause "*C2: Slow cooling fan in the computer*" should be chosen.

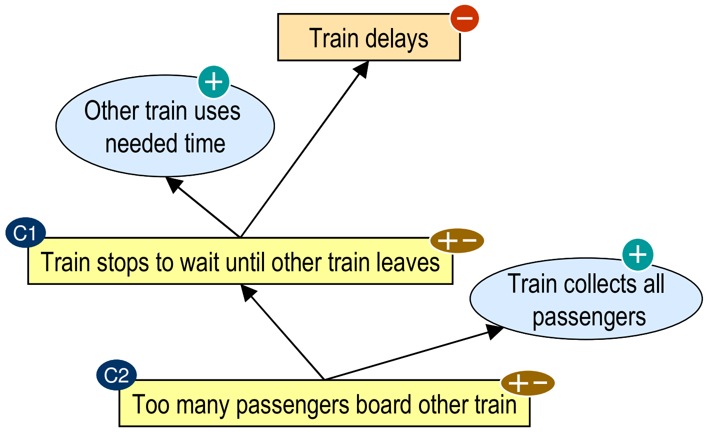
SITUATION 3: CAUSALLY-RELATED CONTRADICTIONS

Situation: In this case, a contradiction cause is also the cause of another contradiction cause, and therefore they form a causal chain of contradictions which ultimately leads to a general negative effect.



Selection Criteria: It does not matter which contradiction is selected from the chain, since elimination of any contradiction will break the chain and will therefore remove the contribution of the entire chain to the negative effect. In such situations, we also chose the Ideality-based criteria.

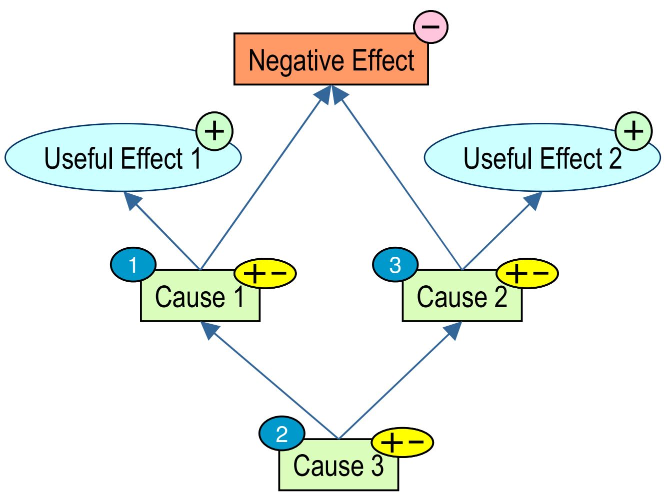
Example 3: Train Delay



In this example, two contradiction causes belong to the same chain. If we apply the Ideality-based criteria within the context of the problem owner (assuming we are a train operator), we can see that the contradiction caused by "*Train stops until other train leaves*" is at the system level, since in this case both the trains and the train station are under our control. In the second contradiction cause "Too many passengers board other train", we deal with the passenger flow which belongs to the supersystem and is therefore more difficult to control and influence.

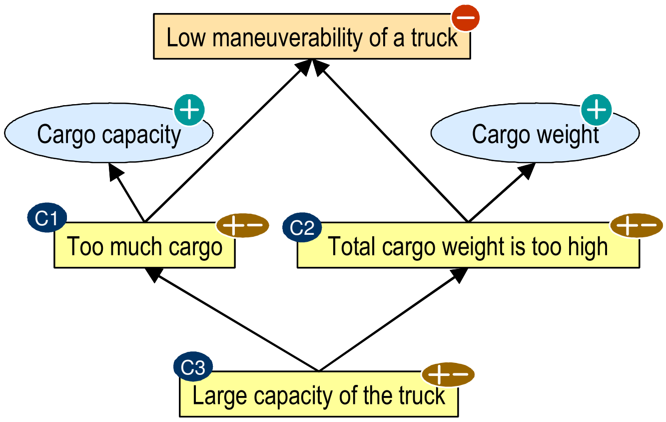
SITUATION 4: "ROOT" CONTRADICTION

Situation: There are situations when two contradictions are independent of each other ("OR" relationship), but they are both caused by the same contradiction.



Selection Criteria: In this situation we apply the rule of the "root contradiction" and eliminate the single underlying contradiction (Cause 3). However in case when we are not allowed to solve this contradiction, we should select the other contradictions and apply the relevant selection criteria.

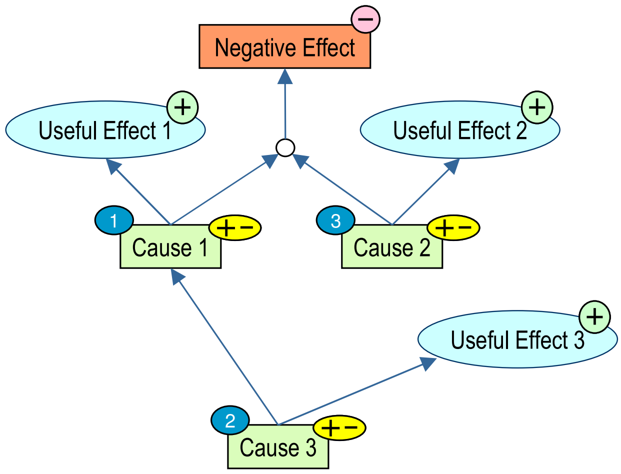
Example 4: Low maneuverability of a truck



In this example, both contradiction causes C1 and C2 are caused by the same root contradiction cause C3: "*Large capacity of the truck*". Therefore this root contradiction cause C3: "*Large capacity of the truck*" should be resolved if we would like to eliminate all causes leading to the negative effect of low maneuverability of the truck.

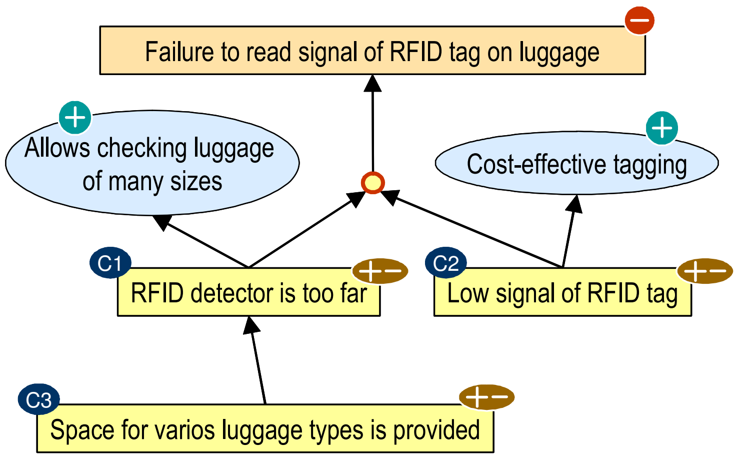
SITUATION 5: COMPLEXLY INTERRELATED CONTRADICTIONS

Situation: In certain cases, contradictions can be interrelated in several different ways, for instance, linked by an "AND" relationship, and at the same time one of the contradiction causes is part of a chain of contradictions. In this case resolving any contradiction will provide a complete elimination of the negative effect.



Selection Criteria: In such situations, we also chose the Ideality-based criteria which are defined in section 4.2. Note that complexly related contradictions do not involve independent contradictions.

Example 5: RFID reading failure



In this example, all three contradiction causes are interrelated, which means that resolving any contradiction will result in a complete elimination of the negative effect "*Failure to read signal of RFID tag on luggage*". By applying the criteria of Ideality, we can see that the contradiction cause "*C1: RFID detector is too far*" should be selected first, since both other causes "*C3: Space for various luggage types is provided*" and "*C2: Low signal of RFID tag*" involve components of the supersystem (customer's luggage and RFID tag) and thus are more difficult to change or influence.

C: CASE STUDY

Step 1: Description

To illustrate the applicability of the approach introduced above, we use a case of an offshore electric windmill. An offshore electric windmill is installed in a sea near the coastline and converts wind energy into mechanical energy produced by rotation of the blades, which is subsequently converted into electricity. However, due to strong winds, the velocity of the tips of the blade becomes very high. This causes the upper part of the blades (tip) to hit the dust particles and water droplets which are present in the air with high force. As a result, the tip's surface gets deformed, which reduces the overall performance of the windmill. The blades should be periodically replaced which is a quite cost-ineffective procedure.

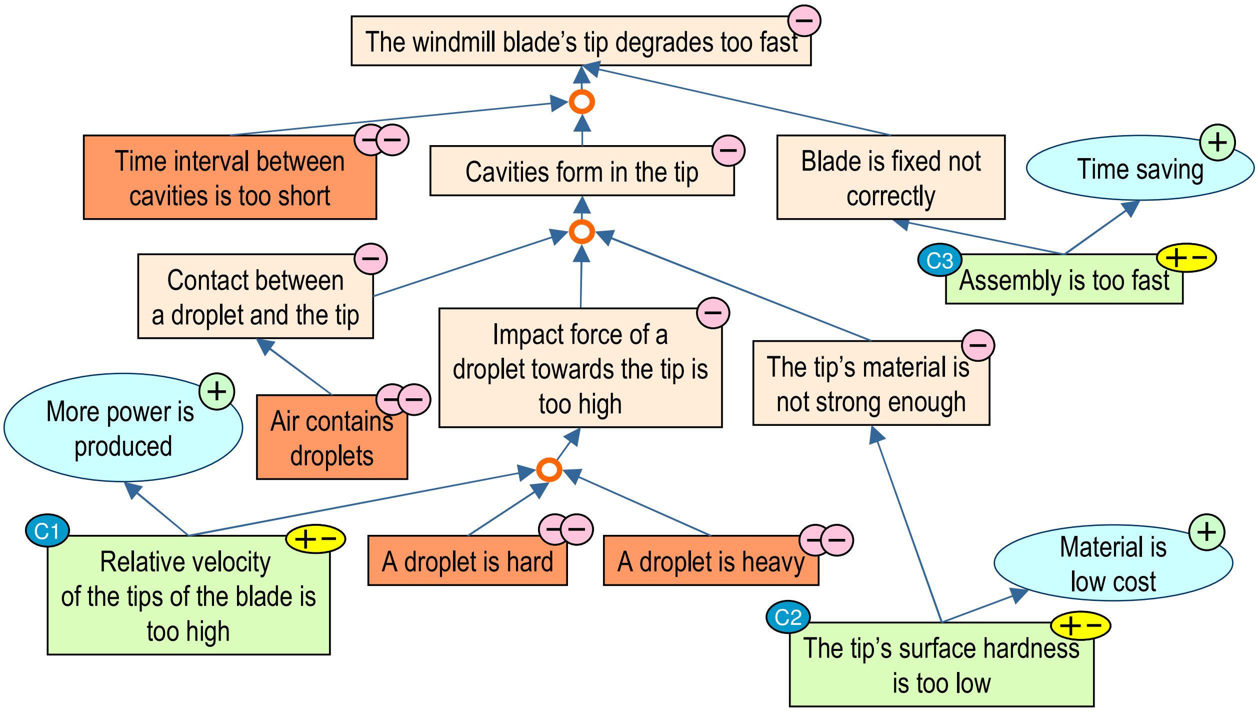
Offshore Electric Windmill Generators.

The goal of this case study is only to demonstrate the analysis and selection phases since solving the problem is beyond the scope of this Guide.

Step 2: RCA+ model

The RCA+ diagram of the problem is presented below and shows a causal decomposition of the general negative effect "The *windmill blade's tip gets deformed too fast*" to a number of negative causes and underlying contradictions. Those negative causes which are formed by the elements of the supersystem of the electric windmill were not analyzed further (e.g. "*too many drop*lets" or "*a droplet is too heavy*").

As can be seen, the diagram includes many of the situations presented above:



- **Independent contradiction causes:** "C1*: Relative velocity of the tips of the blade is too high*" and "*C3: Assembly is too fast*" are independent causes which might lead to the same negative effect. Thus these contradictions should be solved separately, since solving one contradiction does not solve the other one.
- **Dependent contradiction causes:** "*C1: Relative velocity of the tips of the blade is too high*" and "*C2: The tip's surface hardness is too low*". These two causes have to act together to produce the negative effect "*Cavities form in the tip*".
- **"Root" contradiction cause:** there is no root contradiction in the diagram. Perhaps, we could make the analysis deeper, by analysing the underlying causes of the contradiction causes C1 and C2. Although it is not forbidden by the philosophy of RCA+ to perform such exploration, we should always first try to solve a problem given at the level of upper causes in an RCA+ diagram. As practice shows, in such cases we introduce less complex changes to solve the main problem. However, when a desired solution is not found, a deeper analysis might be helpful.
- **Complexly related contradiction causes:** The entire sub-tree of contradictions below the "AND" relationship above the cause "*Impact force of a droplet towards the tip's surface is too high*" forms a network of interrelated contradictions. This happens because all contradictions in the sub-tree (C1-C2) are related either causally or by an "AND" relationship. This means that elimination of any of these contradictions will solve the general problem (under the assumption that contradiction C3 will be solved independently or ignored).

Step 3: Contradiction selection

Since we focus on the complexly related contradictions, we evaluate each contradiction as proposed in section "B2: Selection Criteria" by listing its cause, positive effect, negative effect, parts involved to the contradiction, property (parameter) which forms a physical contradiction, and time when the contradiction occurs.

#	Cause	Positive Effect	Negative Effect	Part(s)	Property/ Parameter	Time of conflict
C1	Relative velocity of the tips is very high	More power is produced	Strong impact force	Blades, tips of the blades, wind, droplets	Velocity, length of the blades	During strong wind
C2	The tip's surface hardness is too low	Material is low-cost	The tip's materias is not strong enough	Tips of the blades, water droplets	Hardness of the material	During strong wind
C3	Assembly is too fast	Time saving	Blade is fixed not correctly	Entire blade, wind	Speed of assembly	During strong wind

As we can see, contradictions C1 and C2 include the tips of the blades and the water droplets. By looking at the parameters responsible for the contradiction, it is logical to conclude that we can more easily manipulate the hardness of the tips of the blades which is a property of the tips rather than deal with the high relative velocity of the tips which is caused by the wind and entire length of the blades. Therefore, the contradiction related to the hardness of the tips of the blade is chosen (C2). Contradiction C3 is ommitted from a procedure of selection since it is independent from contradictions C1 and C2.

D: GLOSSARY

General problem	A general description of a top-level negative effect which we would like to eliminate or prevent from occurrence.
Contradiction	A situation when the same cause causes both positive and negative effects.
Positive effect	Any positive result.
Negative effect	Any negative effect.
Negative cause	A cause which leads to a negative effect and does not cause any positive effects. A negative cause can become a contradiction cause in case it contributes to both positive and negative effects.
Assumptive cause	A cause which is not proven but might exist. Should be verified.
Dependent causes	If two negative causes must act together to produce a negative effect they are considered dependent.
Independent negative cause	A cause which leads to a negative effect (without any positive effect) and does not require other causes to act together.
Independent contradiction cause	A cause which contributes to both positive and negative effects and does not require other causes to act together.
Dependent contradiction causes	A cause of a contradiction which requires some other contradiction cause(s) to produce a negative effect.
Causally related contradiction causes	If one contradiction cause contributes to another contradiction cause, they are considered to be causally related.
Complexly related contradiction causes	A situation when different types of relationships exist between contraction causes which contribute to the same negative effect.
Root contradiction cause	A contradiction cause which contributes to two or more other contradiction causes.
Cause of a contradiction	A negative effect which produces both positive and negative effects.
System	A set of objects we can directly control and influence.
Supersystem	Any objects which interact or might interact with a system but do not belong to a system during performing an RCA+ process.
Ideality	One of the key concepts of TRIZ which states that all men-made systems tend to evolve towards the highest degree of ideality by reaching the highest value of ratio "Value/Costs".
Non-changeable cause	A cause which may not be changed due to constraints that we are unable to influence.

Acknowledgements

Our special thanks to Patrik Hendriks, Wim van Elschout, Jaap Beetstra, Albert van der Kuji, Jenci Kuria, Don van Sonsbeek, and Dmitry Kucharavy for useful discussions on the RCA+ underlying methodology.

Among customers:

Valeri V. Souchkov was born on August 1, 1966, in Minsk, Belarus and is a citizen of the Netherlands. He received M.Sc degree in Computer Science and Engineering from Belarus University of Informatics and Electronics in 1988.

In 1989, he co-founded Invention Machine Labs, (currently known as Invention Machine Corporation in Boston, USA, www.invention-machine.com), and which is regarded today as a world leading company developing IT support for early stages of innovation. Until he left the company in 1996, he was a member of its Executive Board. In 1999, Invention Machine was named one of the most innovative companies of the USA by the *Fortune* magazine.

During this period, he took very extensive training – over 450 hours in TRIZ (Theory of Solving Inventive Problems) and related methodologies of systematic innovation, and was certified as TRIZ Specialist by the founder of TRIZ G. Altshuller in 1991.

In 1993-1997 he was an affiliated researcher at the University of Twente (The Netherlands) where he was involved to study of a knowledge-based support for innovation, and authored his own courses for professional education in TRIZ. He was the first who started public TRIZ training in Western Europe on a regular basis since 1995.

In 1997-2003, Valeri was a partner with a number of companies where he facilitated and trained numerous organizations in systematic innovation. In 2000, he originated and co-founded the European TRIZ Association (ETRIA, www.etria.net) and currently is a member of the Executive Board of ETRIA.

Since 2000, Valeri has been developing *xTRIZ*: further extension of TRIZ, which introduces a structured approach to systematic front-end of innovation, integrates different methodologies, and introduces new tools for systematic support of problem solving, new idea generation, and solution strategies evaluation. He also developed and launched courses for Systematic Innovation in non-technological fields, primarily in business and management areas. He contributed to the improvement of several classical TRIZ techniques as well as authored and developed several new techniques which improve analytical stages of the innovation process: Root Conflict Analysis (RCA+), Value-Conflict Mapping (VCM), and Demand-Trend Matrix (DTM).

Since 2003, Valeri is a founder and managing director of ICG Training & Consulting (Enschede, Netherlands), a company with over 200 customer organizations, and dedicated to delivering most advanced methods of systematic innovation to the global market. The company established and has been continuously expanding a global network of accredited trainers in TRIZ and xTRIZ techniques.

Valeri is also invited lecturer of the University of Twente (Netherlands, www.utwente.nl) on TRIZ and Systematic Innovation where he teaches a full length 130-hour course for B.Sc and M.Sc students, and a range of shorter courses for undergraduate students of various disciplines.

Among Valeri's customers are ABN AMRO, Capgemini, DSM, DuPont, ING Bank, Legrand, Norit, Orange, Reckitt Benckiser, Philips, PriceWaterhouse Coopers, POSCO, Siemens, Shell, Unilever, Thales, TNT Post, and a number of major government agencies, including Ministries of Defence, Economics, and Foreign Affairs of the Netherlands.

In total, since 1991 Valeri trained over 4.000 professionals in TRIZ and Systematic Innovation worldwide, facilitated and coached over 100 projects that resulted in innovative solutions, as well as assisted top management of several organizations on implementing the most effective tools and methods of innovation.

Valeri is a co-author of 2 books, editor of 1 book, and author of more than 70 papers on TRIZ and Systematic Innovation, problem solving and knowledge management, including publications in peer-reviewed magazines and proceedings of scientific conferences. Valeri is regularly invited to speak about systematic innovation and TRIZ to different countries. His TRIZ and xTRIZ-related courses have been licensed and provided in a number of countries worldwide.

In addition to his professional activities, Valeri enjoys modern arts, music, literature, photography, history of civilizations, and is a master of fencing.