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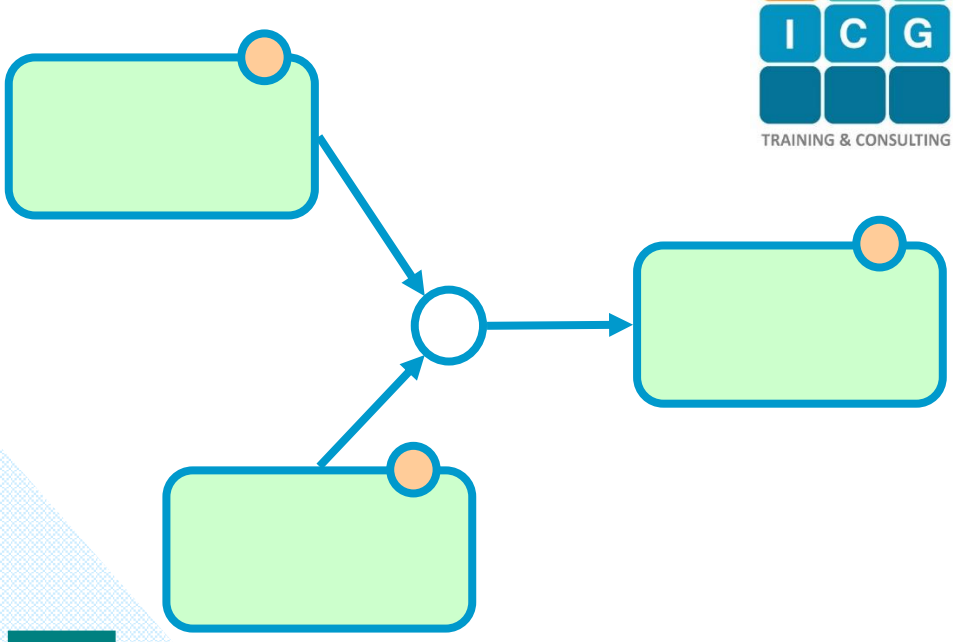


TRIZ & SYSTEMATIC INNOVATION

A Guide to Root Conflict Analysis (RCA+)

Edition 2.0

Valeri V. Souchkov

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

Edition 2.0

CONTENTS

Root Conflict Analysis (RCA+) is analytical tool aimed at helping to manage complexity of inventive problems by extracting, identifying and formulating contradictions which contribute to a problem and relations between these contradictions.

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 cars from creating road accidents, eliminate a possibility of errors made by pilots during flights, eliminate traffic jams, etc.)
3. To predict and eliminate potential failures within systems and processes (e.g. to identify possible causes of a machine or project failure).

This document explains how to analyze and model problems with RCA+ and assumes that the reader is familiar with the TRIZ basics; although RCA+ can be used without TRIZ for problem analysis.

PART A: INTRODUCTION AND TRIZ PROCESS WITH RCA+

INTRODUCTION TO ROOT CONLFICT ANALYSIS (RCA+)

Root Conflict Analysis (RCA+) was first introduced in 2003. It is a technique for defining, structuring, and visually representing problems and problem situations. RCA+ is mostly helpful in situation when a problem solver faces a problem which is not clear how to solve. The tool helps managing complexity of understanding and defining problems through top-down discovery of *contradictions* which prevent a problem solver from solving a problem in a straightforward way and defining how these contradictions are related to each other. Such contradictions convert standard problems which can be effectively solved with known means to inventive problems where a way of how to resolve contradiction is not know to the problem solver. Therefore discovery and extraction of all contradictions which compose a problem is essential to properly identify relevant problem solving directions.

RCA+ is domain-independent tool. It was developed by combining key ideas of three approaches: a classical method of Root Cause Analysis, Theory of Constraints, and TRIZ.

It is very important to note that while traditional methods of cause and effect analysis of problems (for example, RCA: Root Cause Analysis) focus on finding *root* causes of problems, the underlying RCA+ philosophy ***is different***. Often problems can not be easily solved even after we identify a root cause. Such situations usually emerge when either elimination of a root cause would require considerable change of a system where the problem arises or elimination of the root cause is not possible due to constraints, for example, defined by laws or nature.

In addition, difficult problems are usually featured by situations when just finding a cause of a certain problem does not make it easy to solve the problem by eliminating the cause because the same cause contributes to a positive effect. For example, a traffic light slows down travel time of a car which is definitely negative effect. On the other hand, the same traffic light prevents the car from an accident. In this example, a traffic light is a cause of both negative and positive effects and therefore if we eliminate the traffic light, we eliminate the positive effect as well. Therefore to get a more complete picture of our problem we should understand not only the causes of negative effects but also define if these causes contribute to positive effects. RCA+ helps to identify such contradictions that create a problem rather than investigate a causal chain of causes only.

Second important difference between the root cause analysis techniques and RCA+ is that instead of trying to find the lowest cause in a chain (root cause), RCA+ targets at discovering all contradictions that reside as close as possible to a general negative effect which represents a problem. Our experience of applying previous versions of RCA+ to hundreds of problems shows that it is easier to solve a problem by eliminating a contradiction *which resides closer* to a general negative effect than a contradiction which is lowest in the causal chain of contradictions and negative causes.

RCA+ is a universal technique which is not limited to any specific domain and can be performed within the scope of three tasks:

- To model a specific problem related to a certain specific product, service or a process (e.g. polishing glass takes too long, sales of a specific service produced by a specific company are too low).
- To model a broad problem related to a whole class of products, processes or services (e.g. to reduce traffic jams, to eliminate mistakes by a call centre, etc.)
- To predict potential failures within systems and processes (e.g. to identify possible problems which might be caused by a newly developed camera, or predict potential causes of project failure).

In summary, RCA+ helps with:

- Decomposing a problem to a number of related causes and effects.
- Identifying "invisible" causes and conflicts.
- Extracting and presenting contradictions.
- Structuring and visualizing a problem.
- Reaching a common agreement and vision of a problem situation.
- Improving collaboration among team members when defining and solving a problem.
- Providing direct input for contradiction resolution techniques.

RCA+ can be used in every area where problems, contradictions, and undesired effects take place and can be used independently of TRIZ to analyze problems and situations. In addition, coupled with TRIZ techniques for resolving conflicts, RCA+ provides a powerful platform not only for understanding problems but for solving problem as well.

RCA+ can be used both within a specific formalized TRIZ process and independently.

TYPES OF PROBLEMS WITH RCA+

In general, there might be four categories of problems which can be analysed with RCA+:

1. **Negative effect**. Something that happens which we do not want to happen at all. In most cases negative effects are caused by harmful functions. It can be a damage as a result of an accident, loss of control, irreversible emergence of a defect, process failure, etc.

   Examples: a) A gas ballon explodes. b) Camera lens collect dust. c) *Knife scratches table surface.*

2. **Insufficent effect**. A positive result which we wish to obtain but which is not achieved with a desired degree of performance, completing, or quality.

   Examples: a) Focusing lens in a camera takes too long. b) Polishing of glass does not remove all defects. c) Image was made with too low resolution. d) Not enough information is obtained about an object of study.

3. **Excessive effect**. A positive effect which we wish to have but which causes excessive waste of costly resource.

   Examples: a) Painting a wall with liquid paint leaves more paint on the wall than necessary. b) Continous heating of a room without thermostate consumes more energy than needed.

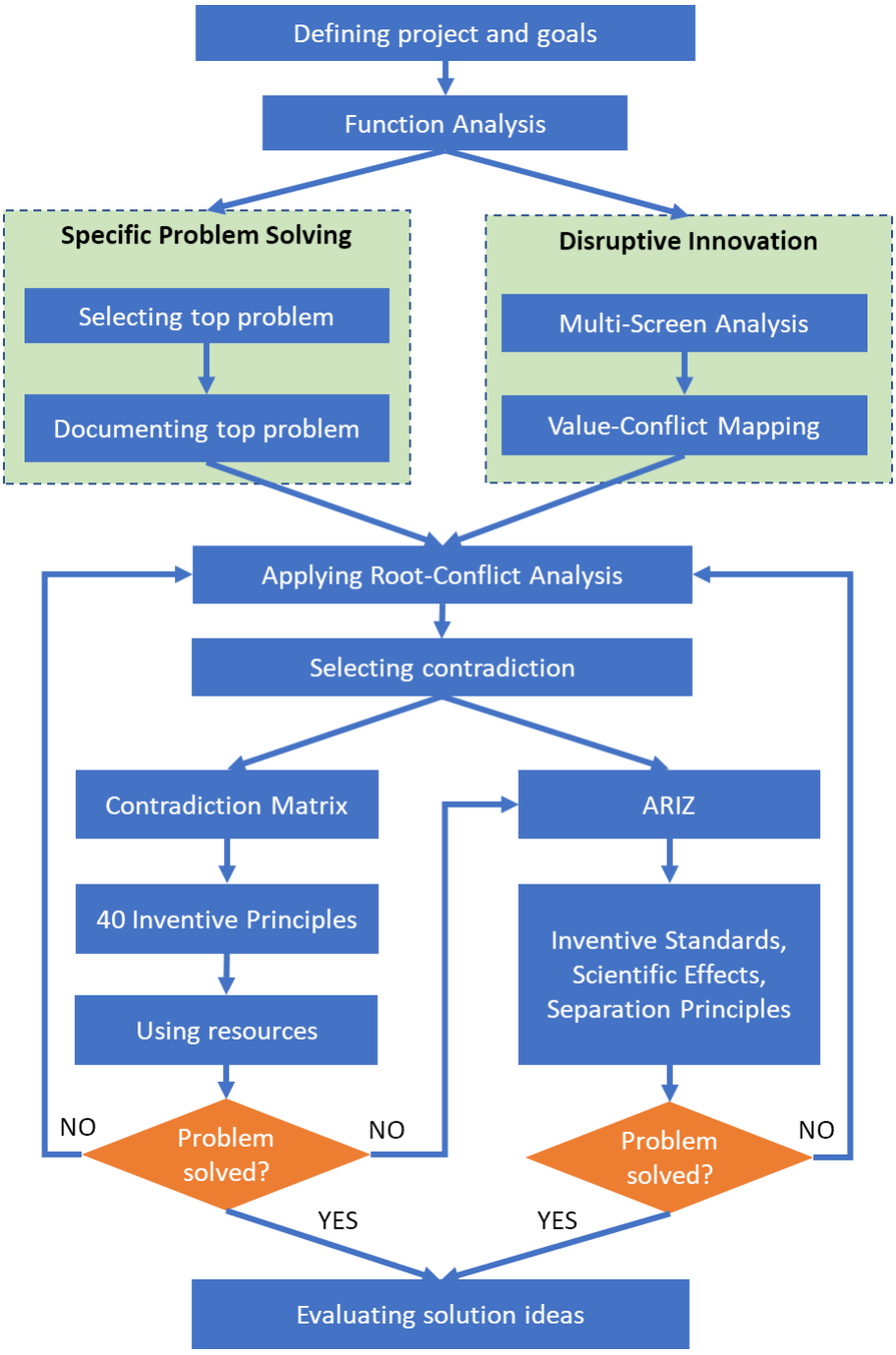
4. **Ineffective control**. It happens when we wish to control a certain system, or its attribute, and we have the means of control but the process of control takes too long, or is not accurate enough, etc.

   Examples: a) It is difficult to maintain the right temperature in a room. b) It is difficult to find an exact position of the lens in a camera during zooming. c) It is difficult to control the desired intensity of flame in a stove.

Note that problems involving insufficient or excessive effects, or ineffective control are not the same as problems which relate to negative effects. Negative effects address situations when a certain action or result occur but we absolutely do not want even a smallest fraction of this action or result.

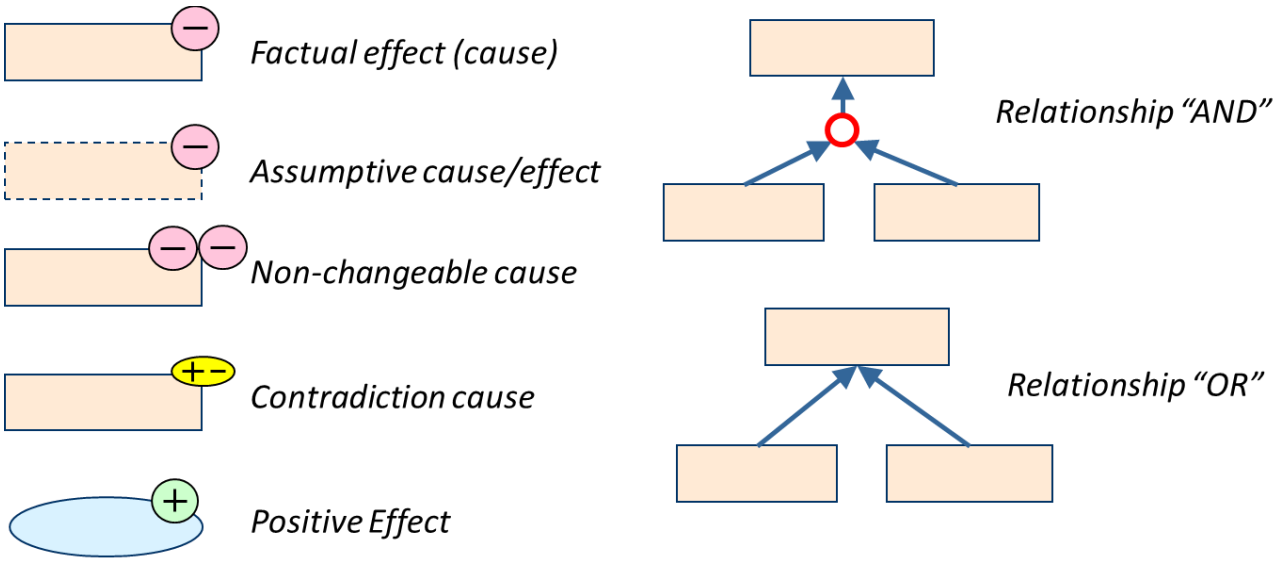
TRIZ Process with RCA+

The overall process of problem solving based on using RCA+ in TRIZ 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 (Contradiction 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.



Although RCA+ was developed as a technique to support the analytical phase of the TRIZ process, today it is also used to analyze, understand and visualize complex problems as an independent and domain0-ndependent tool as well.

RCA+ Legend

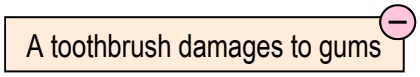

Factual effect (cause)
Assumptive cause/effect
Non-changeable cause
Contradiction cause
Positive Effect
Relationship "AND"
Relationship "OR"

PART B: PROCESS OF RCA+ FOR MODELING AND BUILDING RCA+ DIAGRAMS

STEP 1 State the general (top) problem and start drawing the RCA+ diagram in a top-down manner. A problem should be formulated as a single sentence and belong to one of four categories of problems mentioned in Part A:

- Negative effect
- Insufficient effect
- Excessive effect
- Ineffective control

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?***" ot "***What is a cause of this effect?*** to find all the causes of the negative effect.

a. A cause should be stated as either:

i. **A function.** Function must represent a physical action. Usually a function is defined by a triad: "**subject** (noun) which produces action + an **action** (verb) + **object** (noun) upon which the action is directed". Often the object might be discarded. If necessary, conditions can be refined with extra words:
***Example**: a knife slices bread; water flows in a pipe; wire conducts electric current; sand moves; electromagnetic field attracts ferromagnetic powder; etc.*

ii. **Relative value of some parameter** of an object or a field, or their property (in some cases, the word "too" can be used):
***Example**: temperature is high; speed is low; friction is too high; concentration is too dense; etc.*

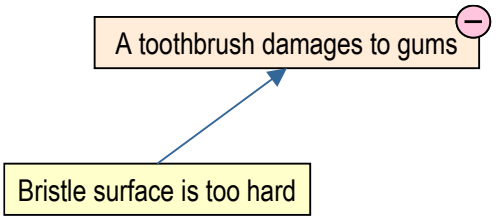
iii. **Change of a property (state)** of a field or an object and its relative value with respect to the desired situation: e.g. maintain (is), change, increase, decrease + a property or field or an object + its relative value:
***Example**: Decrease of temperature is too fast; increase of voltage is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

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

b. When thinking about where a cause can take place, it is important to consider the following categories:
- Time
- Space
- Geometry
- Information
- Property
- Supersystem

c. 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.

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



Note: A cause must always be a sentence or at least a part of sentence

Each cause in each box must be written as a sentence. Single word is not allowed.

Note: Avoid the question "why"

In classical Root Cause Analysis, the question "*Why?*" (e.g. "*Why are you going to the supermarket*?") can be interpreted in 2 different ways: (1) what for? (which indicates a goal, e.g. "*to buy bread*") or (2) what is a current cause? (e.g. "*I am hungry*"). Therefore when constructing an RCA+ diagram we prefer to ask the question "*What causes …*?" When answering the questions "*What causes …?*" or "*What is a cause?*" we have to identify exactly:

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

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

Note: 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 effect "*Temperature increases too much*" two causes might be identified: 1) "*An object is exposed to heat radiation for too long time*" and 2) "*Internal exothermic reactions create extra heating*". While the first cause can be defined as factual since we know exactly that the object is exposed to heat for long time, the second cause is assumptive: we might not be completely sure if there are exothermic reactions which take place inside the object; this fact has to be verified. 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.

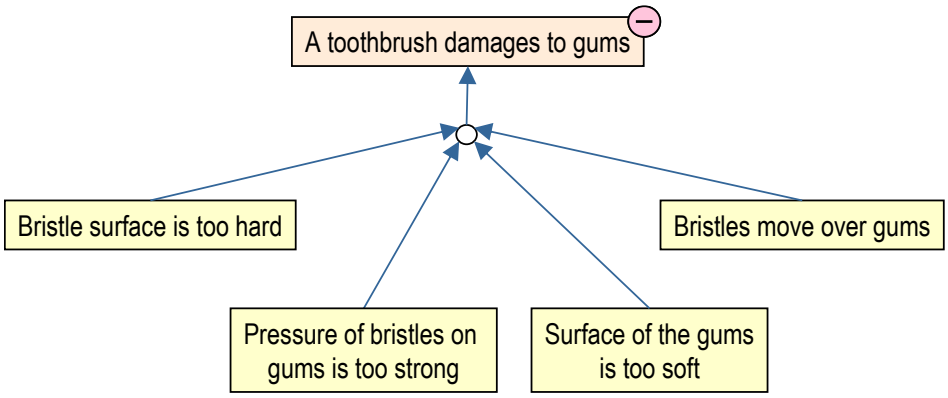
STEP 3

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, sometimes as a circle with ampersand inside), because if we remove just any one cause, the negative effect will **completely disappear**.

Note: Importance of discovering causes related with "AND"

If most of cause-effect analysis methods are focused on in-depth analysis, RCA+ focuses on in-breadth analysis. Finding all dependent causes which create the effect is essential to define resources for solving a problem. The more causes related with "AND" relation are found, the more resources and opportunities will be found to solve a problem.

STEP 4

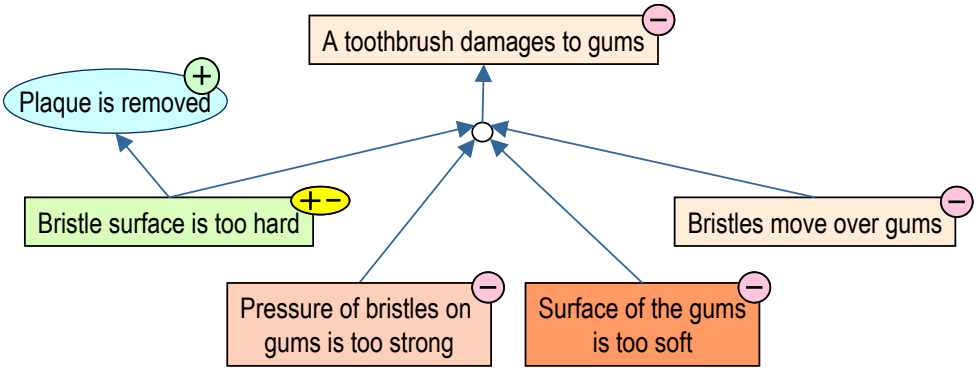
Once all causes where identified, check if each cause also produces a **positive effect**. A cause which produces both a positive and negative effect identifies a **contradiction cause**.

We can have four types of causes/effects in an RCA+ diagram:

a. ***Negative*** (**-**): the cause/effect is totally negative, does not produce any positive effect, and we would like to fully eliminate it. There are two types of negative effects: factual, when we know that the cause takes place, and assumptive, when we are not sure that the cause takes place and it requires verification.

b. ***Positive*** (**+**): the effect is positive, there is no need to change. Positive effects in RCA+ are identified from the point of view of problem stakeholders. For example, if glass in a window's car often breaks under stress, it can be considered as a positive effect from the viewpoint of glass manufacturer or car service. However from the point of view of a car's owner broken glass does not result in any positive effect.
The positive causes may 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 since we may not influence the cause. In most cases 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 tags the RCA+ diagram to distinguish between different types of causes and effects:

a) tagged with "+-": a cause (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

Note: Selecting Positive Effect

There might be a situation when the same cause produces several positive effects. In such cases, only most important positive effect must be brough to the RCA+ diagram. If a cause must be presented as a sentence, a positive effect may be presented as a fact.

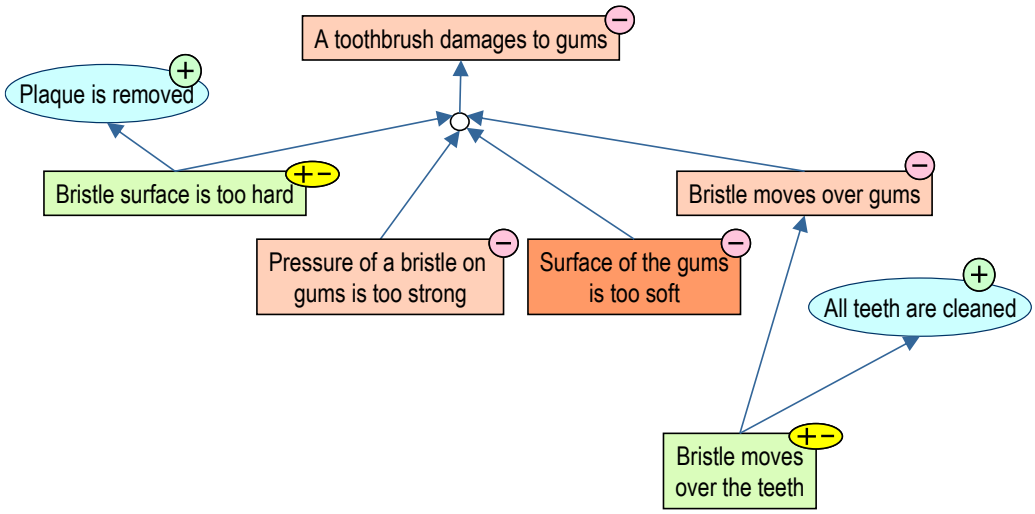
STEP 5

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

Stop a chain when either:

- You reach a cause which is a *demand or requirement that is impossible to change* or *control*, 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 "the contradiction cause". However, in certain situations it might be useful to continue deeper analysis to investigate the underlying causes of the contradiction cause 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.



Note: Stopping Analysis after Defining a Contradiction Cause

The reason why we stop after we defined a contradiction cause is that we already defined a cause of the contradiction cause, and it is a positive effect; although it is not presented as a cause but as an effect.

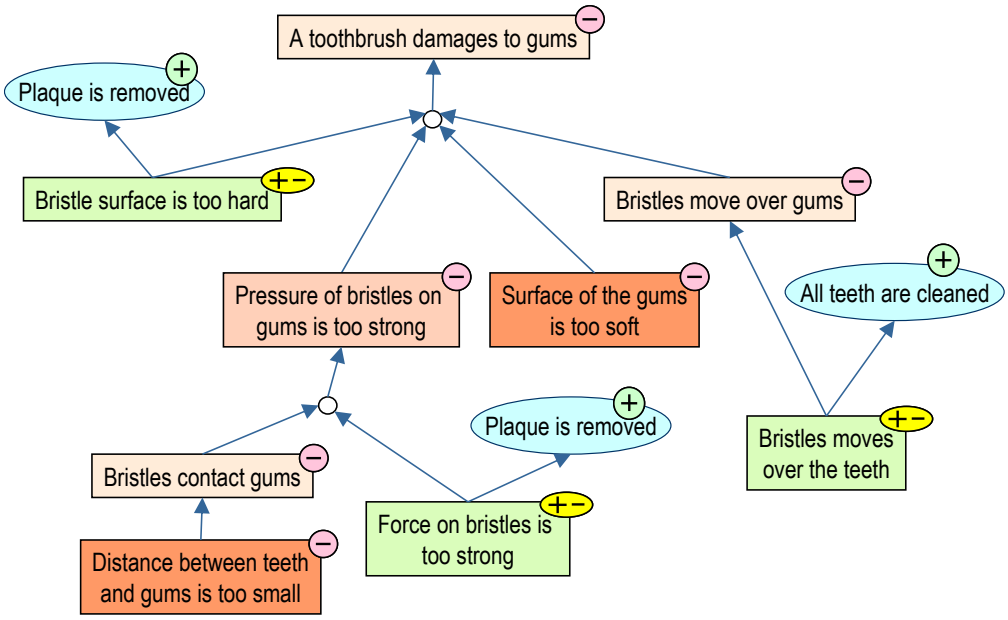
In case we use RCA+ in combination with TRIZ tools for problem solving, it makes no sense to explore deeper causes of the contradiction cause since we can apply the TRIZ tools to solve the contradiction. Statistically, solving a contradiction which is closer to the top problem provides a more ideal solution.

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 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 also listed in the table.

Example:

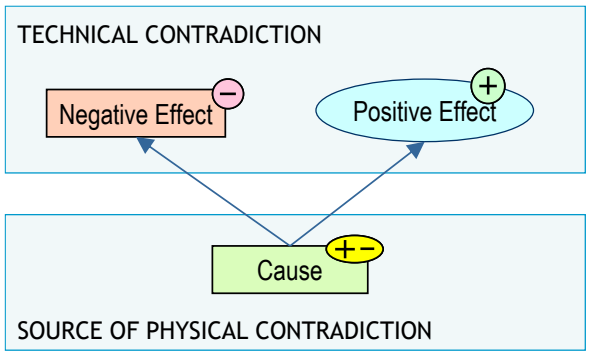
Cause	Type of cause	Positive Effect	Negative Effect
Bristle surface is too hard	N+P	Plaque is removed	A toothbrush damages to gums
Pressure of bristles on gums is too strong	N	-	A toothbrush damages to gums
Surface of the gums is too soft	NC	-	A toothbrush damages to gums
Bristles move over gums	N	-	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:

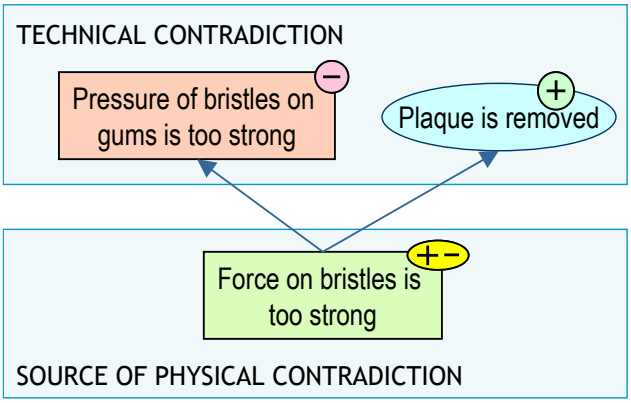
1. If the RCA+ diagram contains a negative cause which is possible to change and without an underlying contradiction, solve the problem by eliminating the cause. In most innovative and complex problems, however, negative effects have underlying contradictions; and therefore they may not be directly eliminated.
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: MOVING TO PROBLEM SOLVING 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 and further solved with 40 Inventive Principles.
- 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 resolved either with Principles for Conflicting Demands 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 effectively remove plaque and should be weak to avoid creating strong pressure on gums*".

PART C: 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
Dependent 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 (or branches in RCA+ diagram)	In case of independent contradiction causes (branches) 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 (or an independent branch with contradictions) that contributes most to the general (top) problem can be identified by subsequently comparing the degree of contribution to the general problem by each contradiction (or independent branch) and selecting a top candidate. The degree of contribution by a contradiction is defined by estimating which of two contradictions to be compared produces a more severe effect and how frequently.
Ideality-based criteria	a) dependent, b) causally related c) complexly related	Choosing a contradiction from a number of dependent contradictions might be difficult due to the fact that it is not possible to guarantee in advance solving which contradiction will provide the most ideal 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 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 can complete a table for each contradiction which includes the following elements: 1. The cause of the contradiction. 2. The positive effect produced by the contradiction. 3. The negative effect produced by the contradiction. 4. 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. 5. 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. 6. The time when a contradiction (conflict) occurs. After the table is complete, we analyze what contradiction matches the criteria presented above best of all.
"Root" Criteria	Chained contradictions	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 top problem. 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

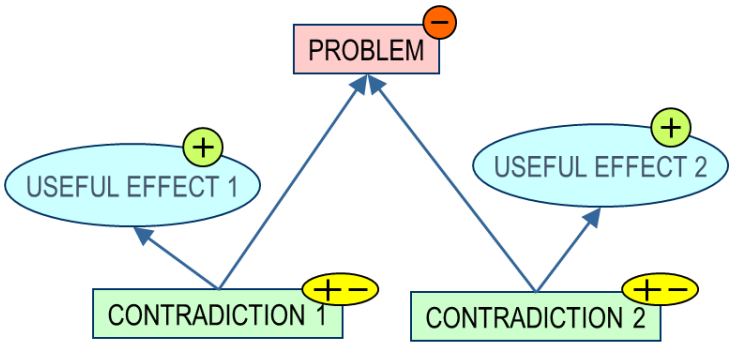
For all situations: when a selected contradiction does not produce a desired solution, the next best candidate should be chosen according to the same selection criteria and recommendations for each specific situation.

B2. FIVE SITUATIONS OF RELATIONSHIPS

Note: The examples presented in this section only show fragments of actual RCA+ diagrams.

SITUATION 1: INDEPENDENT CONTRADICTIONS

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



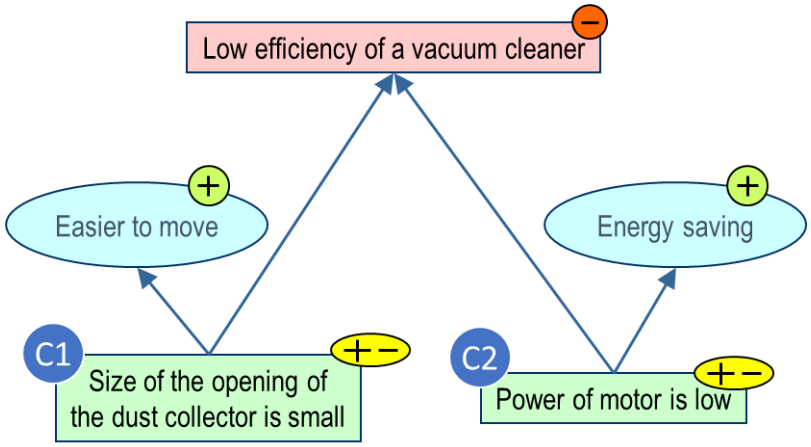
Selection Criteria: To decide which contradiction to resolve first, we estimate the degree of contribution of each contradiction to the negative effect (severity and frequency of occurrence), and then select the most contributing contradiction. After that, if we want to completely eliminate all potential causes of the negative effect, we should eliminate the other independent contradiction(s) too. Sometimes after 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 before starting resolving it.

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 problems of failure prevention for a general category of systems, or quality/performance problems. 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) A 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.

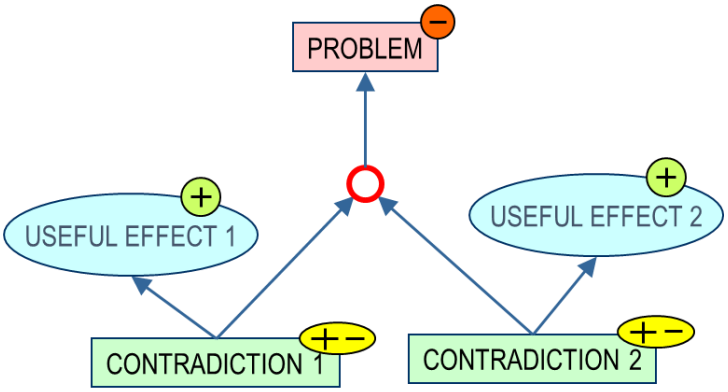
Example 1: Low efficiency of a vacuum cleaner:



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 critical within the context of the given problem than increasing the power of the motor, and thus selected "*Size of the opening of the dust collector is small*" to solve.

SITUATION 2: DEPENDENT CONTRADICTIONS

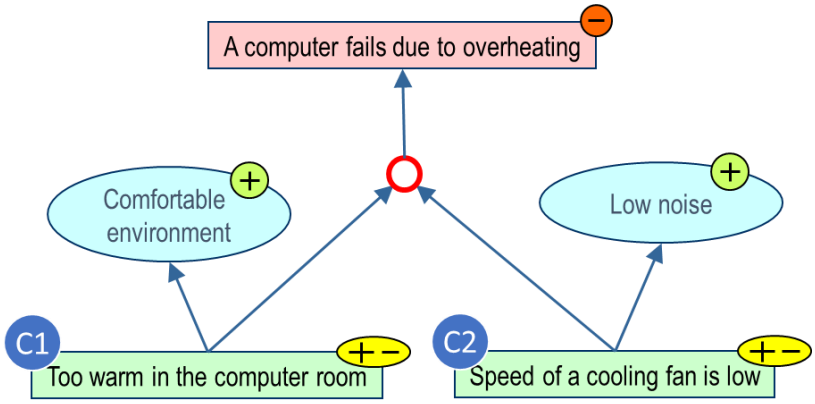
Situation: These contradictions are interrelated with each other by an "AND" relationship and therefore contribute to the same effect. In this situation, no matter how many contradictions are connected via the same "AND" relationship, it is enough to eliminate just any single contradiction, and the negative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



Selection Criteria: For such situations, we should select Ideality-based criteria which are defined in section B1, and select a contradiction which a) involves the lowest number of components, b) excludes supersystem components, and c) includes the easiest

to change components, and d) better matches the problem solver's strategy.

Example 2: Computer overheating:

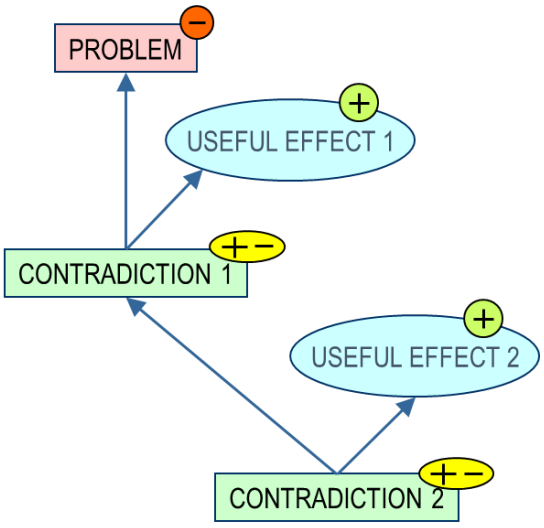


In this example (assuming that we are a computer manufacturer), we can not influence the temperature in the computer room where the computer is supposed to work, but we can change the design of the cooling fan. Therefore the contradiction cause *"C2: Speed of a cooling fan is low"* should be chosen.

SITUATION 3: CAUSALLY-RELATED CONTRADICTIONS

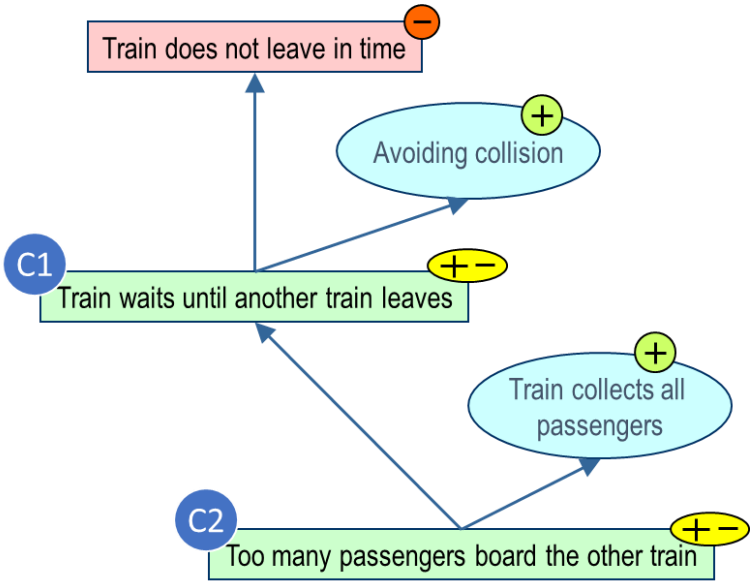
Situation: In this case, one contradiction cause is also the cause of another contradiction cause, and therefore they form a causal chain of contradictions which ultimately leads to a general negative effect.

Note: One of the rules of RCA+ is that once a contradiction found, its deeper analysis should not be performed. However, in come cases when no solution to a problem can be found during an attempt to solve the problem, the contradiction cause can be explored deeper.



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.

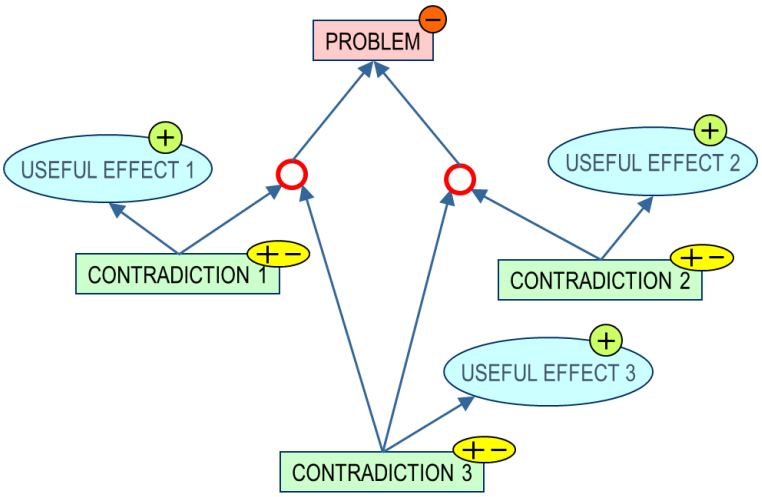
Example 3: Train does not leave in time:



In this example, two contradiction causes belong to the same cause and effect 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 C1 caused by "*Train waits 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 C2 "Too many passengers board other train", we deal with the passenger's flow which belongs to the supersystem and is therefore more difficult to control and influence.

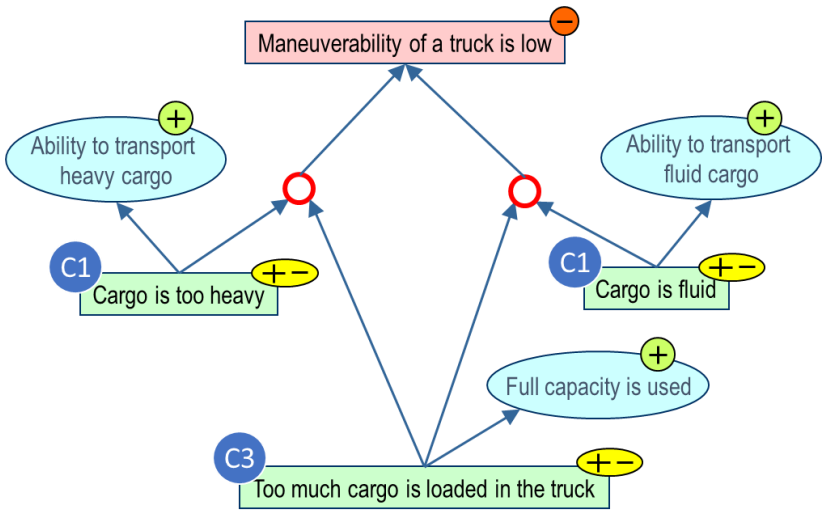
SITUATION 4: "ROOT" CONTRADICTION

Situation: There are situations when several contradictions (or several branches from the top problem) are independent of each other (through "OR" relationship), but they all are caused by the same contradiction.



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

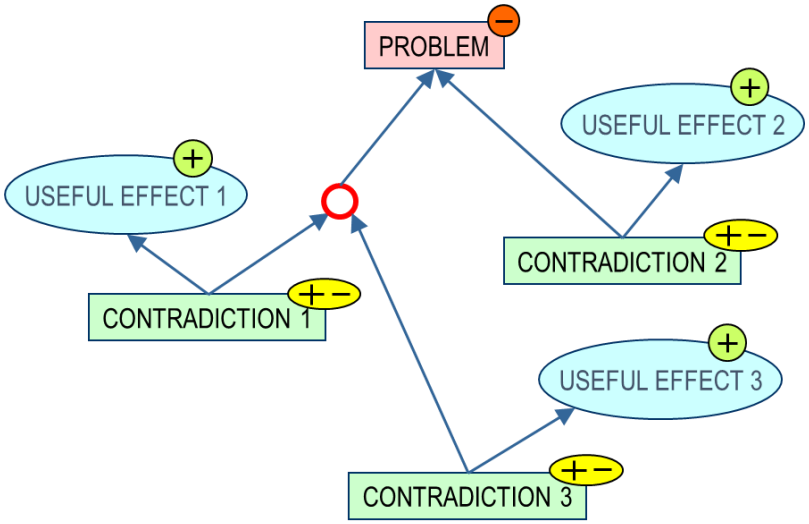
Example 4: Low maneuverability of a truck:



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

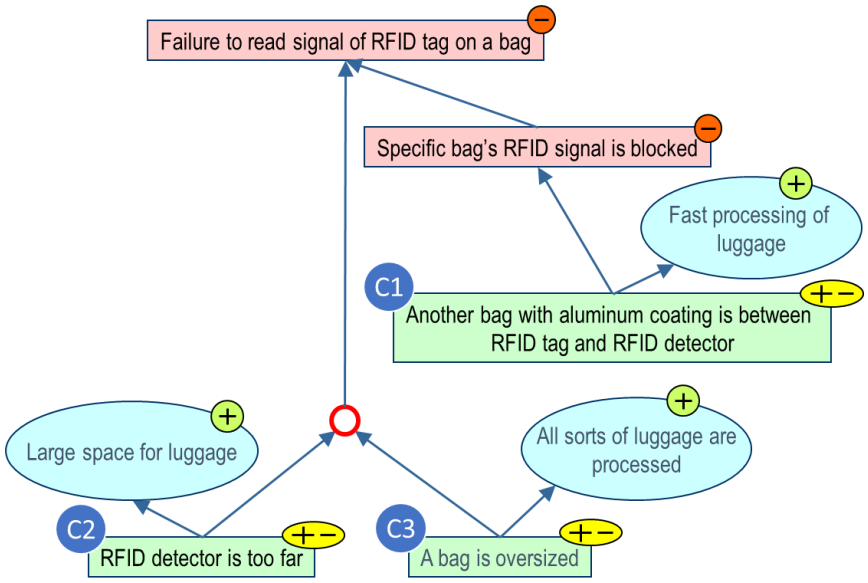
SITUATION 5: COMPLEXLY RELATED CONTRADICTIONS

Situation: In many cases, RCA+ diagrams contain both contradictions or branches related by both "OR" and "AND" relationships. In such situations, it is important to develop a problem solving strategy. First, specifically in cases when a top problem is created by two or more independent branches, we must identify most critical branch through comparative ranking of independent branches. Second, we should identifty an order of selecting those branches which include contradiction causes connected with "AND" relationship. In this case resolving any contradiction will provide a complete elimination of the negative effect. A complete solution to the problem will be eliminating all independent branches.



Selection Criteria: Both comparative ranking and ideality-based criteria in relevant places of an RCA+ diagram.

Example 5: RFID reading failure:



In this example of automatic check of the luggage at an airport, we can see two independent branches which have nothing to do with each other. However, one of the branches includes two dependent contradtions. First, we decide which branch is most contributing to the top problem (we can use comparative ranking to check both branches against severity and frequency of occurrence). As follows from the study of the airport, most critical is the branch with blocking RFID signal. It means that contradiction C1 " *Another bag with aluminum coating is between RFID tag and RFID detector* " has to be solved first. Since there is a single contradiction in the branch, there is no need to use either comparative ranking or ideality-based criteria.

However, in the second branch we should use ideality-based criteria to identify which one of two contradictions is easier to solve. As clear, contradiction C2 "*RFID detector is too far*" better matches the ideality-based criteria.

PART D: 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 costly and time consuming process.

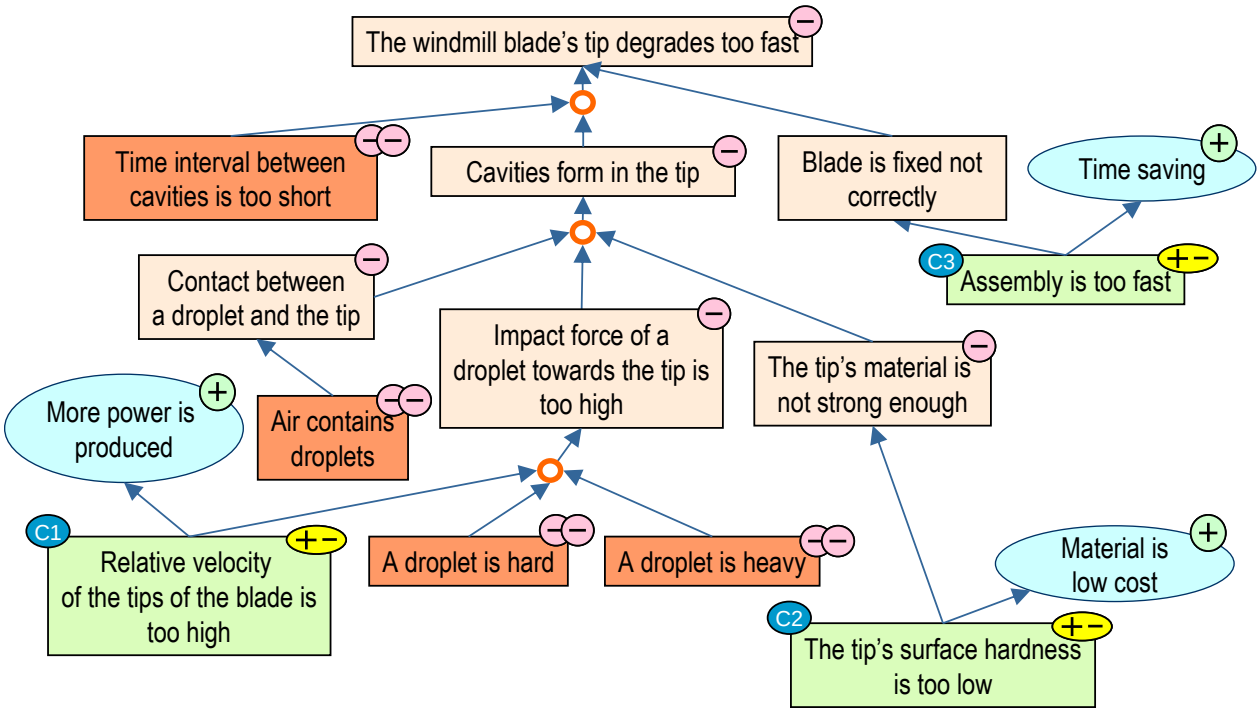
Offshore electric windmill generators.

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.
- **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 material 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 omitted from a procedure of selection since it is independent from contradictions C1 and C2.

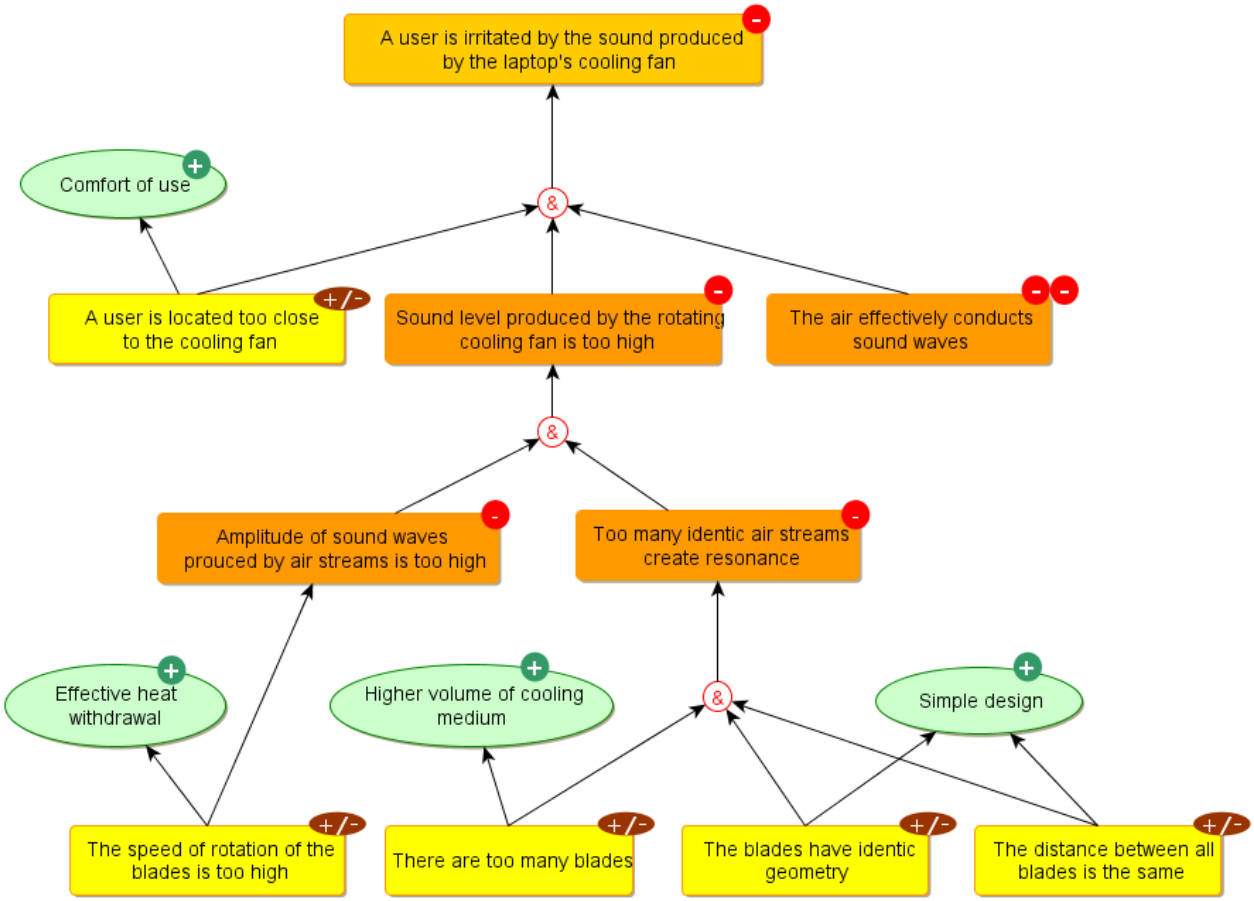
PART E: EXAMPES OF RCA+ DIAGRAMS

The RCA+ diagrams shown below are supposed to be self-explanatory. Note that these diagrams use RCA+ rules for stopping top-down analysis after a contradiction or a non-changeable cause was discovered during top-down analysis.

In addition, completeness of RCA+ diagram is subjective and depends on how carefully intermediate causes were identified. Each problem can be decomposed to less or more detailed diagrams.

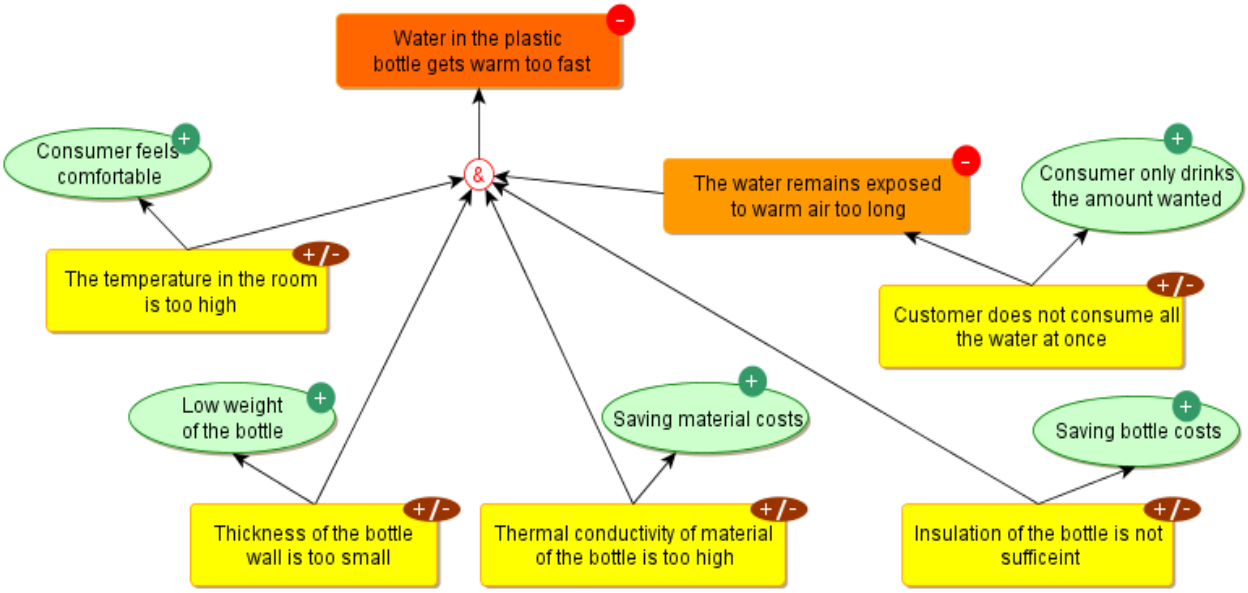
Example 1: A cooling fan installed in a notebook PC produces too much noise.

A typical situation almost everyone is familiar with. After a while, a compact notebook PC gets overheated and its cooling fan increases its rpm rate which leads to emergence of acoustic noise. Note that the RCA+ diagram does not include heat as a cause since the analysis was stopped earlier according to RCA+ rules. There are 5 dependent contradictions in the model, which means it is enough to solve just one of them to solve the top problem. If none of the contradictions can be resolved to produce a solution desired, the analysis can be continued in depth.



Example 2: Water in a plastic bottle gets warm too fast

After a typical plastic bottle with drining water from a local supermarket is taken out from a refrigerator and moved to a space with comfortable room temperature, water in the bottle gets warm rather fast since it tends to establish thermal balance with temperature of the air in the room. The model of the problem also includes 5 dependent contradictions.



Example 3: Dehydration in desert

The problem: a tourist goes to desert and carries a limited supply of water. To save money, he decides to walk without a guide in the unknown territory. Eventually the tourist gets lost and when water supply is over, the suffers from severe dehydration and may die.

Similar to previous examples, this model only includes dependent contradictions.

Example 4: Late processing of insurance claims.

This example demonstrates use of RCA+ in business domain. A problem is that an insurance company is late with processing claims by internal examiners. This RCA+ model includes both dependent and independent branches with contradictions.

Example 5: Stealing digital content.

This model addresses to a very general problem: many companies producing multimedia digital content (text, audio, video) suffer from potential loses due to Internet piracy. Since the problem is quite complex, its model is complex too and includes a number of dependent and independent branches with contradiction causes.

PART F: RCA+ GLOSSARY

General (top) 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 cause	A cause which produces 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 cause 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.

RCA+ represents a cause-effect modelling approach similar to Root Cause Analysis and Theory of Constraints to enable problem analysis and solving with the TRIZ methodology for contradictions definition and elimination.

Special thanks to Karel Bolckmans, Patrik Hendriks, Wim van Elschout, Jaap Beetstra, Don van Sonsbeek, Dmitry Kucharavy, Nikolai Khomenko, and Andrei Kuryan for useful discussions and contribution to the RCA+ underlying methodology.